

THE EFFECT OF HIGH ALUMINA NITRIC PHOSPHATE
ON THE YIELD AND COMPOSITION OF CROPS

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THE EFFECT OF HIGH ALUMINA NITRIC PHOSPHATE ON THE
YIELD AND COMPOSITION OF CROPS

By

Raman G. Menon

AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan
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R. L. Cook

ABSTRACT

The effect of high alumina nitric phosphate on the yield and phosphorus uptake of crops was studied in the laboratory, greenhouse and field.

Incubation studies were set up in the laboratory with eight soils using fertilizers with their water soluble phosphorus contents varying from 10 to 85 percent. Further incubation studies were conducted with one clay soil and one sandy loam on the migration of phosphorus from the fertilizer granule and its movement in soil, with two fertilizers of 30 and 85 percent water soluble phosphorus content.

Corn and bean plants were grown on acid muck soil in the greenhouse with different rates of lime to give pH 4.5, 5.4, 6.5 and 7.5, using high alumina nitric phosphate of low and medium water soluble phosphorus contents, so as to study the effect of water solubility of fertilizer phosphorus, soil reaction and method of placement on the yield and composition of plants.

Field experiments were conducted with tomato and corn crops grown on sandy soils with different ratio of fertilizers with varying water soluble phosphorus contents.

The laboratory studies indicated that the extractability of phosphorus increased with an increase in the water soluble phosphorus content of the fertilizer, increase in rate of application, and a decrease in organic matter and clay contents of soil. The movement of phosphorus from fertilizer



granules decreased after 24 hours incubation.

Greenhouse studies showed that the phosphorus uptake and dry weight of plants increased with increase in water solubility of the fertilizer phosphorus. The high alumina nitric phosphates with medium water soluble phosphorus content was found to be as effective as concentrated superphosphate. A pH of 5.4 to 6.5 was found to be optimum for corn on acid muck soil.

The yield of corn and tomatoes increased with increase in water soluble phosphorus content of fertilizer. The plants treated with high alumina nitric phosphates with medium water soluble phosphorus content, gave yields comparable to those to which concentrated superphosphate applications were made. Best results for tomatoes were obtained from 150 to 100 pounds P_2O_5 per acre.

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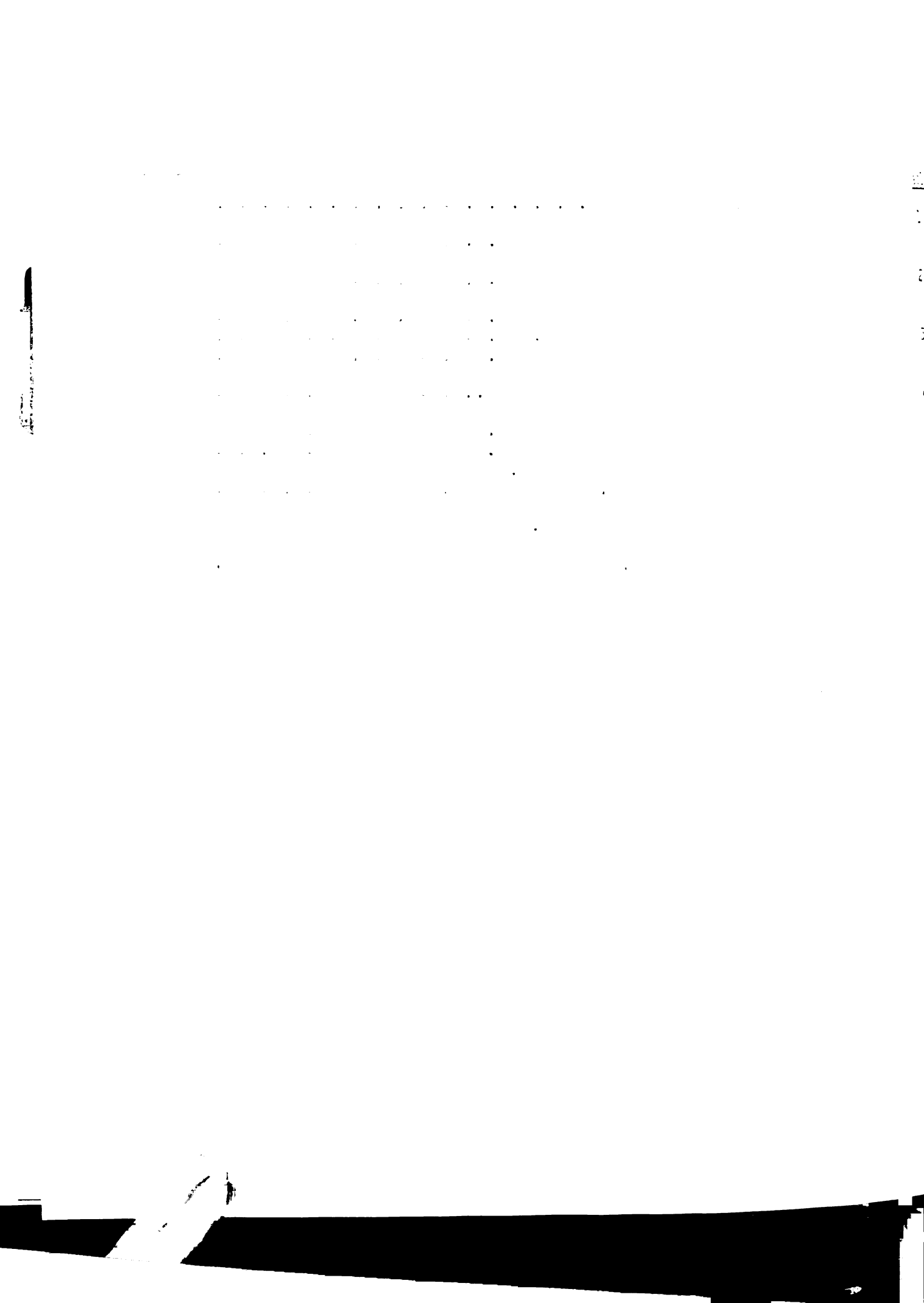
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INTRODUCTION

Phosphorus is one of the most important of the essential elements found in all living organisms. Ever since its discovery in 1669 by Henning Brandt, man has been trying to elucidate the mysterious ways in which phosphorus functions in regulating the activities of living organisms.

Since the role of phosphorus in the mineral nutrition of plants was expounded by Liebig, an enormous amount of work has been done in developing suitable phosphate fertilizers for crop production.

The utility of leached zone ores of Florida had attracted the attention of scientists for some time. Yet little emphasis has been placed on these deposits as a source of phosphate, since high grades of rock phosphate are still easily available. These ores contain 10 to 15 percent of phosphorus pentoxide which is present primarily in the form of wavellite and pseudowavellite, with small amounts of apatite. In addition, uranium can be recovered from these deposits. However, at the present time, the bulk of the ore is being discarded. The Tennessee Valley Authority is now studying processes of production of fertilizer from these leached zone ores. Whether it will be economically feasible to use this phosphorus source has not been fully determined to date. Considerable information is needed on the behavior of high alumina nitric phosphate fertilizers under different soil and cropping conditions.

The present study was undertaken in order to study the availability of phosphorus from high alumina nitric phosphates to plants.

The objectives of the present study were:

1. To study the effect of water solubility of the fertilizer phosphorus on the uptake of phosphorus and dry weight of plants grown in the greenhouse.
2. To study the effect of water solubility of the phosphorus content of the fertilizer on the yield and composition of different crops in the field.
3. To study the chemical availability of phosphorus from different high alumina nitric phosphate fertilizers.

REVIEW OF LITERATURE

Since the year 1840, when Liebig gave his historic address before the British Association of Science on the role of minerals on plant nutrition, extensive investigations have been carried out on the agricultural importance of phosphorus, its functions in the nutrition of plants, the different sources of phosphorus and factors that govern its availability.

For some time past, the suitability of iron and aluminum phosphate as a fertilizer material had attracted the attention of scientists in many countries. One of the early workers in this field was Merrill (25) who found that redondite, a phosphate of iron and aluminum, gave better results than did rock phosphate when applied to grasses.

Iron and aluminum phosphates were found by Nagoaka (27) to be as effective as superphosphate for rice plants, particularly during the first year of application. However, ferric phosphate became less available during the second and third years.

Some of the most important and extensive work during this early period was undertaken by Prianschnikov (33). He established that precipitated iron and aluminum phosphate were readily available to plants. This worker also noted that addition of 0.25% calcium carbonate decreased the availability of phosphorite but did not affect aluminum phosphate. Data obtained by Prianschnikov showed aluminum phosphate hydrolyses

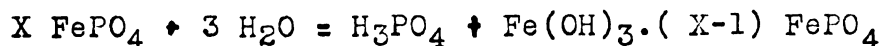
in water making phosphoric acid available to plants. This fact was also confirmed by Cameron, Bell and others (9), who found that a liter of pure water acting on a precipitated phosphate of iron and aluminum could bring into solution by hydrolysis up to 0.1 gram or more of phosphoric acid.

Ellet and Hill (12) compared ferric and aluminum phosphate with calcium phosphate and they found that under certain conditions ferric and aluminum phosphates were superior to calcium phosphate as a source of phosphorus to crops. Their findings were later confirmed by Jordan (16).

Patterson (28) also obtained similar results. In his work with reverted phosphate of iron and aluminum, he found that they produced a higher yield than reverted phosphate of lime. Florida soft phosphate, a phosphate of iron and aluminum, was found to be a very satisfactory source of phosphorus for corn.

One of the most significant contributions to the study of phosphates was made by Truog (39) in 1916. He found that plants utilized aluminum phosphate to a considerable extent. Ferric and ferrous phosphates were also used by plants, but to a lesser degree. Earley thrived exceptionally well when treated with ferric phosphate.

Like Prianischnikov, Truog believed the high availability of iron and aluminum phosphate to be due to the following hydrolysis reaction:



Truog further suggested that as phosphoric acid is removed by cropping or leaching, the original phosphate becomes more and more basic and hence less available to plants. In this way he explained the earlier findings of Nagoaka that the availability of ferric phosphate became less with time.

Some interesting results were obtained by Marias (21) who found that not only were iron and aluminum phosphates valuable sources of phosphorus to plants, but in some cases they were even superior to calcium phosphate. The nitrification of urea with the consequent production of acids acts very favorably in releasing phosphoric acid. According to this worker, chemically pure iron and aluminum phosphates were as valuable to plants as calcium phosphate. However, the mineral phosphate of iron and aluminum were not so readily available since most of them were hydrated basic phosphates. Upon igniting the aluminum phosphate Marias found a substantial increase in availability of the phosphorus. In addition, he observed that aluminum phosphate was best suited to calcareous soils.

Brious (7) reported that the capacity to assimilate phosphorus from iron and aluminum phosphates depended to some extent on the nature of the plants. Whereas flax, spurry, buckwheat and yellow clover could thrive well on aluminum phosphate, iron phosphate was more suited for barley.

McGeorge and Breazele (23) also found that wheat plants absorbed phosphate very readily from iron and aluminum phosphates. When equal amounts of iron and aluminum phosphates

were used, a greater amount of phosphorus was absorbed from aluminum phosphate due to the fact that this phosphate is more soluble than iron phosphate. When cultures were prepared with carbon dioxide free water, wheat plant did not absorb any phosphorus from lazulite, wavellite or dufrenite, but was able to extract phosphorus readily from vivianite. These workers noted that absorption of phosphorus was greater as the CO_2 concentration of water increased. In the presence of calcium carbonate, all iron and aluminum phosphate except wavellite reverted to extremely insoluble forms in soil.

Bartholomew and Jacobs (3) found synthetic aluminum phosphate and unignited ferric phosphate to be very satisfactory sources of phosphorus for plants. Ignition had no effect on citrate solubility of synthetic aluminum phosphate but decreased the citrate solubility of synthetic ferric phosphate. On the other hand, ignition markedly increased the citrate solubility of natural, hydrated aluminum phosphate from 9 to 63 percent. The yield of sudan grass on soil treated with synthetic aluminum phosphate and ignited, natural aluminum phosphate was similar to that where superphosphate or monocalcium phosphate were used.

As early as 1911, Patterson (30) reported that iron and aluminum phosphates form comparatively insoluble complexes with organic matter. Later Truog (39) reported that the basic phosphate may combine with acidic humic compounds or acid silicates and form very resistant and insoluble compounds.

Considerable work has been reported on the toxicity of aluminum to plants. Soluble aluminum is toxic to plant growth because, according to Szues (36), it acts on the protoplasm, causing it to set. Aluminum salts were observed to thicken the main root of plants and make it impervious to nutrient solutions.

Fluri (14) noted that when aluminum is added to a nutrient solution, starch formation is inhibited.

Magistad (20) found that aluminum in water cultures prevented the formation of lateral rootlets on barley but not on rye. Similar results were obtained by Hartwell and Pember (15), who found that equivalent amounts of aluminum sulfate and sulfuric acid, when added to an optimum nutrient solution, produced about the same growth depression of barley plants. Treatments of acid soils with phosphate reduced the amount of active aluminum in soils. These workers and Blair and Prince (4) reported that adding phosphorus to soil, in addition to increasing the phosphorus level of the soil, decreased the injurious effect of aluminum.

McLean and Gilbert (24) classified plants according to their tolerance to aluminum. The most sensitive crops are lettuce, beets and timothy whereas medium sensitivity was exhibited by radishes, sorghum, cabbage, oats and rye. Corn, turnips and red top grass were noticeably resistant to aluminum toxicity. First evidence of the injurious effects of aluminum generally appeared to be a dwarfing and injury to the

rootlets. Aluminum absorbed by the plant accumulated in the cortex, mainly in the protoplasm and nucleus.

According to Austin (2), the presence of aluminum in acid soil does not make soluble phosphate insoluble, if other compounds are present which may react both with aluminum and phosphoric acid.

Wright and Donahue (40) grew barley plants in culture solutions containing aluminum, to which radioactive phosphorus was added. They found that in plants grown in solutions containing aluminum, P^{32} accumulated in the root systems, whereas in the absence of aluminum, there was an accumulation of P^{32} in the tops of barley plants.

The sections of roots showed that aluminum accumulation took place on root surfaces and in the cortex, but very little was found in the vascular systems. A considerable modification of internal structure was observed. According to these workers, aluminum primarily inactivates phosphorus within the roots of plants and thus interferes with the normal metabolism of plants.

The use of nitric phosphates as a source of fertilizer has been studied recently. Rogers (35) received the results of many experiments and compared the efficiency of NP and NPK fertilizers made by treating phosphate rock with nitric acid and phosphoric or sulfuric acid followed by subsequent ammoniation, with other phosphate carriers. He found that phosphorus in nitraphosphate was as effective as that in commercial type

mixtures of similar NPK ratios or superphosphate for corn, cotton and small grains on acid soils in the Southeast. As a factor affecting plant availability of phosphorus, water solubility was important only in alkaline soils or soils extremely deficient in phosphorus. Of these fertilizers, Rogers concluded that particles of size -12 - 50 mesh gave best results.

Byekowski and Ostromecka (8) in their experiments with nitric phosphate on coarse, ferrous sandy soil, acid sandy soil, neutral clay soil and muck, in Poland, found that pulverized nitric phosphate produced the same yield as superphosphate. Granulation of nitric phosphate decreased their efficiency.

Mulder (26) experimented with nitric phosphate in the field and greenhouse in the Netherlands and he came to the conclusion that nitric phosphate is less effective than superphosphate, especially on alkaline soils. The effectiveness of nitric phosphate was increased by an increase in the water soluble phosphorus content or decrease in granule size.

Cooke (10) summarized experiments done in the United Kingdom and Holland and concluded that nitric phosphates were most efficient on acid soils, being 50 to 75 percent as effective as superphosphate.

Thorne, et al. (38) reviewed the results of 130 field and greenhouse experiments conducted in 11 states and they found that, in general, nitric phosphates were as effective

as superphosphate for crop production. The nitric phosphates of low water solubility gave poor yield but the same was the case with commercial mixed fertilizers of the same water soluble phosphorus content.

The Tennessee Valley Authority has been investigating the use of Florida leached zone ores for the production of fertilizers. These ores, according to DeMent and Seatz (11), are low in phosphorus content and high in aluminum and silica contents, containing 10 to 15 percent phosphorus pentoxide, 8 to 16 percent alumina, 52 to 66 percent silica and 2 to 12 percent calcium oxide.

Starostka, et al. (37) compared the phosphates produced from Florida leached zone ores with land pebble phosphate. They found that high alumina nitric phosphates with less than 10 percent water soluble phosphorus contents, were less effective than land pebble materials. However, high alumina nitric phosphates with medium phosphate water solubility compared very well and gave crop yields comparable to those of concentrated superphosphate. They determined that water solubility of nitric phosphate was a more important source of variation than the type of phosphate ore from which the product was prepared.

Rapp and Hardesty (32) found that the storage property of high alumina nitric phosphates was very good and their drilling characteristics excellent.

Preliminary greenhouse tests of high alumina nitric phosphates conducted at the University of Tennessee on two unlimed acid soils showed that the high alumina nitric phosphate produced as much rye grass as did concentrated superphosphate. Upon liming these soils to pH 6.1, it was observed that the high alumina nitric phosphates of low water soluble phosphorus contents resulted in lower yields than when superphosphate was used. Further greenhouse trials were conducted at Iowa State College and it was seen that high alumina nitric phosphates were less effective than concentrated superphosphate for oats.

Field studies comparing the effectiveness of high alumina nitric phosphates with concentrated superphosphate have been undertaken by Alabama, Georgia, Iowa, Kentucky, Mississippi, New York, Tennessee, Virginia, and Washington experimental stations. According to DeMent and Seatz (11), high alumina nitric phosphates were satisfactory sources of phosphorus for cotton, small grains, and corn. High alumina nitric phosphates, especially those with less than 5 percent water soluble phosphorus content, were not as effective a starter fertilizer for corn as superphosphate or nitric phosphate on acid or neutral soils. The high alumina nitric phosphate containing 20 to 30 percent of its phosphorus soluble in water were 90 to 95 percent as effective as concentrated superphosphate.

METHODS AND MATERIALS

In order to study under a variety of soil conditions, the behavior of high alumina nitric phosphates, experiments were conducted in the field, greenhouse and laboratory with different types of soils. The physical and chemical properties of the soils are given in Tables 1, 2, and 3.

Greenhouse studies

Greenhouse experiments were initiated to study the effect of variation in reaction of organic soils due to liming on plant availability of phosphorus from high alumina nitric phosphates and other fertilizers. In addition, an attempt was made to study the effect of rate of application, water solubility of the fertilizer phosphorus, and method of placement of fertilizers on dry matter production and total phosphorus uptake by two different crops.

Rifle peat from Clinton County, Michigan, was used in this study.

Lime rates:

0 tons lime per acre	pH 4.0
5 tons lime per acre	pH 5.4
10 tons lime per acre	pH 6.5
15 tons lime per acre	pH 7.5

Fertilizers

Four different grades of fertilizers with varying water soluble phosphorus contents were used in this study.

Table 1.

Some physical and chemical characteristics of the
eight soils used in the incubation studies

Soil type	pH	Percent			
		Organic matter	Sand	Silt	Clay
Appling sandy loam	5.0	0.84	81.2	12.0	6.8
Bearden silt loam	7.6	4.07	52.2	35.0	12.8
Clarion silt loam	5.5	5.94	50.2	35.0	14.8
Marshall silt loam	5.4	3.15	44.2	36.0	19.8
Memphis silt loam	4.9	1.30	40.2	46.0	13.8
Miami silt loam	6.0	1.07	64.2	27.0	8.8
Oshtemo sandy loam	7.4	1.25	85.2	10.0	4.8
Houghton muck	6.2				

Table 2.

Total exchange capacity and exchangeable bases of
the soils used in the incubation studies

Soil type	Exchange capacity m.e. per 100 gms.	Exchangeable cations m.e. per 100 gms.			
		Ca	Mg	K	Na
Appling sandy loam	2.0	0.98	0.57	0.17	0.08
Bearden silt loam	24.2	14.8	8.12	0.72	0.09
Clarion silt loam	23.9	13.8	8.12	0.85	0.08
Marshall silt loam	23.5	10.3	7.0	0.79	0.06
Memphis silt loam*	2.6	1.24	1.23	0.18	0.01
Miami silt loam	8.8	6.1	2.7	0.14	0.04
Oshtemo sandy loam	7.4	6.13	1.68	0.90	0.01
Houghton muck	131.0	74.0	22.0	0.62	-

*Low values

Table 3.

Phosphorus contents of soils used in the incubation studies

Soil type	Ppm, Total P			Ppm P available*
	Total	Organic	Inorganic	
Appling sandy loam	593	162	431	12
Bearden silt loam	835	280	595	6
Clarion silt loam	1032	682	350	16
Marshall silt loam	682	381	301	16
Memphis silt loam	750	412	337	26
Miami silt loam	562	375	187	20
Cshtemo sandy loam	592	367	225	32
Houghton muck	-	-	-	56

* Ignition method

**Extracted with 0.025 N HCl and 0.03 N NH_4F

Fertilizer	Analysis	TVA No.	% P soluble in water	
High alumina nitric phosphate	14-14-14	217	9.6	
High alumina nitric phosphate	15-15-15	219	31.8	
Concentrated super phosphate	0-49-0	179-194	95.0	NH ₄ NO ₃ and KCl in dry mix added
Diammonium phosphate	21-53-0	-	100.0	N and K ₂ O adjusted to 1:1:1 ratio with NH ₄ NO ₃ and KCl in dry mix

N and K₂O were adjusted to 400 pounds per acre in all pots and phosphorus was the variable factor as far as the fertilizer was concerned. The high alumina nitric phosphates were applied at four levels equivalent to 0, 50, 200 and 400 pounds P₂O₅ per acre, whereas superphosphate and diammonium phosphate were applied only at a single level of 200 pounds per acre.

Fertilizer placement

The high alumina nitric phosphates were applied in both mixed and banded placement, while with the superphosphate and diammonium phosphate, only the mixed placement was used.

One gallon glazed porcelain pots were used in this study. The soil was first mixed with the approximate amount of lime and incubated in a moist condition for two weeks. The fertilizer was then thoroughly mixed with the soil or applied in a circular band two inches below the soil surface.

Replications

Three replications were used for each treatment.

Cultural practices

Four corn seeds were planted in each pot. The pots were irrigated by the addition of a measured quantity of distilled water at regular intervals. After two weeks, the stand of corn was thinned to two plants per pot, and the other two were removed for analysis. To find the effect of different fertilizers on the growth of plants, the heights of plants were measured at intervals during the course of the experiment.

The plants were harvested when they started to tassel. The above ground portion of the plant was removed, dried in an oven at 70° C and weighed. The samples were then ground in a Wiley mill and analyzed for total phosphorus.

Field beans were planted in the same pot after the corn crop was harvested without disturbing the soil in the pots and without any further addition of fertilizers.

Eight seeds were planted in each pot. Two weeks after planting, four plants were removed from each pot, dried and ground for analysis. The pots were irrigated with distilled water. Harvesting was done when the plants began to flower. These samples were dried and ground for chemical analysis.

Field trials

Field trials were conducted to compare high alumina nitric phosphates with 1:2:2 ratio fertilizers of varying water soluble phosphate contents as affected by yield and

phosphorus uptake at different stages of growth of plants.

Both types of fertilizers were produced by the Tennessee Valley Authority.

Experiment 1.

Crop: Corn

Soil 1: Metea sandy loam, University farm, Ingham County, Michigan. This is a light textured, well drained soil with a pH of 6.8, which is low in available phosphorus.

Fertilizers: (Field diagram 1)

<u>Fertilizer</u>	<u>Analysis</u>	<u>TVA No.</u>	<u>Percent P soluble in water</u>
NK	21.5-0-21.5		
Complete fertilizer	14.5-14.5-14.5		95 *
High alumina nitric phosphate	14-14-14	217	9.6
High alumina nitric phosphate	15-15-15	219	30.0
Complete fertilizer	10-10-10		25.0
Complete fertilizer	6-12-12	169 C-199 C	25.0
Complete fertilizer	7-14-14	200 C	6.0
Complete fertilizer	10-20-20	170 C	50.0
Complete fertilizer	11-22-22	171 C	100.0

*Mixture of NH_4NO_3 , KCl and superphosphate.

The first six were applied at the rate of 25 pounds and 50 pounds per acre where as the last three were applied only at one level of 50 pounds P_2O_5 per acre.

Plot diagram 1

11	2	8	14	10	3	6	12	1	9	2		6	10	4	8	5	4	11	13	1	7
7	13	5	12	1	9	4	14	7	5	11		2	13	8	9	14	6	2	10	3	12
I											II					III					
University farm																					

Plot diagram 2

	5	9	11	6	8	3	10	2	12	
IV	1	4	7	2	8	6	3	10	1	
	11	3	5	10	5	11	7	9	4	III
II	4	1	8	6	2	7	9	11	2	
I	6	10	7	5	3	9	1	4	8	
W. K. Kellogg farm										

High alumina nitric phosphate (TVA) experiment on corn.

Corn experiment

University Farm (Metea sandy loam) and W. K. Kellogg Farm
(Fox sandy loam)

Treatment number	Fertilizer	Pounds P_2O_5 per acre	Percent water soluble phosphorus
1	21.5-0-21.5	-	-
2	21.5-0-21.5	-	-
3	14.5-14.5-14.5	25	95
4	14.5-14.5-14.5	50	95
5	14-14-14	25	10
6	14-14-14	50	10
7	15-15-15	25	30
8	15-15-15	50	30
9	10-10-10	25	25
10	10-10-10	50	25
11	7-14-14	50	6
12	6-12-12	50	25
13	10-20-20	50	50
14	11-22-22	50	100

Experimental design

A randomized block design with three replications per treatment was used. Each plot consisted of two rows of plants, each row being 50 feet long. The fertilizer was placed to the side and below the seed with an experimental corn planter.

Sampling and harvest

In order to study the uptake of phosphorus at different stages of growth, samples were taken at regular intervals. The first sample which was taken 24 days after planting, consisted of 30 entire plants per plot. The second and third samples taken 39 and 54 days respectively after planting, consisted of 30 leaves per plot. The fourth leaf from the top was taken in each case. The samples were dried, ground and analyzed for phosphorus.

When the ears were ripe and dry, they were picked by hand and weighed. Representative samples were taken from each plot for moisture determination.

Soil 2: Fox sandy loam, W. K. Kellogg farm, Kalamazoo County. It is a light textured soil, pH 6.3 and low to medium in available phosphorus.

Fertilizers:

<u>Fertilizer</u>	<u>Analysis</u>	<u>TVA No.</u>	<u>Percent P soluble in water</u>
NK	21.5-0-21.5		
Complete fertilizer	14.5-14.5-14.5		95 *
High alumina nitric phosphate	14-14-14	217	9.6
High alumina nitric phosphate	15-15-15	219	30.0
Complete fertilizer	10-10-10		25.0

* Mixture of $\text{N H}_4\text{NO}_3$, KCl and superphosphate.

All were applied at the rate of 25 and 50 pounds P_2O_5 per acre. A randomized block design was employed with four replications per treatment. Each plot consisted of four rows of plants, 35 feet long and 3.5 feet apart. The fertilizer was side dressed when the plants were 2 to 3 inches tall.

Sampling and harvesting

Preliminary plant samples were taken 16, 30, and 50 days after the application of fertilizer. The first sample represented 30 entire plants whereas the second and third samples consisted only of 30 leaves per plot. These samples were dried and ground for analysis.

At harvest time the corn was picked by hand, and representative ears were taken for moisture determination.

Experiment 2.

Crop: Tomatoes

Soil 1: Metea sandy loam, University farm, Ingham County, Michigan.

Fertilizers: (Field diagram 3)

<u>Fertilizer</u>	<u>Analysis</u>	<u>TVA No.</u>	<u>Percent P soluble in water</u>
NK	21.5-0-21.5		
Complete fertilizer	14.5-14.5-14.5		95.0
High alumina nitric phosphate	14-14-14	217	9.6
High alumina nitric phosphate	15-15-15	219	30.0
Complete fertilizer	10-10-10		25.0

Fertilizers were applied at the rate of 100 and 200 pounds P_2O_5 per acre.

Plot diagram 3

I		6	2	7	1	4	9	5	10	8	3	
II		5	8	3	10	7	2	6	9	4	1	
III		10	1	9	5	4	8	3	7	2	6	

University Farm

High alumina nitric phosphate (TVA) experiment
on tomatoes

Tomato experiment
University Farm (Metea sandy loam)

Treatment number	Fertilizer	Pounds P_2O_5 per acre	Percent water soluble phosphorus
1	21.5-0-21.5	0	-
2	21.5-0-21.5	0	-
3	14.5-14.5-14.5	100	95
4	14.5-14.5-14.5	200	95
5	14 -14-14	100	10
6	14-14-14	200	10
7	15-15-15	100	30
8	15-15-15	200	30
9	10-10-10	100	25
10	10-10-10	200	25

Experimental design

A randomized block design, utilizing three replications were used in this experiment. Ten seedlings were planted when they were 4 to 6 inches tall, in single row plots 6 feet apart with a 3 foot spacing between plants. Fertilizer was applied in 9 inch diameter circular bands, 4 inches deep around the plants, 4 days after transplanting. Individual plants received a quart of water twice in the early season when the soil became excessively dry.

Sampling and harvesting

Plant samples were taken two weeks and five weeks after transplanting. These samples, consisting of thirty leaflets per plot, were dried and ground for chemical analysis.

When the fruits were ripe, they were picked by hand and sorted out into three grades, depending on their size and quality; namely, grade 1 - 3 to 5 inches in diameter, grade 2 - 2 to 3 inches in diameter, and grade 3 - culls. The graded tomatoes were then weighed.

Soil

Coloma sandy loam, Jackson prison farm, Jackson County. This is a light sandy soil with a pH of 6.1, having medium level of available phosphorus.

Fertilizers (Field diagram 4)

Field diagram 4

I	8	13	10	5	1	9	12	3	15	2	11	14	6	4	7
II	12	5	2	6	3	11	7	14	8	4	5	10	13	1	9
III	9	1	14	4	8	13	10	15	6	12	7	2	11	5	3

Jackson prison farm

High alumina nitric phosphate (TVA) experiments on
tomatoes

Tomato Experiment
Jackson Prison Farm (Coloma sandy loam)

Treatment number	Fertilizer	Pounds P_2O_5 per acre	Percent water soluble phosphorus
1	21.5-0-21.5	-	-
2	21.5-0-21.5	-	-
3	21.5-0-21.5	-	-
4	14.5-14.5-14.5	50	95
5	14.5-14.5-14.5	150	95
6	14.5-14.5-14.5	300	95
7	14-14-14	50	10
8	14-14-14	150	10
9	14-14-14	300	10
10	15-15-15	50	30
11	15-15-15	150	30
12	15-15-15	300	30
13	10-10-10	50	25
14	10-10-10	150	25
15	10-10-10	300	25

<u>Fertilizer</u>	<u>Analysis</u>	<u>TVA No.</u>	<u>Percent P soluble in water</u>
NK	21.5-0-21.5		
Complete fertilizer	14.5-14.5-14.5		95.0
High alumina nitric phosphates	14-14-14	217	9.6
High alumina nitric phosphates	15-15-15	219	30.0
Complete fertilizer	10-10-10		25.0

The fertilizers were applied under three levels of 50, 150 and 300 pounds P_2O_5 per acre. The fertilizers were applied in 9-inch circular bands, 4 inches deep around plants, several days after the transplants were set.

Experimental design

A randomized block design with three replications was employed for the experiment. Each plot consisted of 10 plants in a single row, 30 feet long. Spacing between the rows was 6 feet.

Sampling and harvest

Thirty leaflets per plot were taken two weeks and five weeks after the application of the fertilizer. These samples were dried, ground and analyzed for total phosphorus.

The tomatoes were picked by hand when they were ripe and sorted and weighed into the following three grades: grade 1, fruits 3 to 5 inches in diameter; grade 2, fruits 2 to 3 inches in diameter; and, grade 3, culls.

Laboratory Studies

Experiment 1

Incubation studies were set up with eight different soils so as to study the relative chemical availability of phosphorus from high alumina nitric phosphates and other fertilizers after different periods of incubation.

The soils selected were as follows:

Red and Yellow soils	-	Appling
Gray Brown Podzolic	-	Miami, Oshtemo
Prairie	-	Clarion, Marshall
Chernozem	-	Bearden
Organic	-	Houghton muck

The physical and chemical properties of these soils are given in Tables 1, 2, and 3.

Fertilizers:

12-12-12	-	85% of its phosphorus soluble in water
14-14-14	-	10% of its phosphorus soluble in water
15-15-15	-	30% of its phosphorus soluble in water.

Each material was applied in amounts equivalent to 100, 200, 400 and 800 pounds P_2O_5 per acre. Each treatment was set up in duplicate.

Experimental procedure

The necessary amount of fertilizer was thoroughly mixed with 300 grams dry soil and the mixture was kept in a deep freeze. When the soil was sufficiently cool, a weighed amount of fine flakes of ice, equal to the moisture required for the

field capacity of the soil, was mixed with the soil and the mixture was put in a pint Mason jar and the jar was sealed. The jars were removed from the freezer room and were kept at room temperature. When the ice flakes melted, a uniform mixture of soil and water was obtained.

The jars were incubated at room temperature and samples were taken after 2 days, 7 days and 14 days incubation. The samples were extracted with 0.03 N NH_4F and 0.025 N HCl and analyzed for phosphorus.

Experiment 2

An experiment was set up to evaluate the diffusion of phosphorus from fertilizer granules and its migration in soil. Two soils, Metea sandy loam and Brookston clay loam, were selected for this study. Soil 1 was kept at 12 percent moisture and soil 2 at 14 per cent moisture.

Two granular fertilizers of -10 -12 mesh size were used for this study, namely 12-12-12 with 85 percent of its phosphorus soluble in water and 15-15-15 with 30 percent of its phosphorus soluble in water. Moisture cans were used as containers for the soil. The cans were filled with moist soil and a small hole was made exactly in the center of the soil mass. Twenty five weighed granules of the fertilizer were placed inside the hole, which was then filled with soil. The cans were covered tightly and incubated at room temperature.

Individual cans were opened for sampling after 1, 2, 7, 14, and 28 days of incubation. In order to be able to remove the fertilizer granules, the center of the soil mass in the

moisture can was located using a pair of compasses and the fertilizer granules were removed using a small cork borer. All the soil particles sticking to the granules were removed, as far as possible, using a brush.

To study the migration of phosphorus in soil, soil samples were taken at various distances from the fertilizer source. Here again the cork borers were used to get an undisturbed soil column. Samples were taken from 0 to 3, 3 to 5, and 5 to 8 millimeters distant from the center of the container. These samples were air dried and extracted with 0.03 N NH_4F and 0.025 N HCl and analyzed for phosphorus. The fertilizer granules were dissolved in acid and the amount of total phosphorus retained determined.

Laboratory Techniques

Soils

The soils for the laboratory experiments were analyzed for pH, organic matter, sand, silt and clay, exchange capacity, exchangeable bases, available phosphorus, total acid soluble phosphorus and organic phosphorus. Soils used in the greenhouse and field were analyzed for pH, sand, silt and clay and available phosphorus.

Soil reaction was determined by glass electrode using a 1:1 soil-water ratio.

Organic matter was determined by the dry combustion method of Piper (30, 32).

Percent sand, silt and clay were determined by using the hydrometer procedure of Bouyoucos (5).

Exchange capacity was determined by the neutral ammonium acetate method of Peech (31).

For determining exchangeable potassium, calcium, magnesium and sodium, a Beckman DU flame photometer was used.

Available phosphorus was determined by extracting the soil with 0.03 N NH_4F and 0.025 N HCl as outlined by Bray (6).

Organic phosphorus was determined by the combustion method of Legg and Black (19).

Phosphorus in the fertilizer granules was determined by dissolving the fertilizer in concentrated nitric and hydrochloric acid as discussed in the Handbook of the Association of Official Agricultural Chemists (1).

In all cases after extraction, phosphorus was determined colorimetrically as molybdenum blue, using a Coleman Spectrophotometer.

Plant Samples

The plant samples were wet ashed by the perchloric acid method of Piper (32).

One gram sample was taken in a 125 milliliter tall form beaker and 15 milliliters of concentrated nitric acid was added to it. The sample was digested in an electric hot plate until almost all the organic matter was destroyed and a clear solution was obtained. Six milliliters of 70 percent perchloric acid was then added to the solution and the digestion continued until the oxidation was complete and a clear, colorless solution was obtained. The solution was then evaporated almost to

dryness, cooled, and the volume was made up to 100 milliliters with 0.05 N HCl. The solution was filtered through Whatman No. 42 filter paper.

The phosphorus in solution was determined as molybdenum blue. One milliliter of the solution was diluted to ten milliliters and six drops of ammonium molybdate-sulfuric acid reagent was added, followed by the same amount of Fiske-Subbarow (13) reagent. The solution was shaken, and after fifteen minutes, the transmittance of blue color developed was measured in a Coleman spectrophotometer using a red filter (650 mμ).

RESULTS AND DISCUSSION

Laboratory Studies

Incubation studies were set up in the laboratory in order to study the chemical availability of phosphorus from high alumina nitric phosphates and other fertilizers applied to soils having widely different properties. Some of the physical and chemical properties of these surface soils are given in Tables 1, 2, and 3.

Appling sandy loam is a soil from North Carolina, belonging to the Red and Yellow Podzolic Great Soil Group. It is low in clay and organic matter and thus has a low cation exchange capacity. Available phosphorus in this soil is also known to be low.

Data in Table 4 show the amount of phosphorus extracted from the soil after different periods of incubation. It should be pointed out that this extraction procedure may include phosphorus in fertilizer residues at the time of sampling and drying. The release of soluble phosphorus from fertilizer and its ability to remain in easily extractable form depends to a large extent on the water soluble phosphorus content of the fertilizer and the fixing capacity of soil.

After two days and seven days incubation, no definite relationship was apparent between the phosphate water solubility of the fertilizers and the quantity of extractable soil phosphorus. However, after two weeks, the quantity of phosphorus extracted from soils which received applications

Table 4.

The availability of phosphorus in Appling sandy loam, Bearden silt loam and Clarion silt loam which received different rates of high alumina nitric phosphates and other fertilizers

Fertilizer	Percent fertilizer P soluble in water	Pounds P ₂ O ₅ per acre	Ppm P extractable after different periods of incubation									
			Appling sandy loam		Bearden silt loam		Clarion silt loam		Number of days	2	7	14
			2	7	2	7	2	7				
14-14-14	10	100	31	42	27	15	21	22	31	25	44	44
		200	46	54	46	20	40	40	35	36	62	62
		400	76	66	148	30	54	66	52	48	83	83
		800	124	113	199	56	66	83	103	92	138	138
15-15-15	30	100	28	32	33	16	23	27	44	25	46	46
		200	57	43	60	21	36	43	52	36	66	66
		400	92	56	80	30	45	66	80	54	95	95
		800	144	100	202	48	95	94	140	113	137	137
12-12-12	85	100	36	46	62	22	42	34	38	44	44	44
		200	48	60	91	35	48	53	58	60	62	62
		400	72	82	116	52	66	83	90	64	72	72
		800	102	133	163	112	98	106	135	111	126	126

*Phosphate determined after extraction with 0.03N NH₄F and 0.025 N HCl; initial P in soil 12 ppm for Appling, 6 ppm for Bearden and 16 ppm for Clarion.

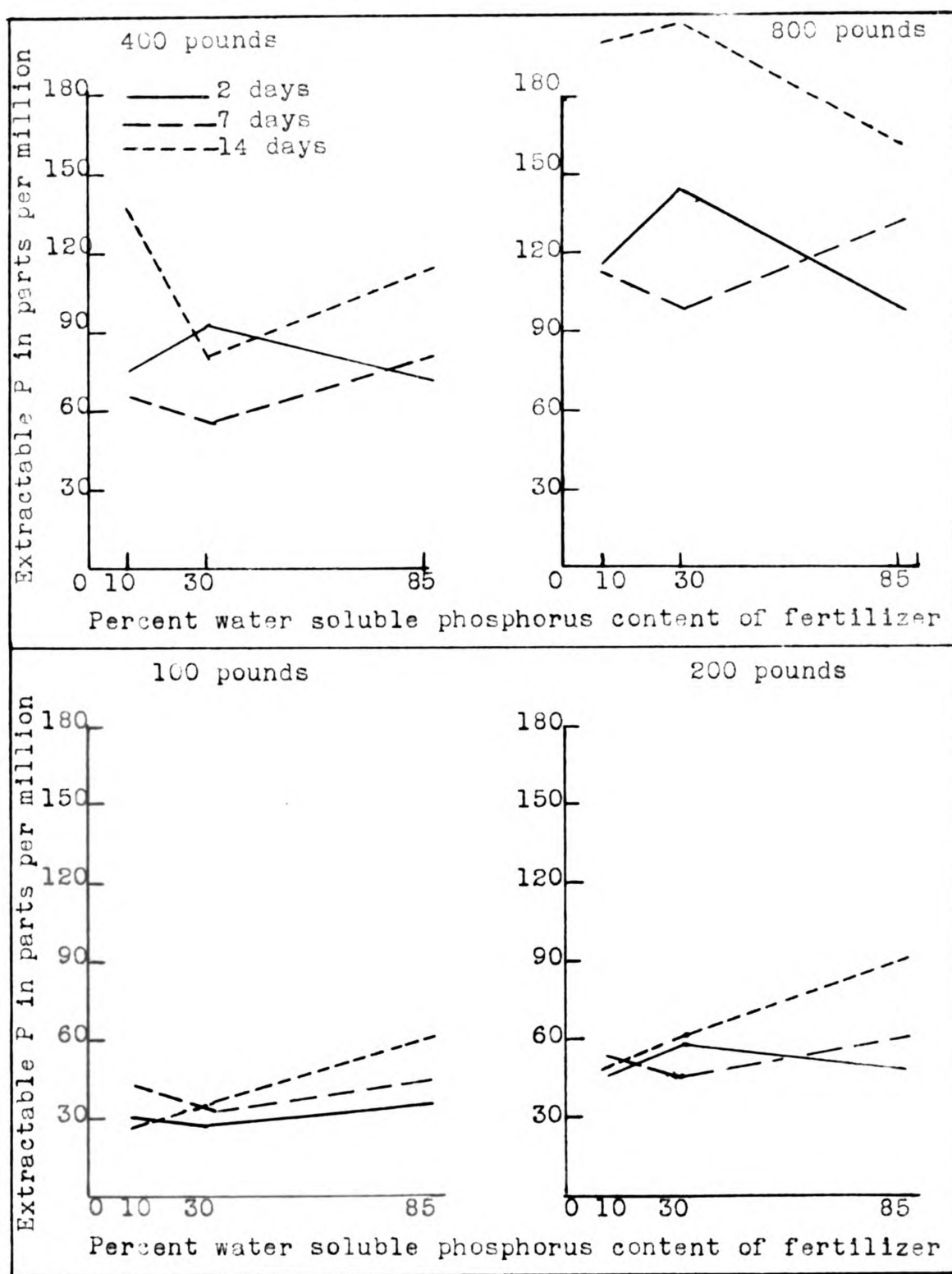


Figure 1. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from Appling sandy loam

equivalent to 100 and 200 pounds P_2O_5 per acre was closely related to the solubility of the fertilizer phosphorus. Yet this was not the case where the two higher rates were used.

In the case of H AL NP-10 systems there was an increase in the extractable phosphorus as the incubation period increased only when the higher rates of phosphates were applied. A similar increase in extractable phosphorus was found only for soils treated with 800 pounds H AL NP-30. With each added increment of phosphate supplied as 12-12-12 fertilizer, the available phosphorus content of this soil increased with time of incubation. These data suggest that phosphorus was continually diffusing out of the granules of the highly soluble fertilizer. With the high alumina nitric phosphates, only when a large amount of fertilizer was applied, there was sufficient soluble phosphate to more than satisfy the fixing capacity of the soil.

Bearden: This silty loam is from the Red River valley bottom, North Dakota, belonging to the Chernozem group. It has organic matter and clay contents of 4.075 percent and 12.8 percent respectively and is low in available phosphorus.

The extractable phosphorus from soil fertilizer mixtures after various periods of incubation is given in Table 4. A comparison of the extractable phosphorus from soils to which high alumina nitric phosphates were applied shows that these two fertilizers reacted rather similarly despite a difference in phosphate water solubility, at all incubation periods.

In contrast, considerable more phosphorus was removed from soils treated with fertilizer having 85 percent of its phosphorus soluble in water.

Considering each fertilizer, it can be noted that there is a continual increase in the amount of phosphorus extracted at different incubation periods. This is true for all rates of phosphate application and this relation is exhibited in Figure 2 as rather distinct, separate curves within each sampling time.

Clarion: This soil, a series within the Prairie group, was developed on glacial till in central Iowa. It has a clay content of 12.8 percent and contains 5.94 percent organic matter and 16 parts per million available phosphorus. The quantities of the phosphorus fraction after incubation with different rates of fertilizers is given in Table 4.

In general, the amount of extractable phosphorus is positively related to the degree of phosphate water solubility of the fertilizer for the two and seven day samples. However, apparently after two weeks less phosphorus could be removed from Clarion soil to which concentrated superphosphate had been added. This condition suggests that phosphate from the more soluble material was being rapidly fixed.

For some unknown reason, the quantity of phosphorus removed from the soil after one week of incubation was lower than that from soil sampled after two or fourteen days. As the rate of applied P_2O_5 increased, extractable phosphorus also increased, but not in proportion to the quantity added.

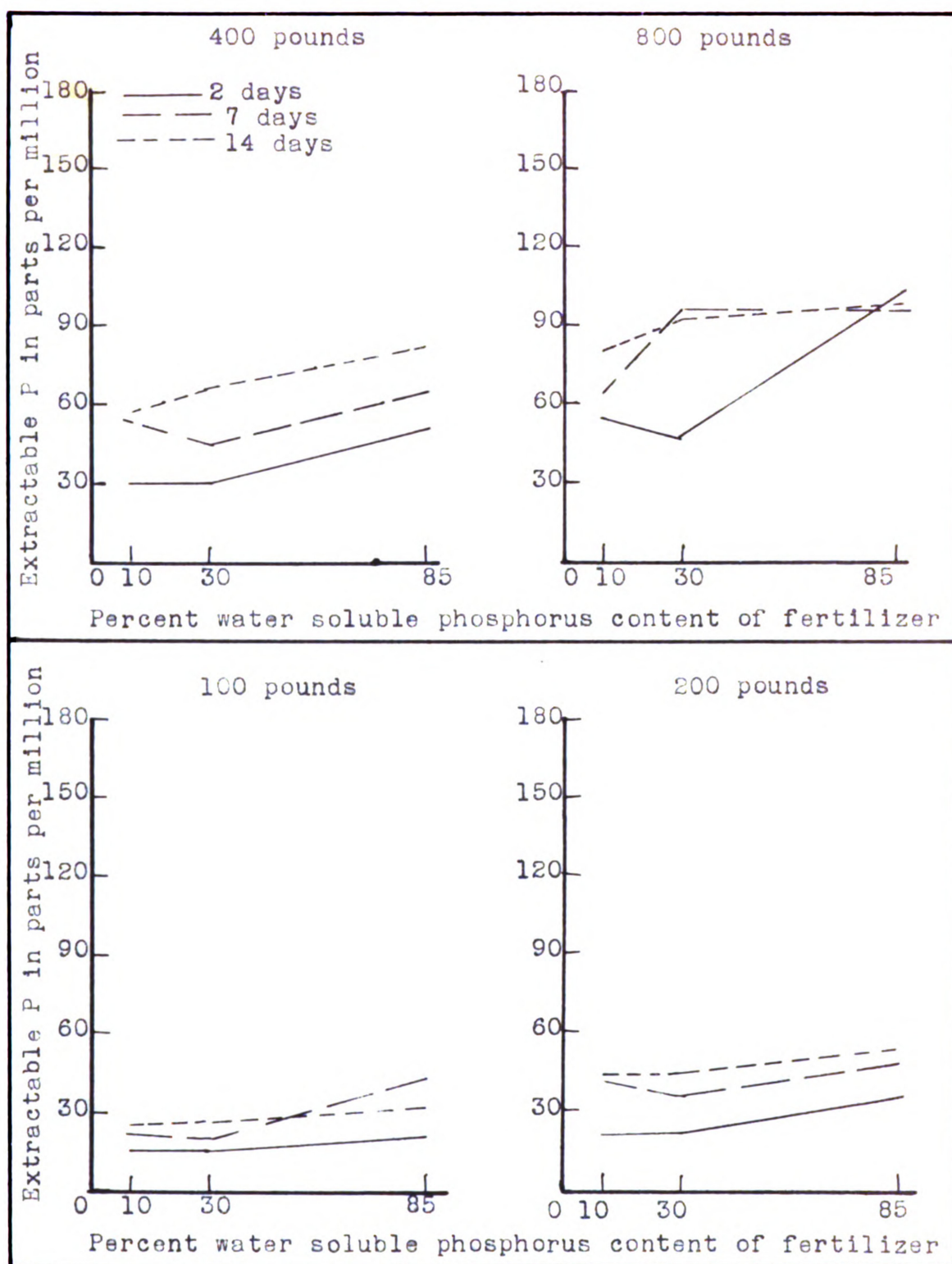


Figure 2. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from Bearden silt loam

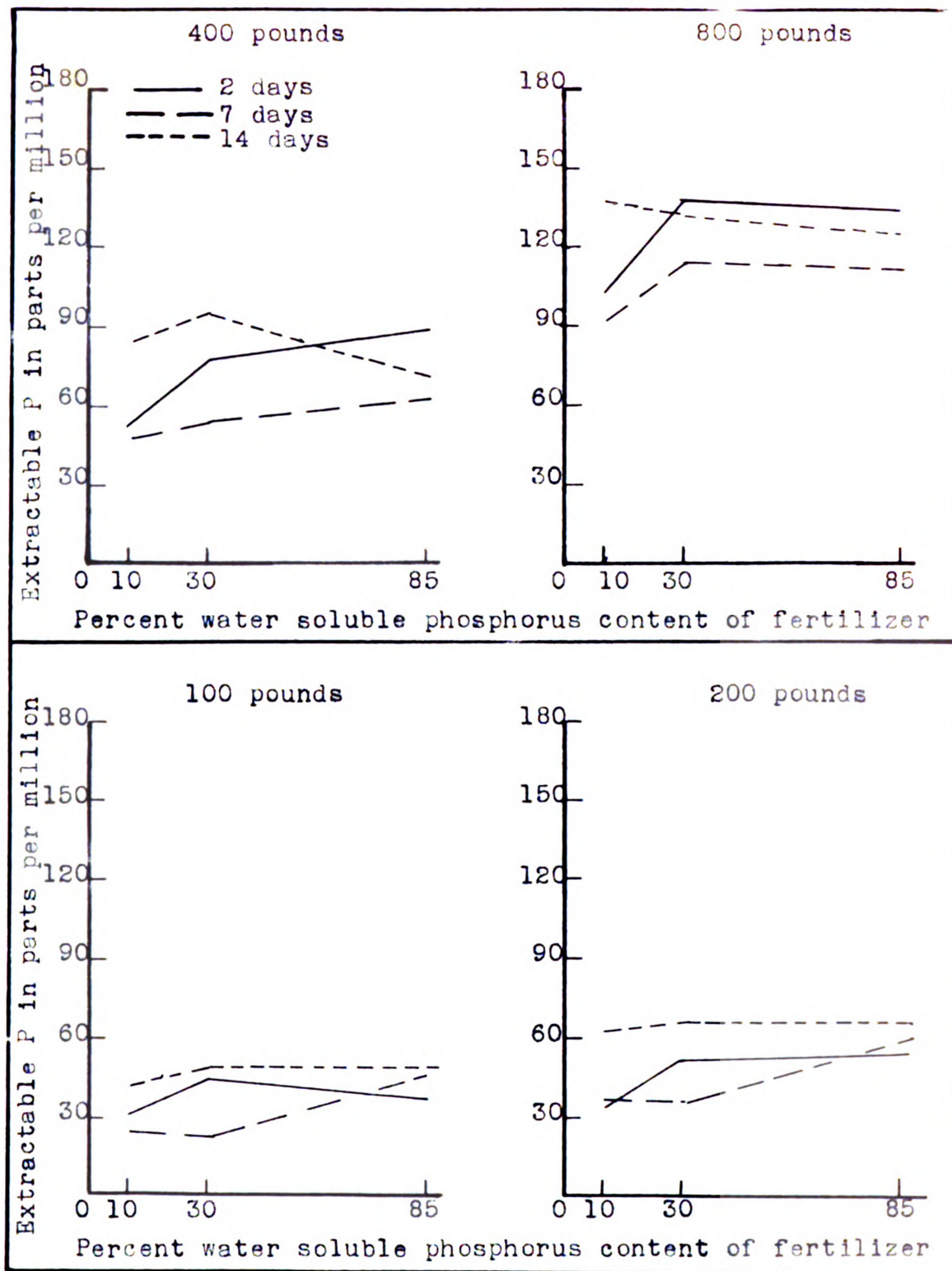


Figure 3. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from Clarion silt loam.

Marshall: This Iowa soil is also of Prairie origin developed largely from loess. It was found to contain 19.8 percent clay, 3.15 percent organic matter and 16 parts per million available phosphorus. Table 5 shows the available phosphorus after different periods of incubation. At the two lower rates of phosphate application, more phosphorus was extracted from soil which had received the high alumina nitric phosphate of lower solubility. Only when 800 pounds of P_2O_5 was applied did water solubility of these nitric phosphates appear to be related to phosphorus removed. As the incubation period increased, the quantity of extractable phosphorus also increased, except when concentrated superphosphate is used. Although the Clarion and Marshall soils had the same original available phosphorus content, considerable more phosphorus was removed from the Clarion soil.

Memphis: This silt loam is a representative of the Red and Yellow Podzolic group. It contains 13.8 percent clay, 1.3 percent organic matter and 26 parts per million available phosphorus.

The data in Table 5 and Figure 5 indicate that phosphate solubility had little effect on the amount of phosphorus removed by the weak acid fluoride solution. In almost all cases when H AL NP-30 was used, values for extractable phosphorus was as high or higher than for fertilizer containing concentrated superphosphate. Another interesting point is that there was little change in phosphorus removed as incubation

Table 5.

The availability of phosphorus in Marshall silt loam, Memphis silt loam and Miami silt loam which received different rates of high alumina nitric phosphates and other fertilizers

Fertilizer	Percent fertilizer P soluble in water	Pounds P ₂ O ₅ per acre	Ppm P extractable after different periods of incubation*											
			Marshall silt loam			Memphis silt loam			Miami silt loam					
			Number of days			Number of days			Number of days			Number of days		
			2	7	14	2	7	14	2	7	14	2	7	14
14-14-14	10	100	40	40	39	52	45	19	34	42	67			
		200	52	52	65	64	49	66	50	44	74			
		400	64	68	80	87	82	93	72	91	86			
		800	85	98	126	112	111	151	108	155	121			
15-15-15	30	100	29	36	42	51	56	62	43	45	55			
		200	37	46	65	84	63	80	51	57	83			
		400	59	66	93	114	86	113	73	82	104			
		800	86	120	162	144	143	183	92	151	104			
12-12-12	85	100	37	56	43	46	53	61	47	64	48			
		200	56	64	60	60	62	83	54	68	80			
		400	74	84	83	84	73	112	90	86	104			
		800	104	112	104	160	111	163	144	125	174			

*Phosphate determined after extraction with 0.03N NH₄F and 0.025 N HCl; initial P in soils, 16 ppm for Marshall, 26 ppm for Memphis and 20 ppm for Miami.

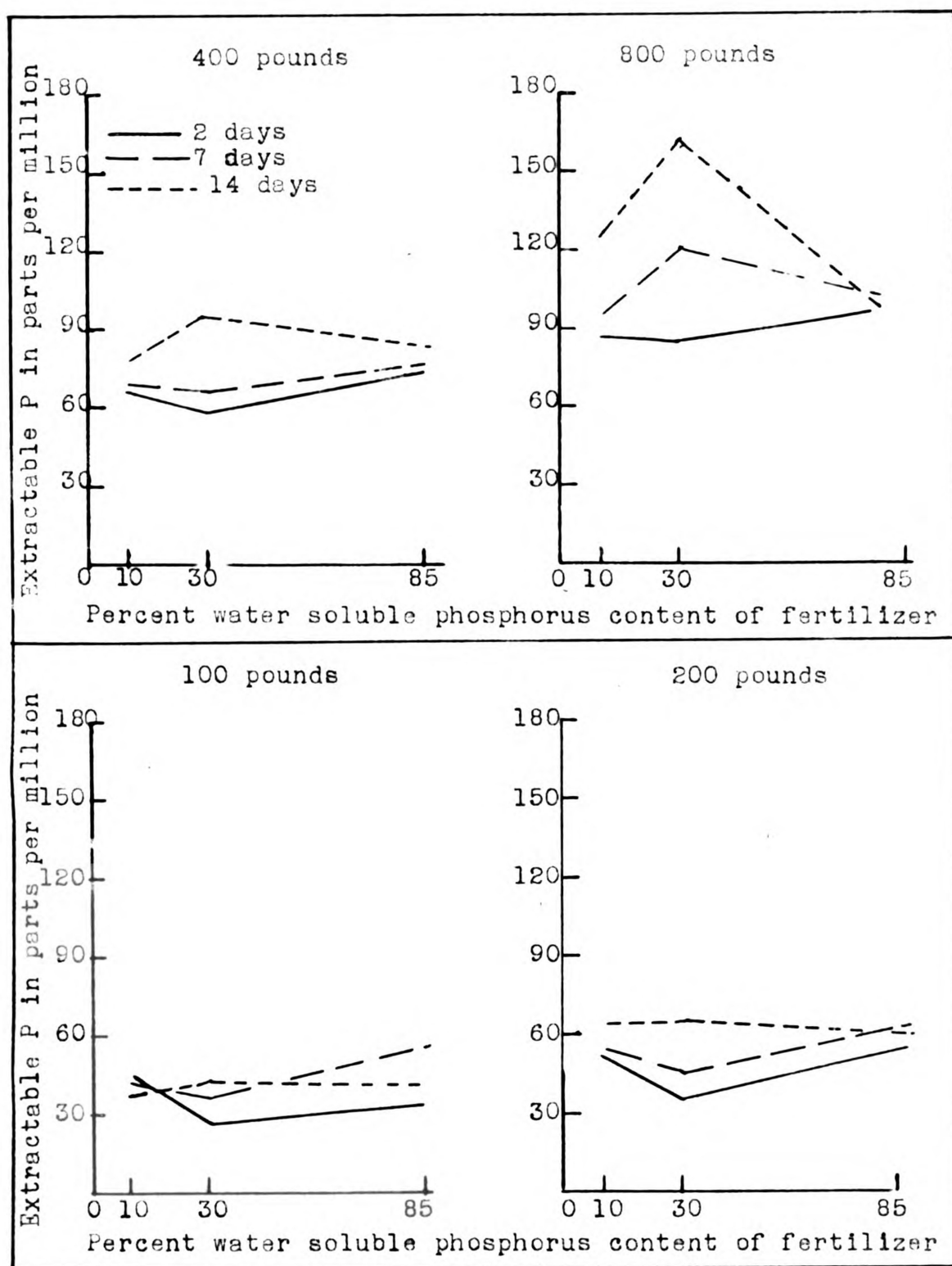


Figure 4. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from Marshall silt loam.

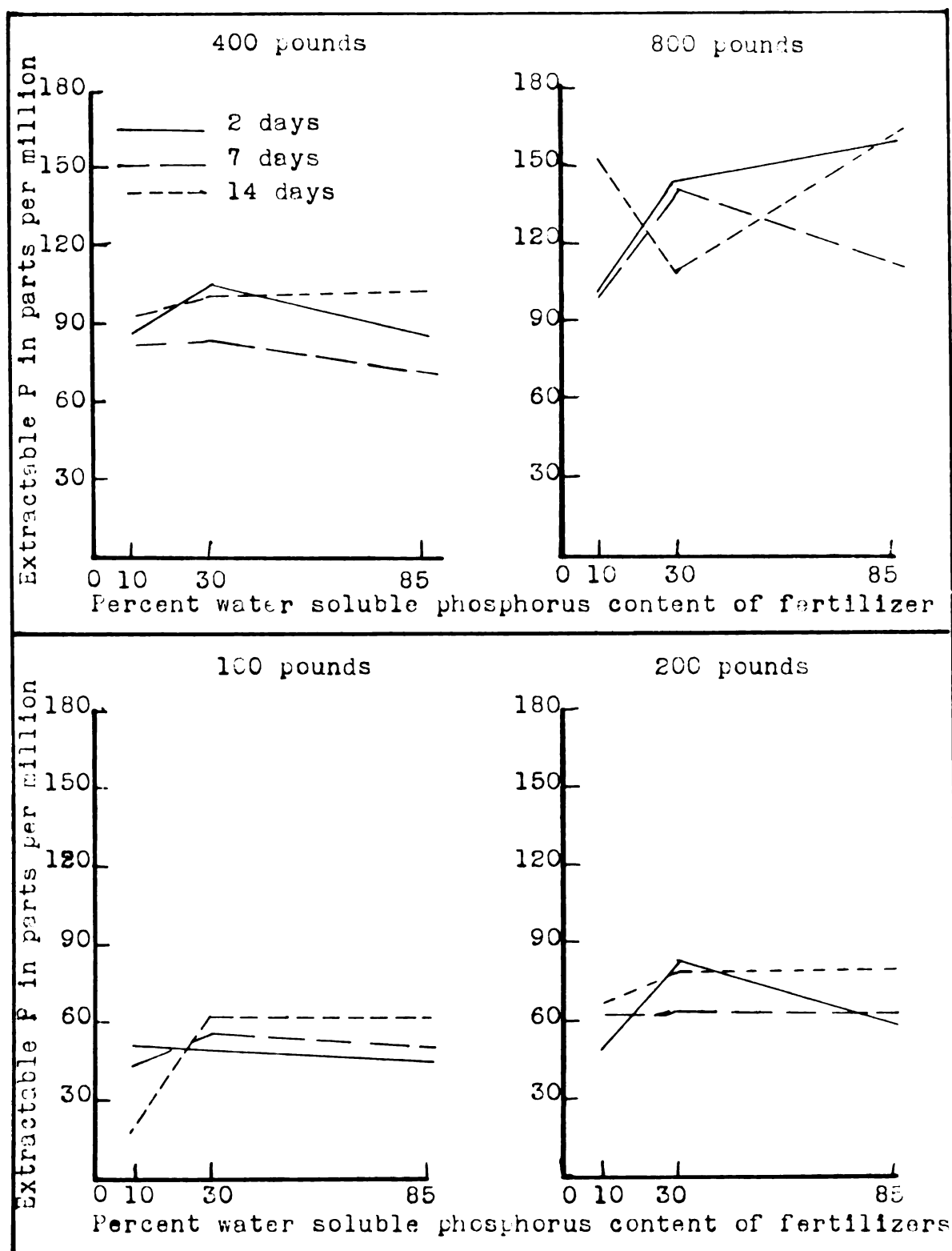


Figure 5. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from Memphis silt loam

increased. As might be expected, the relationship between phosphorus extracted and solubility of phosphorus in the different fertilizers was not the same for Memphis and Clarion soils.

Miami: Miami silt loam is classified as a gray brown Podzolic soil, developed from glacial till in central Michigan. This surface soil contained 8.8 percent clay and was low in organic matter content. Its available phosphorus content was found to be 20 parts per million.

Data in Table 5 and Figure 6 indicate that when 100, 200 and 400 pounds P_2O_5 per acre of the three fertilizers were mixed with Miami soil, the influence of phosphate water solubility was almost nil, especially after two weeks incubation. However, with the highest phosphorus application, more phosphorus was extracted from soil which received the most soluble phosphate, when the early and late sampling periods were considered. As a rule more phosphorus was removed as time of incubation of fertilizer and soil increased, although again there were exceptions to this relationship.

Oshtemo: Oshtemo sandy loam belongs to the gray brown Podzolic group of soils. This wind blown sand from central Michigan has a very low clay and organic matter content but the available phosphorus content was higher than that of any other soil, being 32 parts per million.

From the data in Table 6 and Figure 7 there is some evidence that extractable phosphorus increased as the solubility

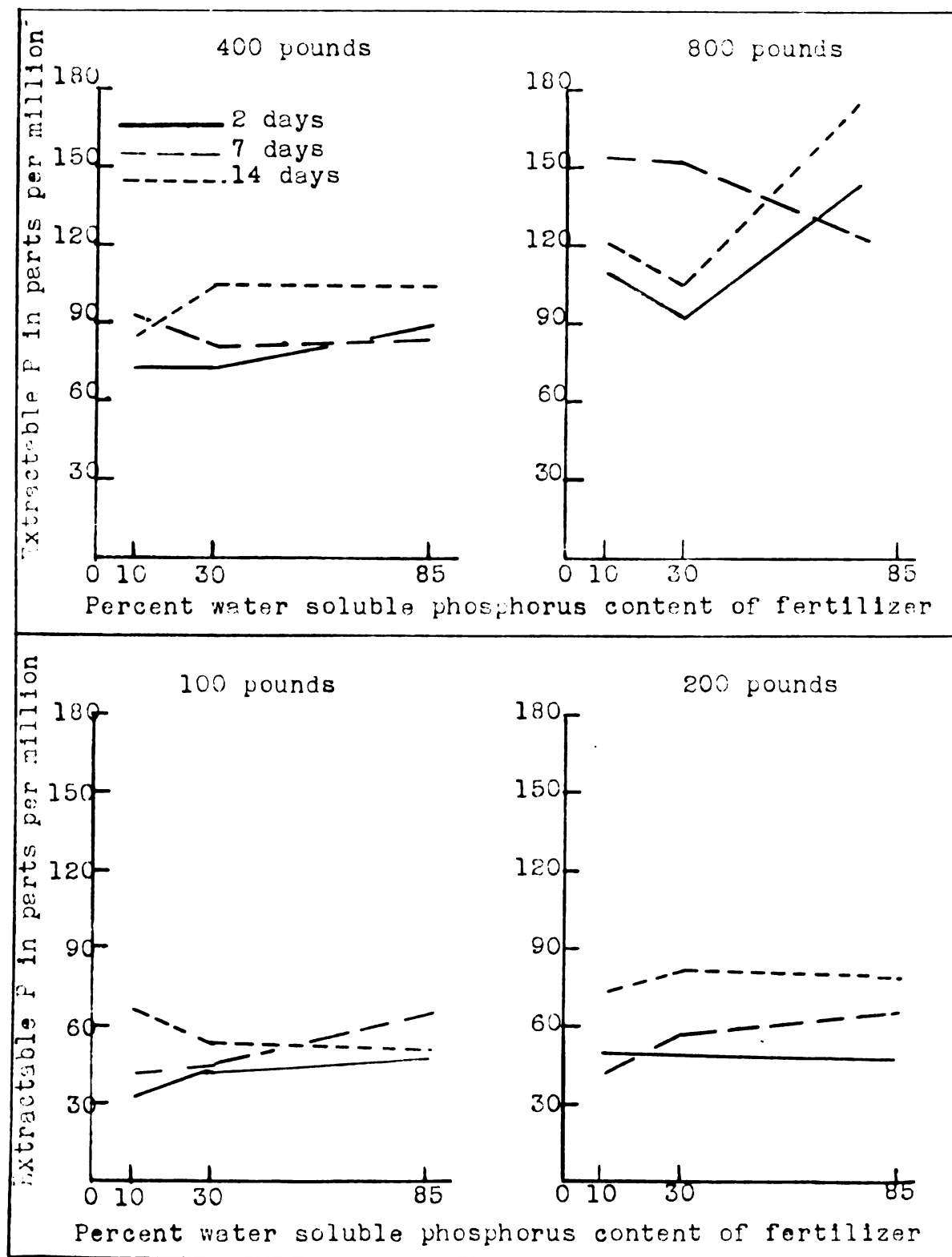


Figure 6. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from Miami silt loam.

Table 6

The availability of phosphorus in Oshtemo sandy loam and muck soil which received different rates of high alumina nitric phosphates and other fertilizers

Fertilizer	Percent fertilizer P soluble in water	Pounds P_2O_5 per acre	Ppm P extractable after different periods of incubation						
			Oshtemo sandy loam			Muck			
			Number of days		14	Number of days		2	7
			2	7		2	7		14
14-14-14	10	100	75	78	84	66	80	93	
		200	100	121	120	148	140	118	
		400	129	162	131	252	212	196	
		800	144	214	195	340	400	444	
15-15-15	30	100	94	80	88	33	80	70	
		200	121	108	108	100	140	113	
		400	180	120	120	160	152	212	
		800	237	169	169	366	266	444	
12-12-12	85	100	88	105	100	48	80	44	
		200	106	110	111	82	120	68	
		400	134	112	140	223	180	140	
		800	228	177	202	320	460	276	

*Phosphate determined after extraction with 0.03N NH_4F and 0.025 $NHCl$; initial P in soil, 32 ppm for Oshtemo and 56 ppm for muck.

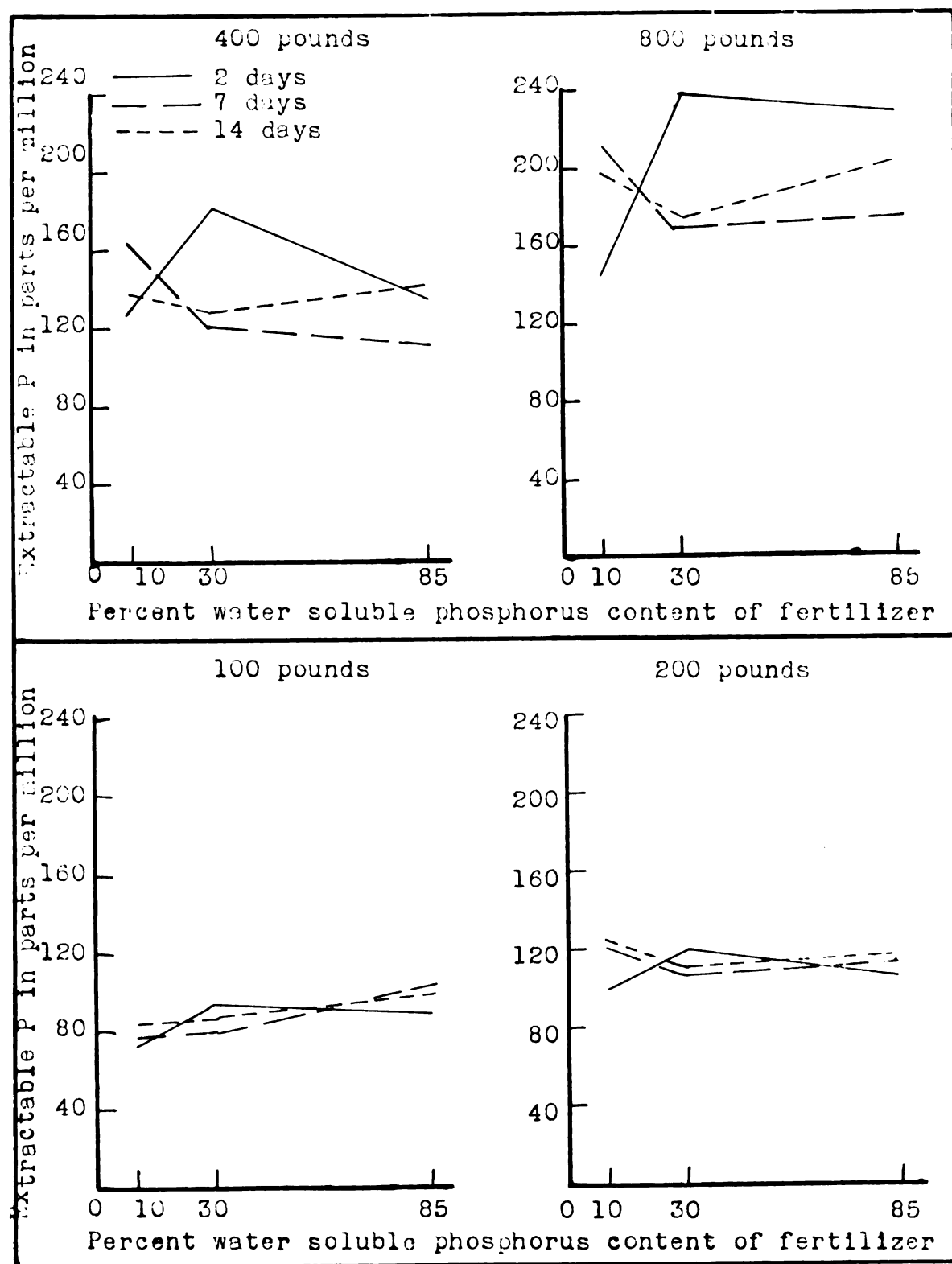


Figure 7. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from Oshtemo sandy loam.

of applied phosphate rose. However, this was true only for the lower fertilizer rates. The pattern of phosphorus removed from soils which received the 400 and 800 pounds P_2O_5 rates is rather disordered. However, one exception is that at the earliest sampling date, the largest amount of phosphorus was removed from soils treated with fertilizers of medium to high water solubility. This trend indicates that phosphorus moving out of the fertilizer particles was being fixed in forms increasingly difficult to extract.

Muck: Several trends in the availability of fertilizer phosphorus from this organic soil are evident that are not apparent for most of the mineral soils in this incubation study. First, the quantity of extractable phosphorus in the organic soil is greater where the 400 and 800 pounds P_2O_5 per acre rates were applied. Secondly, with all treatments except the highest fertilizer rate, the amount of phosphorus extractable from muck after 14 days incubation was lower than that removed from the seven day soil sampled. This condition suggests some kind of fixation mechanism, which may be related to the presence of iron compounds.

Phosphate water solubility, as a factor affecting availability of fertilizer phosphorus, appears to have little influence at the lower rates of applied phosphate.

A comparison of the amount of available phosphorus from these different soils treated with the three fertilizers indicate that in some soils the rate of release of phosphorus was

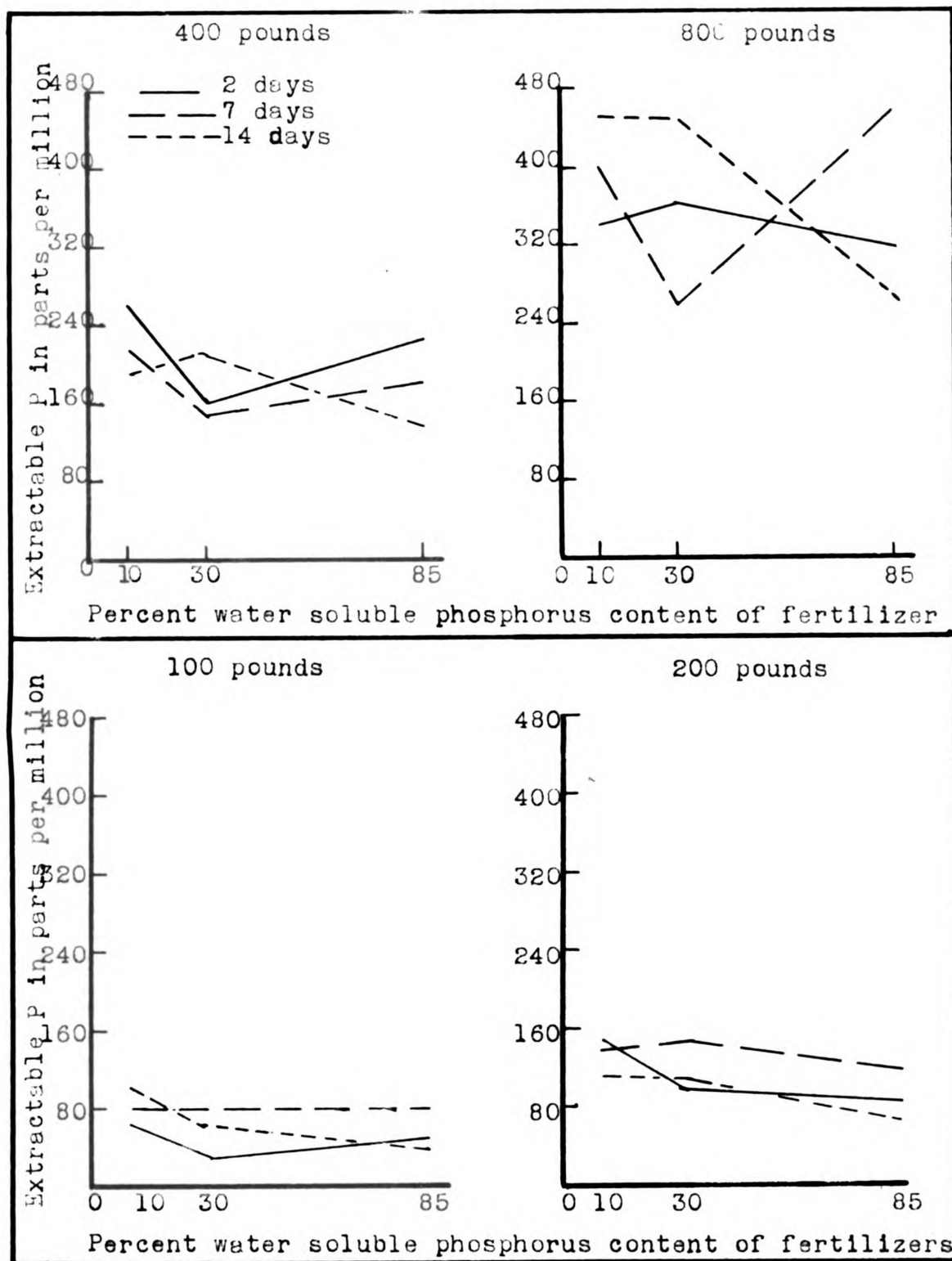


Figure 8. Effect of water solubility of fertilizer phosphorus on the extractable phosphorus from muck soil.

maximum during the first two days after the application of fertilizer after which the rate slowed down. After the first two days, possibly the rate at which phosphorus is released from the fertilizer is less than the rate at which the released phosphorus is fixed by the soil. Any further increase in the available phosphorus content could take place only after the phosphorus fixing capacity of the soil is satisfied.

The availability of phosphorus from H AL NP-30 was comparable to that from the fertilizer containing concentrated superphosphate. In general the amount of phosphorus extracted from the H Al NP-10 was less than those from the fertilizer of high phosphate water solubility.

The rate of release of phosphorus from fertilizer particles of similar size depends on the water solubility of the fertilizer phosphorus, to a large extent. Tests show that with the H Al NP-30 and CSP-85, with almost all soils, the complete release of phosphorus during the first 24 hours, after which the migration of phosphorus from the fertilizer granules slows down to a great extent.

The high alumina nitric phosphate with low water soluble P phosphorus content is slower in releasing phosphorus. In many soils studied, the maximum amount of available phosphorus was found after a weeks' incubation.

The extractability of phosphorus from soil fertilizer mixture depends on the properties of the soil as well as those of the fertilizer. The largest amounts of phosphorus were

removed from the Oshtemo sandy loam when the same rate and type of fertilizer are compared. With an increase in clay content of soil, there was an increase in the amount of fixation of released phosphorus.

Another factor which possibly influenced the fixation of phosphorus was the organic matter of the soil. For Bearden and Clarion soils, which had 4.07 and 5.94 percent organic matter respectively, the chemical availability of phosphorus was much less than with other soils of lower organic matter content. This is in accordance with the findings of Truog (39) and others that aluminum phosphate form irreversibly fixed compounds with humus.

The variation in extractability of phosphorus also depends on the pH of soil, the quality and nature of iron and aluminum compounds in soil, and several other factors. Most likely the interaction of all these factors control the extractability of phosphorus from these fertilizers.

Further incubation studies were held in the laboratory with high alumina nitric phosphates with 30 percent of their phosphorus soluble in water and the 12-12-12 fertilizer, 85 per cent phosphorus of which is soluble in water. The results obtained are given in Table 7.

The analysis of fertilizer particles showed that the maximum migration of phosphorus from the fertilizer granules took place within the first 24 hours of the application of the fertilizer. After that comparatively very little migration

of phosphorus from the granules could be seen. With H Al NP-30 in Metea sandy loam, 58 percent of its water soluble phosphorus was released during the first 24 hours whereas during the next 28 days only 2.7 per cent more phosphorus was released from the fertilizer. According to Lawton and Vomocil (18), the high concentration of phosphorus surrounding the fertilizer particle prevent further migration of phosphorus from the granules.

It was observed that the amount of phosphorus released depends on the water soluble phosphorus content of the fertilizer. The migration of phosphorus increased with an increase in the water solubility of the fertilizer phosphorus. The nature of the soil also seemed to affect the dissolution of phosphorus from fertilizer granule. With H Al NP-30 in Metea sandy loam, 58 percent water soluble phosphorus migrated at the end of 24 hours, whereas with Brookston clay loam only 54 percent moved out during the same period of time.

After the phosphorus moves out of the fertilizer, the distance to which it migrates in soil depends on time. The analysis of soil taken from various distances from the place where the fertilizer granules were placed indicates that during the first 24 hours after the application of fertilizer, the phosphorus is concentrated in a column of soil with its diameter 3 millimeters surrounding the fertilizer. With the high alumina nitric phosphate fertilizer in Metea sandy loam, the maximum rate of diffusion of phosphorus from the area of

Table 7.

The migration of phosphorus from granules and its movement in soil to various distances with time

Soil type*	pH	Fertilizer	Percent fertilizer P soluble in water	Time (days)	Ppm P in soil at different distances from P source			Percent water soluble P remaining in granules
					0-3 mm	3-5 mm	5-8 mm	
Metea sandy loam	6.8	15-15-15 (H Al NP-30)	30	1	602	110	53	42.0
				2	528	193	64	41.6
				7	556	201	68	39.2
				14	465	312	88	39.0
				28	358	342	121	39.3
		12-12-12 (CSP-85)	85	1	530	121	44	31.8
				2	468	182	35	30.2
				7	411	221	58	31.6
				14	386	229	136	29.3
				28	312	323	116	29.8
	6.5	15-15-15	30	1	460	85	55	46.0
				2	580	115	50	46.7
				7	521	181	63	45.2
				14	382	270	109	43.8
				28	298	305	121	43.0
		12-12-12	85	1	470	165	50	36.2
				2	455	185	65	36.5
				7	355	230	70	34.9
				14	290	250	70	35.3
				28	282	262	77	33.0

*Initial available phosphorus content of Metea and Brookston soils was 12 and 16 ppm respectively.

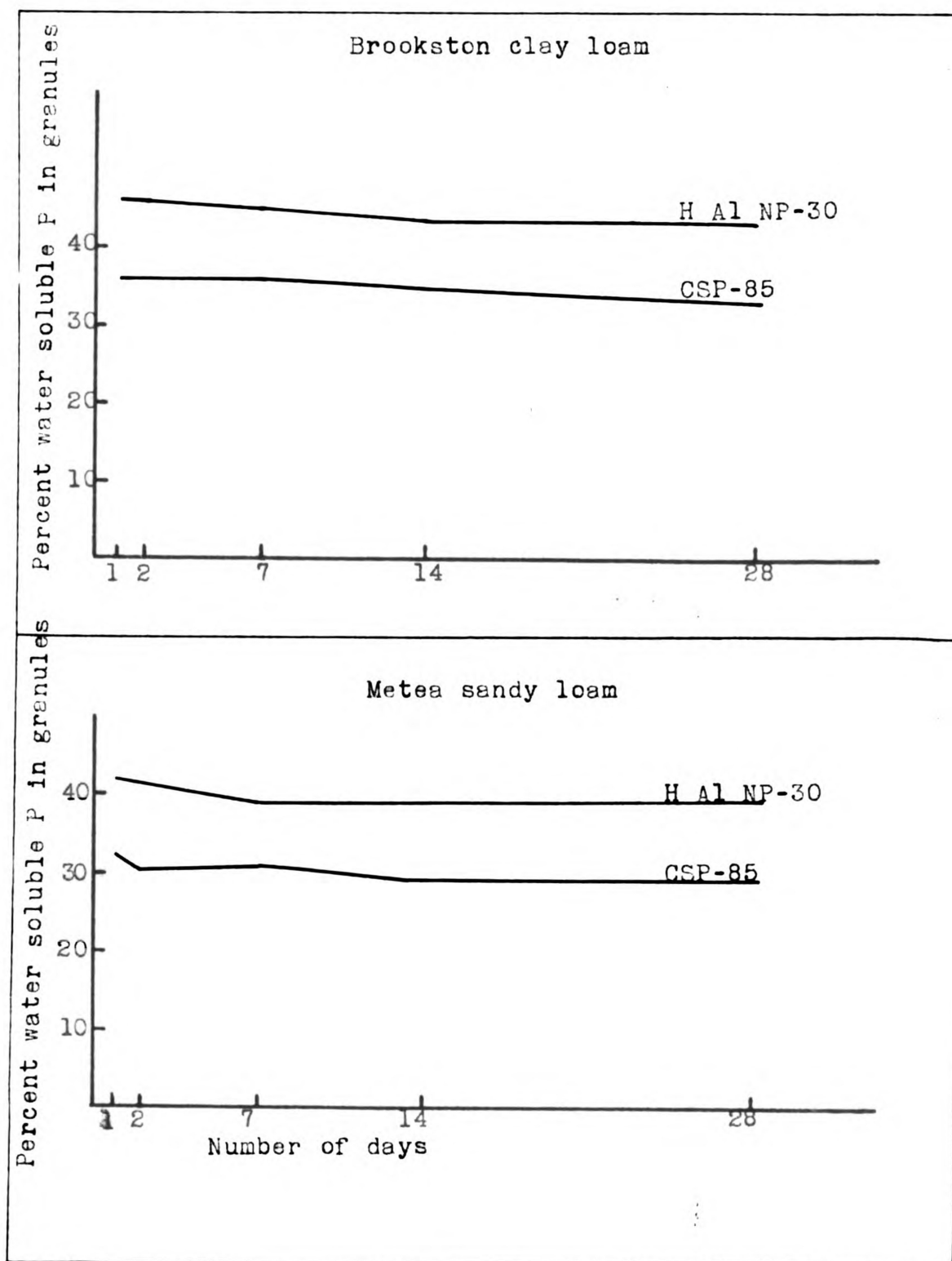


Figure 9. Migration of phosphorus from fertilizer granules.

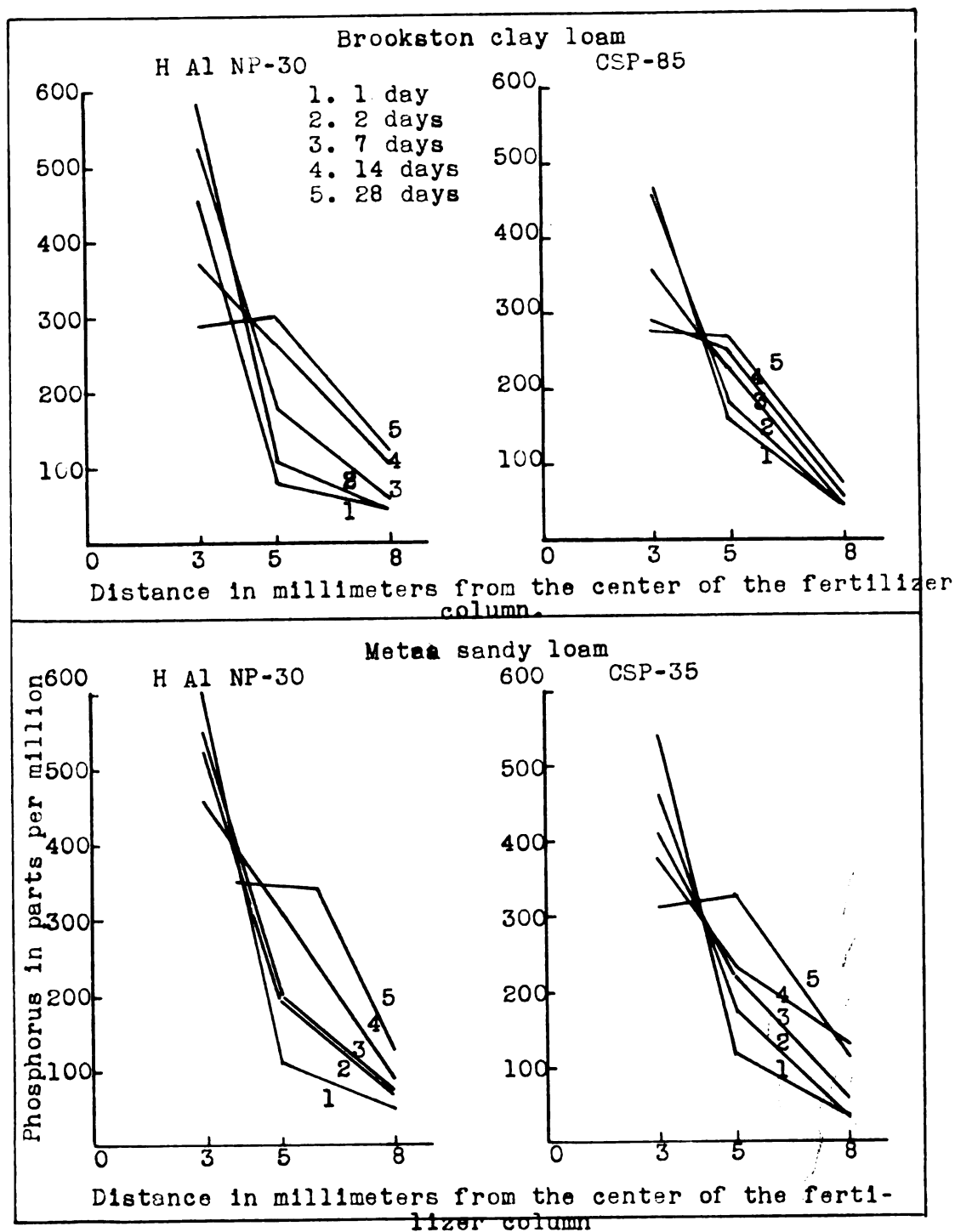


Figure 10. Movement of phosphorus in soil.

concentration took place during the first 14 days incubation. Considerable movement took place to a distance of 3-5 millimeters, and some to a distance of 5-8 millimeters. At the end of 28 days there was an almost equal distribution of phosphorus at 0-3 and 3-5 millimeter distances, but only very little movement took place to a distance of 5-8 millimeters.

With the 12-12-12 fertilizer also similar results were obtained. In Brockston soil there was only slight movement of phosphorus to a distance of 3-5 and 5-8 millimeters during the first 24 hours with the 15-15-15 fertilizer. The movement of phosphorus increased with time up to a period of 14 days and then slowed down.

With the 12-12-12 fertilizer, however, maximum diffusion took place at the end of 7 days. After seven days there was very little further diffusion of phosphorus in the soils.

Greenhouse studies

The effect of high alumina nitric phosphates on the growth of corn plants was evaluated in the greenhouse in terms of dry matter production, heights of plants and phosphorus uptake.

Dry weight

The dry weights of corn plants grown in organic soil to which different amounts of lime and fertilizer were added are presented in Table 8. These data were collected 8 weeks after planting.

Effect of soil reaction, fertilizer placement, and kind of phosphate fertilizer on the dry weight of corn plants grown in an organic soil in the greenhouse

Table 8.

Fertilizer*	Percent of fertilizer P soluble in water	Method of placement	P ₂ O ₅ per acre	Tons of lime per acre			
				Grams dry weight of plants per pot			
				0	5	10	15
14-14-14	10	Mixed	50	21.2	26.8	30.0	22.4
			200	32.6	52.8	40.6	30.6
			400	44.0	57.4	63.2	39.0
	10	Banded	50	20.4	29.2	31.6	26.4
			200	42.8	43.2	38.8	36.8
			400	40.0	49.4	44.0	33.8
15-15-15	30	Mixed	50	24.4	31.4	35.4	24.0
			200	46.2	52.6	44.4	36.0
			400	49.4	52.0	49.0	39.6
0-45-0	30	Banded	50	24.0	31.6	30.6	28.0
			200	40.0	47.4	46.0	34.0
			400	43.0	52.0	52.8	49.8
0-45-0	95	Mixed	200	43.2	53.4	56.0	55.0
21-53-0	100	Mixed	200	43.2	48.0	30.2	48.2
15-0-15	-	Mixed	200	18.0	17.8	20.2	39.2

*N and K₂O applied at the rate of 400 pounds per acre; supplements made using NH₄NO₃ and KCl.

**Average weight of three replications.

A comparison of growth response to the two high alumina nitric phosphates applied in mixed and banded placement is given in Figures 11 and 12.

In the early growth stages the phosphate water solubility of the fertilizer affected the size and height of plants considerably. In general, growth of plants was directly related to the solubility of the fertilizer used, especially when it was banded. However, corn grown in soils which received H Al NP-30, appeared to be as vigorous as that where concentrated superphosphate was used.

At harvest time, the difference in height of plants as a result of fertilizer treatment was less evident. However, there were marked differences in dry matter production. A comparison of the data involving the two high alumina nitric phosphates shows that with minor exceptions growth of corn was better where the material of high solubility was used. If concentrated superphosphate is used as a standard of comparison, it is noted that the high alumina nitric phosphates were somewhat less effective.

The kind of fertilizer placement also influenced the dry weight of corn plants. In general, mixed placement of high alumina nitric phosphates resulted in slightly better growth than banded applications. This trend is similar to that found by Lawton and co-workers (17).

The growth of corn was greatly improved by the use of lime, applied at rates of 5 or 10 tons per acre, which resulted

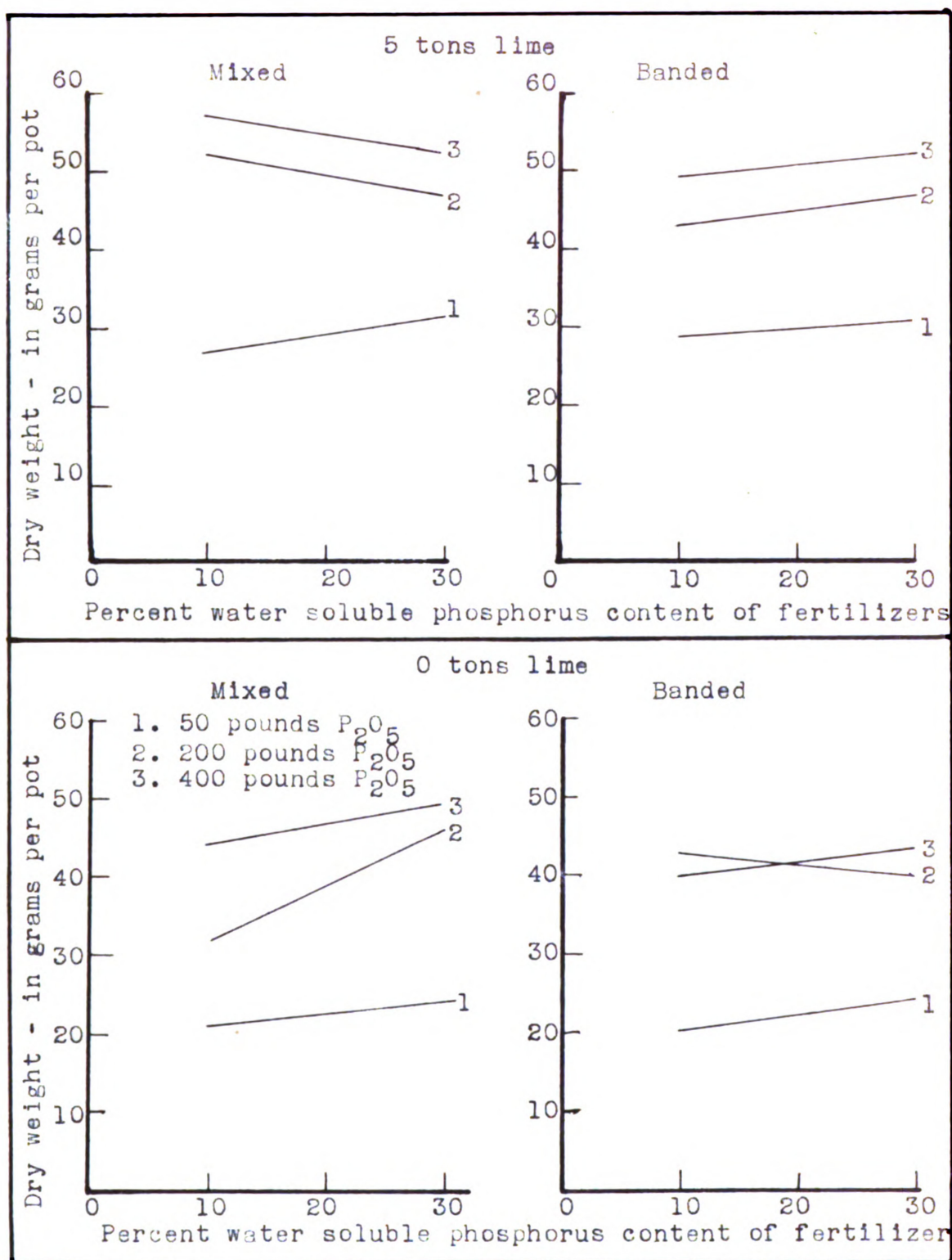


Figure 11. Effect of water solubility of fertilizer phosphorus on the dry weight of corn plants grown in an organic soil in the greenhouse.

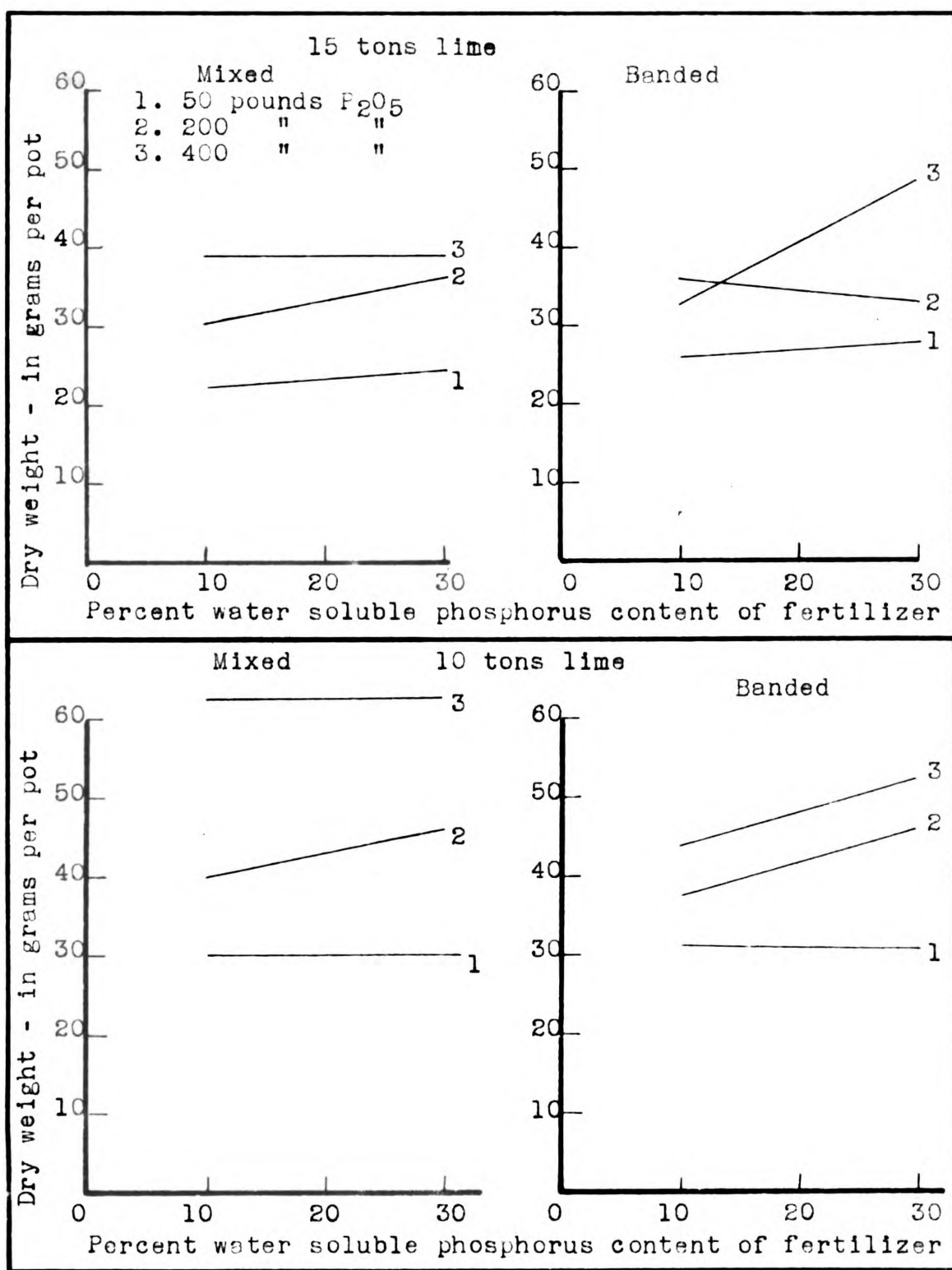


Figure 11. - continued

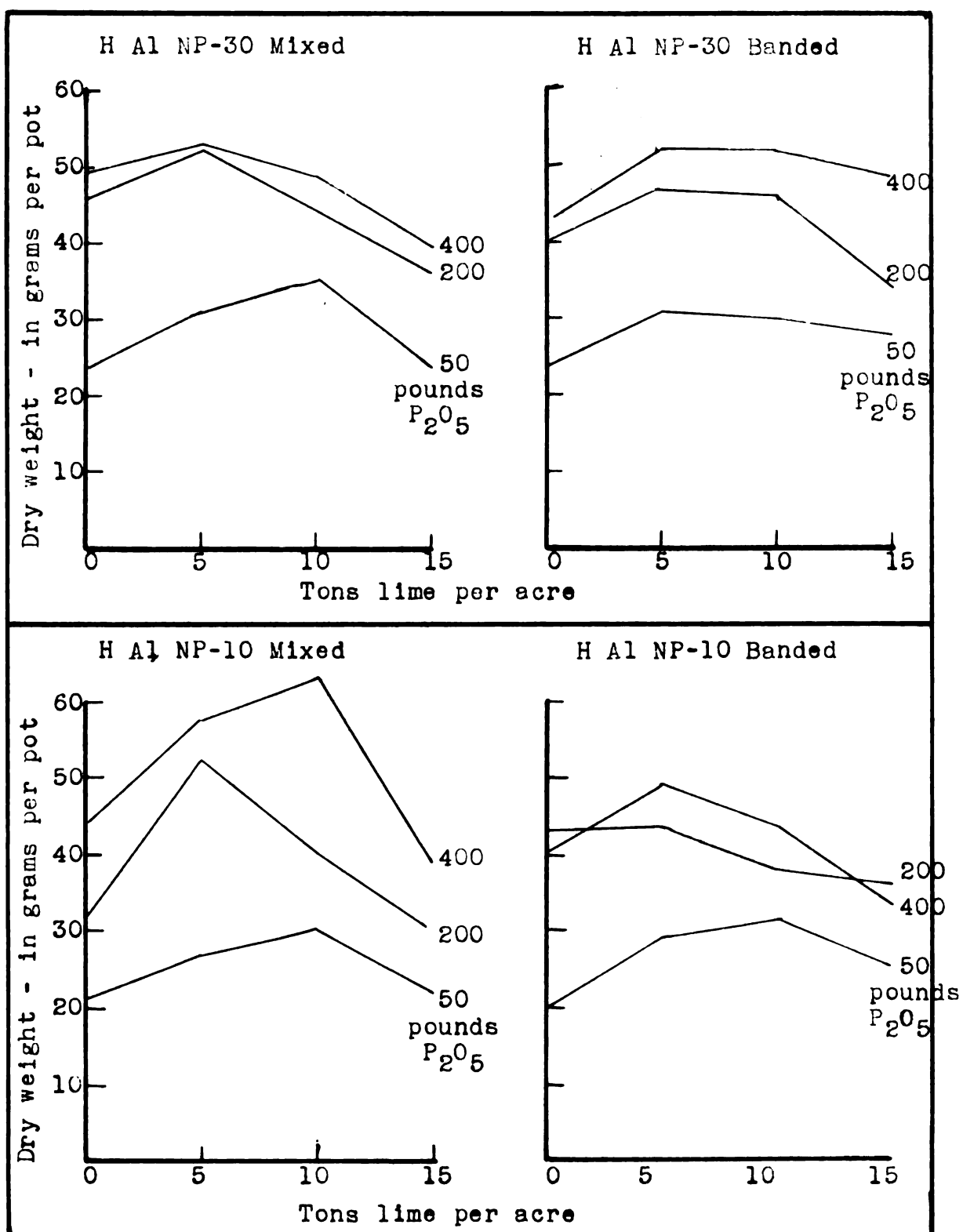


Figure 12. Effect of soil reaction on the dry weight of corn plants grown in an organic soil in the greenhouse with HAlNP.

in pH values between 5.4 and 6.5. Dry weight yields of corn receiving no lime (pH 4.1) or lime equivalent to 15 tons per acre (pH 7.5) were rather similar for all phosphates. In some cases, high lime applications were detrimental.

Phosphorus uptake

The phosphorus contents of young corn plants grown in Rifle peat soil to which varying amounts of different fertilizer and lime were added are given in Tables 9 and 10. As might be expected, as the rate of phosphorus applied increased, the percent of phosphorus in two week old plants also increased, except when this soil was limed to pH 7.5. When similar methods of placements and rates are compared, phosphorus content appears to be related to the phosphorus water solubility of the fertilizer at the two lower pH levels. When appreciable lime was added, the contents of phosphorus in the young plants varied only little.

A comparison of the absorption of phosphorus by corn plants 8 weeks after planting as affected by factors of water solubility of fertilizer phosphorus, and rate and method of placement of high alumina nitric phosphate fertilizers is presented in Figure 13. Without added lime, plant uptake of phosphorus was very low when only 50 pounds of P_2O_5 was applied. Corn grown in soils receiving 400 pounds of H Al NP-30 fertilizer well mixed in, removed almost twice as much phosphorus as plants receiving the same fertilizer placed in bands. This was not true for H Al NP-10 fertilizer.

Table 9.

Effect of soil reaction, fertilizer placement and kind of phosphate fertilizer on the total phosphorus content of corn plants grown in an organic soil in the greenhouse (2 weeks after planting)

Fertilizer*	Percent fertilizer P soluble in water	Method of placement	Pounds P_2O_5 per acre	Tons, lime per acre			
				Percent total phosphorus**			
				0	5	10	15
14-14-14	10	Mixed	50	0.04	0.22	0.20	0.13
			200	0.22	0.23	0.25	0.20
			400	0.47	0.54	0.36	0.17
		Banded	50	0.06	0.16	0.19	0.17
			200	0.40	0.24	0.21	0.19
			400	0.40	0.25	0.32	0.17
15-15-15	30	Mixed	50	0.37	0.26	0.20	0.18
			200	0.51	0.33	0.29	0.13
			400	0.68	0.36	0.44	0.15
		Banded	50	0.36	0.14	0.14	0.15
			200	0.75	0.19	0.25	0.23
			400	0.77	0.44	0.29	0.28
0-45-0 21-53-0 15-0-15	95 100 -	Mixed Mixed Mixed	200	0.44	0.38	0.30	0.20
			200	0.46	0.44	0.36	0.26
			200	0.23	0.10	0.20	0.07

* N and K_2O applied at the rate of 400 pounds per acre; supplements made using NH_4NO_3 and KCl .

**Average of three replications.

Table 10.

The effect of soil reaction, fertilizer placement and kind of phosphate fertilizer on the phosphorus uptake of corn plants grown in an organic soil in the greenhouse (8 weeks after planting)

Fertilizer*	Percent, fertilizer P soluble in water	Method of placement	Pounds P_2O_5 per acre	Tons, lime per acre			
				Milligrams P uptake per pot**			
				0	5	10	15
14-14-14	10	Mixed	50	15.4	19.0	12.0	30.2
			200	25.4	66.5	18.2	33.0
			400	23.3	88.9	20.8	45.2
		Banded	50	10.8	37.9	23.0	18.4
			200	27.8	53.1	27.5	34.2
			400	44.4	36.0	28.6	50.0
15-15-15	30	Mixed	50	14.6	9.4	28.3	13.9
			200	43.8	19.4	34.9	29.9
			400	64.2		47.5	29.7
		Banded	50	16.8	11.0	20.1	17.6
			200	37.5	26.5	51.9	22.1
			400	28.4	52.5	42.2	30.3
0-45-0	95	Mixed	200	46.5	59.2	54.8	45.6
21-53-0	100	Mixed	200	30.6	34.0	28.6	44.2
15-0-15	-	Mixed	200	12.8	12.4		24.3

* N and K_2O applied at the rate of 400 pounds per acre; supplements made using NH_4NO_3 and KCl .

**Average of three replications.

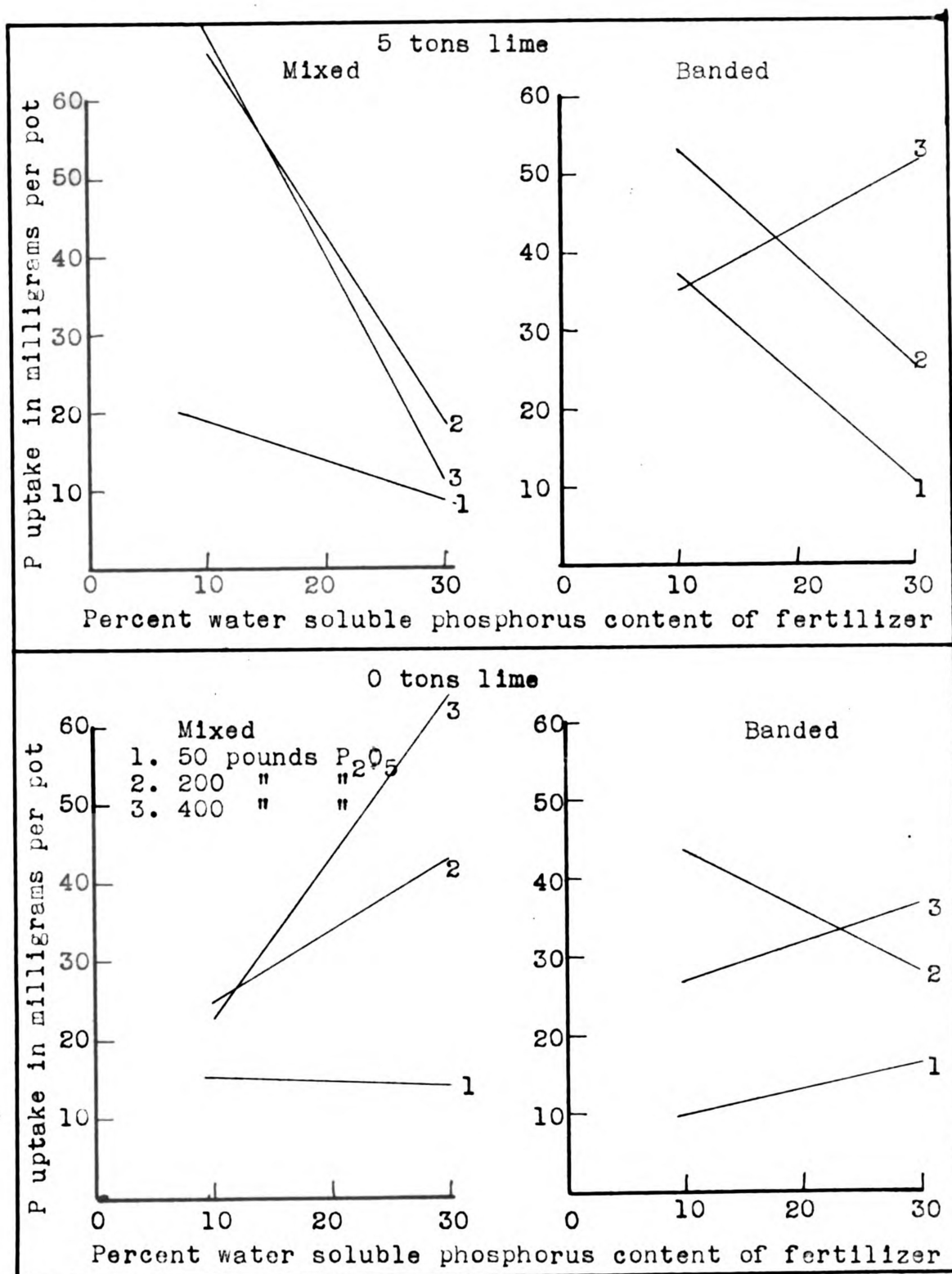


Figure 13. Effect of water solubility of fertilizer phosphorus on the P uptake of corn plant grown in an organic soil in the greenhouse.

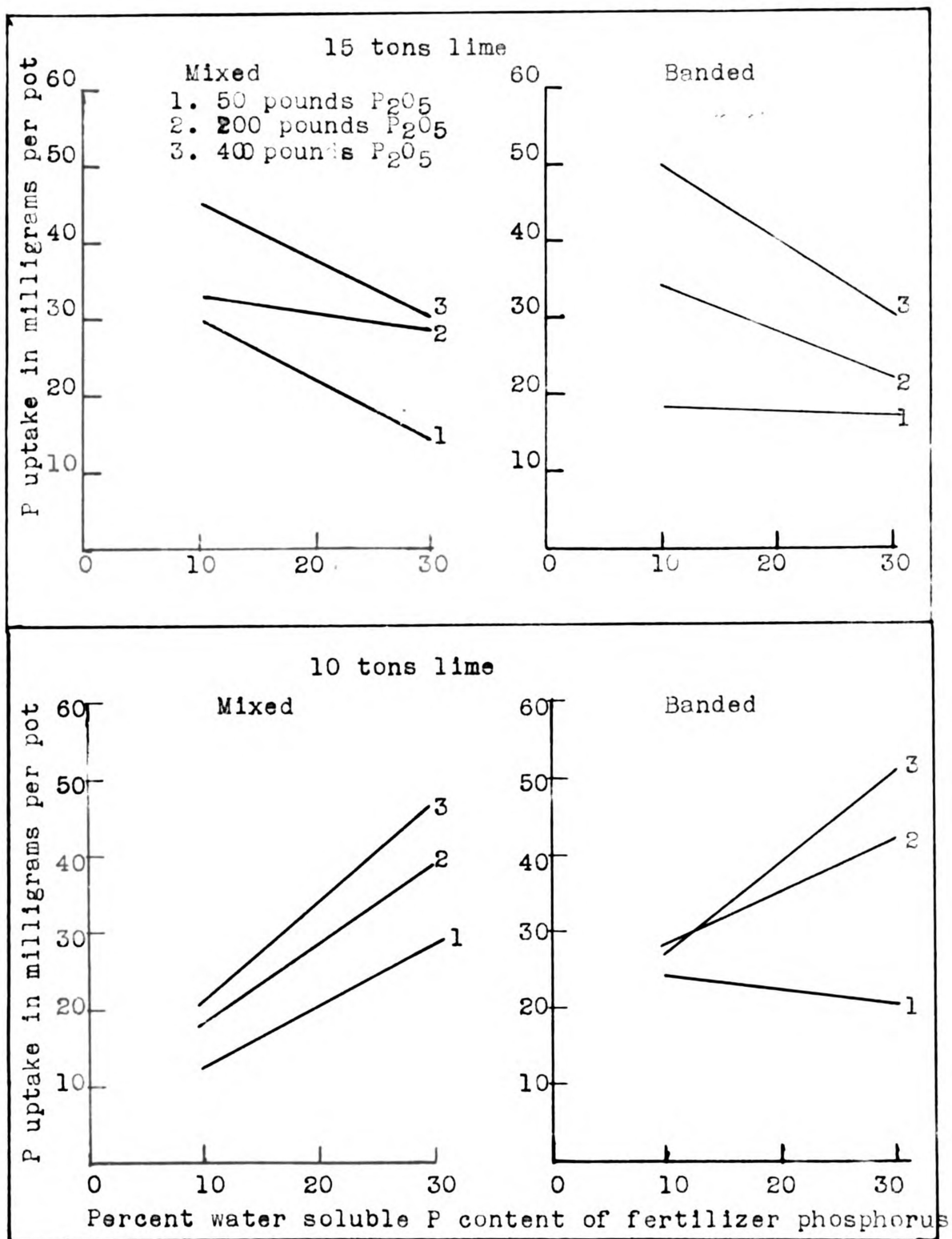


Figure 13 - continued.

When 5 tons of lime was mixed with the acid organic soil prior to fertilizing, uptake of phosphorus was greater from materials of lower solubility in all cases except where 400 pounds of P_2O_5 as H Al NP-30 was applied in a band.

This situation was reversed in the case of peat soil brought to pH 6.5. The data indicate that with one exception, corn plants removed more phosphorus from soils receiving the high alumina nitric phosphates of high solubility. Overliming definitely reduced the availability of phosphate even from the material containing 30 per cent of its phosphorus in a water soluble form. This correlation is evident for both rate and method application, as noted in Figure 13.

Thus it appears that the behaviour of phosphorus from the high alumina nitric phosphates as influenced by liming is not consistent as expressed by uptake values.

Field beans were immediately planted in soil of the same pots after the corn was harvested. After a two-week growth period, the beans were sampled and at the end of six weeks a harvest was made.

It is concluded from dry weight data in Table 11 and Figure 14 that the degree of water solubility of the fertilizers and previous liming had little effect on the growth of field beans. This correlation is difficult to reconcile with the work of Lawton and Davis (176) who found that differential liming had a marked effect on the dry weight values of the same crop grown in the same soil. The residual effect of the

Table 11.

The effect of soil reaction, fertilizer placement, and kind of phosphate fertilizer on the dry weight of bean plants grown in an organic soil in the greenhouse (6 weeks after planting)

Fertilizer	Percent, fertilizer P soluble in water	Method of placement	Pounds P_2O_5 per acre	Tons, lime per acre			
				Grams, dry weight per pot			
				0	5	10	15
14-14-14	10	Mixed	50	4.3	3.8	4.6	4.3
			200	5.6	4.2	4.4	6.0
			400	6.2	4.8	5.4	5.4
	10	Banded	50	4.3	3.4	4.2	4.8
			200	6.7	4.0	5.0	5.1
15-15-15	30	Mixed	400	6.2	5.2	5.1	6.0
			50	5.0	3.8	3.6	3.8
			200	5.8	4.0	5.0	4.6
	30	Banded	400	6.4	4.4	4.8	6.0
			50	5.0	4.2	4.0	4.2
0-45-0 21-53-0 15-0-15	95	Mixed	200	5.6	4.2	4.8	5.0
	100	Mixed	400	6.0	5.4	5.1	5.8
	-	Mixed	200	5.8	4.6	4.9	4.6
* Average of three replications				6.4	4.8	5.6	6.2
				3.6	3.2	3.8	3.2

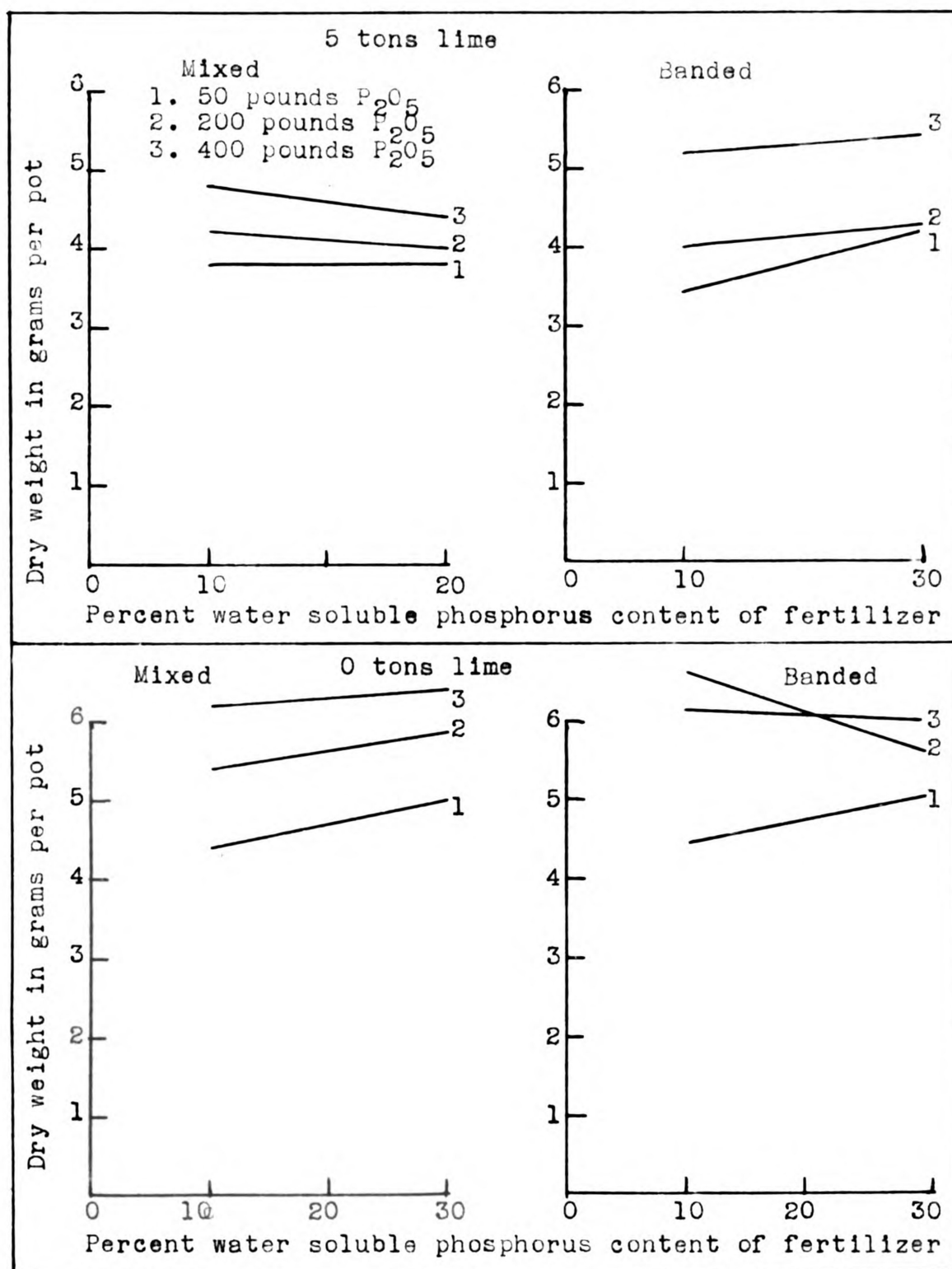


Figure 14. Effect of water solubility of fertilizer phosphorus on the dry weight of beans grown in an organic soil in the greenhouse.

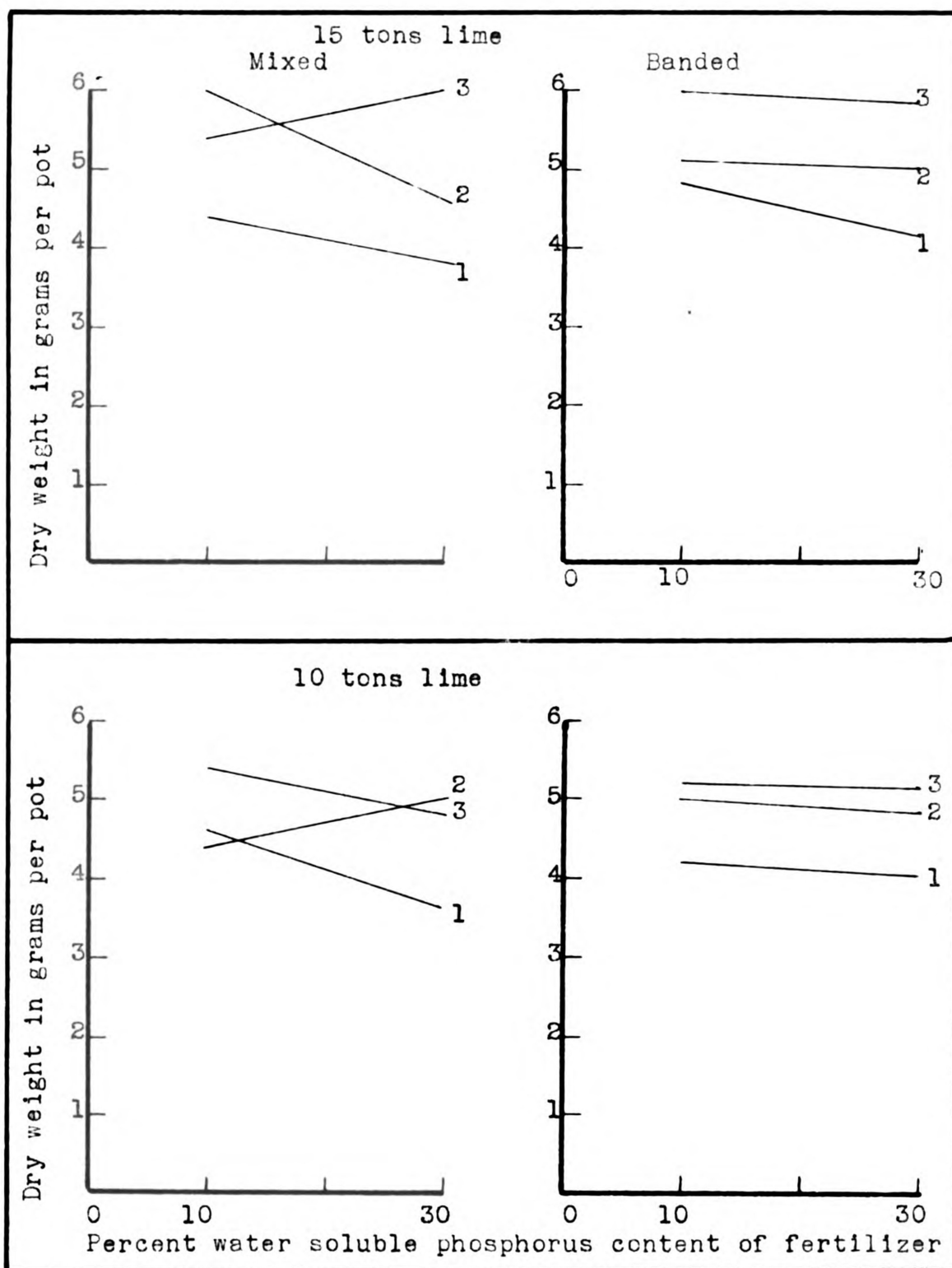


Figure 14 - continued.

Table 12.

Effect of soil reaction, fertilizer placement and kind of phosphate fertilizer on the total phosphorus content of bean plants grown in an organic soil in the greenhouse (2 weeks after planting)

Fertilizer*	Percent, fertilizer P soluble in water	Method of placement	Pounds P_2O_5 per acre	Tons, lime per acre			
				Percent, total phosphorus**	0	5	10
14-14-14	10	Mixed	50	0.24	0.26	0.07	0.13
			200	0.24	0.20	0.11	0.20
			400	0.28	0.20	0.15	0.17
		Banded	50	0.24	0.16	0.12	0.17
			200	0.33	0.15	0.13	0.19
			400	0.37	0.25	0.14	0.17
15-15-15	30	Mixed	50	0.29	0.19	0.05	0.18
			200	0.28	0.20	0.08	0.13
			400	0.28	0.25	0.20	0.15
		Banded	50	0.23	0.19	0.19	0.15
			200	0.24	0.19	0.22	0.23
			400	0.20	0.38	0.28	0.28
0-45-0	95	Mixed	200	0.38	0.26	0.26	0.20
21-53-0	100	Mixed	200	0.42	0.30	0.30	0.26
15-0-15	-	Mixed	200	0.20	0.21	0.34	0.07

* Average of three replications

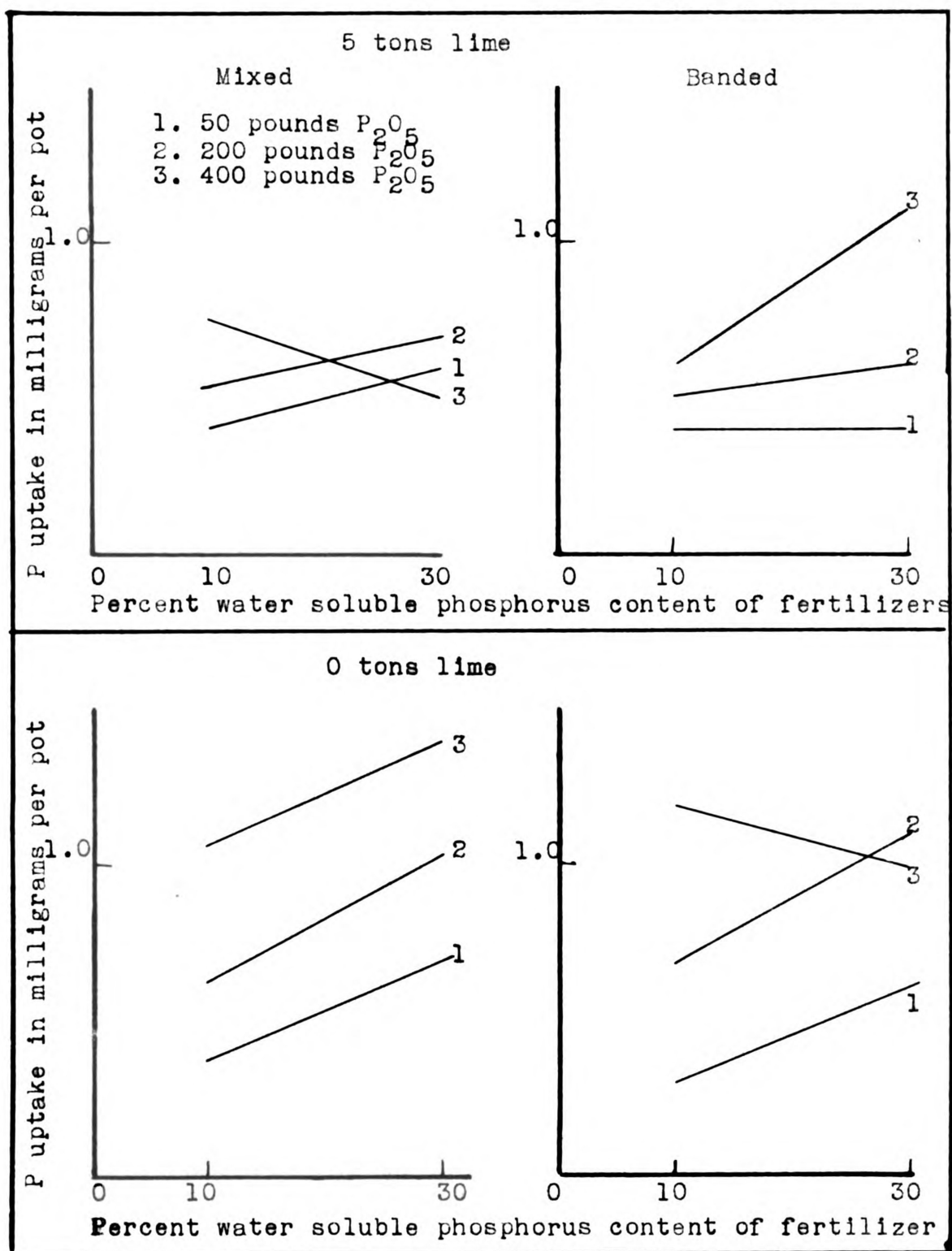


Figure 15. Effect of water solubility of fertilizer phosphorus on the P uptake of bean plants grown in an organic soil in the greenhouse.

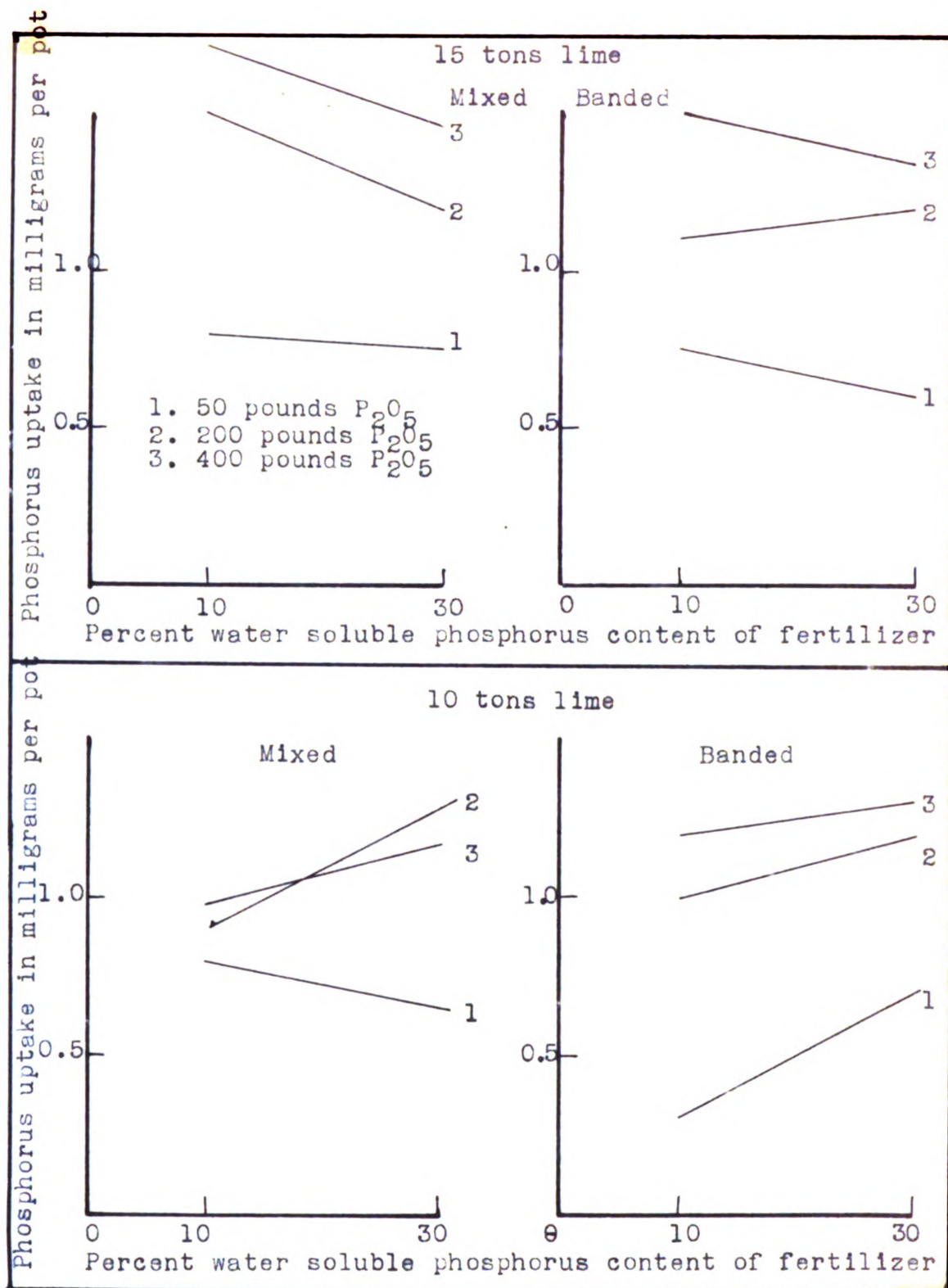


Figure 15 - continued.

applied fertilizer is clearly evident when yield data for the high and low rates of P_2O_5 application are compared regardless of fertilizer, placement, or soil reaction level.

The phosphorus contents and values of phosphorus absorption of bean plants from soil having different lime and fertilizer treatments is presented in Table 12.

The data indicate a great deal of immobility, although the same direct relationship is apparent between phosphorus content and rate of applied phosphorus. Plants from a few treatments had extremely low phosphorus contents, which can be explained in part on variability in growth due to inadequate greenhouse facilities. Total uptake of phosphorus by beans was clearly a function of the rate of previously applied phosphorus, but phosphate water solubility of the fertilizers and liming had little effect on phosphorus absorption. Recent studies by Norland, et al. () also show that as the time from fertilizer application increases, the effects of water solubility are minimized.

Field Experiments

Experiments were conducted on a Metea sandy loam at the University Farm and on a Fox sandy loam at the W. K. Kellogg Farm.

The effects of nine different fertilizers with water soluble phosphorus contents varying from 6 to 100 per cent were studied on the yield of corn and phosphorus content of corn plants at different stages of growth. Corn in bushels per acre is given in Table 14.

Table 13.

Effect of soil reaction, fertilizer placement and kind of phosphate fertilizer on the phosphorus uptake of bean plants grown in an organic soil in the greenhouse (6 weeks after planting)

Fertilizer*	Percent, fertilizer P soluble in water	Method of placement	Pounds P_2O_5 per acre	Tons, lime per acre			
				Milligrams, P uptake per pot			
				0	5	10	15
14-14-14	10	Mixed	50	0.3	0.3	0.8	0.8
			200	0.6	0.5	0.9	1.5
			400	1.0	0.7	0.9	1.7
		Banded	50	0.3	0.3	0.3	0.7
			200	0.7	0.5	1.0	1.1
			400	1.1	0.6	1.2	1.5
15-15-15	30	Mixed	50	0.7	0.6	0.6	0.7
			200	1.0	0.6	1.3	1.2
			400	1.4	0.5	1.2	1.4
		Banded	50	0.6	0.3	0.7	0.6
			200	1.1	0.6	1.2	1.2
			400	0.9	1.1	1.3	1.3
0-45-0	95	Mixed	200	1.4	1.1	1.1	0.9
21-53-0	100	Mixed	200	0.8	0.9	1.4	0.9
15-0-15	-	Mixed	200	0.6	0.7	0.5	0.4

* Average of three replications

Table 14.

Influence of high alumina nitric phosphates and other fertilizers on the yield of corn plants at the University Farm (Metea sandy loam) and W. K. Kellogg farm (Fox sandy loam)

Fertilizer	Percent, fertilizer P soluble in water	Pounds P ₂ O ₅ per acre	Bushels, yield per acre	
			Metea sandy loam	Fox sandy loam
21.5-0-21.5**	-	-	61.7	39.0
21.5-0-21.5***	-	-	63.7	37.8
14-14-14	10	25	68.6	35.1
14-14-14	10	50	68.0	39.8
10-10-10	25	25	77.4	38.3
10-10-10	25	50	74.9	37.4
15-15-15	30	25	71.2	37.5
15-15-15	30	50	70.4	36.4
14.5-14.5-14.5	95	25	72.1	38.1
14.5-14.5-14.5	95	50	70.2	37.8
7-14-14	6	50	70.1	
6-12-12	25	50	68.8	
10-20-20	50	50	71.1	
11-22-22	100	50	75.9	

* Average of four replications

** N and K₂O adjusted to 25 pounds per acre

***N and K₂O adjusted to twice that of previous treatment

1 F value - Metea sandy loam - 1.14 N.S.
Fox sandy loam - 0.61 N.S.

Corn yields: The addition of phosphorus produced a significant response in the yield of corn. However, there was little difference between the various phosphate sources. It can be noted in Figure 16 that the high alumina nitric phosphates were as effective as superphosphate, 10-10-10 fertilizer or the 1:2:2 fertilizers. This relationship is particularly evident in the case of high alumina nitric phosphates of medium water soluble phosphorus content. A slight though not significant increase in corn yield resulted when the water solubility of H Al NP was raised from 10 to 30 percent.

A comparison of the yield obtained from the use of 1:2:2 fertilizers indicates that the water solubility of the fertilizer phosphorus did not influence the yield. Likewise there was little difference in the effect of 1:1:1 and 1:2:2 fertilizers on corn yields.

On the Fox sandy loam, the study involved only a comparison of 1:1:1 fertilizers. No response to phosphorus was obtained at this location from the addition of phosphorus. This was due to adverse climatic conditions, for during the later part of July and the month of August there was only very little rainfall. This dry condition caused a great decrease in the yield of corn. Hence no comparison could be made regarding the effect of water solubility on the yield of corn.

Phosphorus uptake by corn: The total phosphorus contents of corn plants at various stages of development, grown in Metea sandy loam and Fox sandy loam are presented in Tables 15 and Figures 16 and 17.

Table 15.

Influence of high alumina nitric phosphates and other fertilizers on the phosphorus content of corn plants at different stages of growth at the University Farm (Metea sandy loam) and W. K. Kellogg Farm (Fox sandy loam)

Fertilizer*	Percent fertilizer P soluble in water	Pounds P ₂ O ₅ per acre	Metea sandy loam			Fox sandy loam		
			Days after planting			Days after planting		
			24	39	54	16	30	50
21.5-0-21.5**	-	-	0.17	0.22	0.26	0.26	0.28	0.25
21.5-0-21.5***	-	-	0.17	0.24	0.25	0.29	0.26	0.16
14-14-14	10	25	0.19	0.23	0.26	0.28	0.24	0.24
14-14-14	10	50	0.17	0.23	0.20	0.28	0.30	0.26
10-10-10	25	25	0.18	0.23	0.23	0.31	0.27	0.29
10-10-10	25	50	0.17	0.25	0.29	0.25	0.27	0.30
15-15-15	30	25	0.19	0.23	0.20	0.28	0.30	0.25
15-15-15	30	50	0.16	0.24	0.28	0.27	0.32	0.35
14.5-14.5-14.5	95	25	0.19	0.23	0.26	0.29	0.26	0.16
14.5-14.5-14.5	95	50	0.22	0.28	0.25	0.27	0.20	0.32
7-14-14	6	50	0.16	0.22	0.26			
6-12-12	25	50	0.18	0.21	0.21			
10-20-20	50	50	0.26	0.22	0.22			
11-22-22	100	50	0.15	0.18	0.27			

* Average of three replicates. First sample consisted of entire above ground portion of the plant; second and third samples consisted of leaves of approximately same physiological age.

** N and K₂O adjusted to 25 pounds per acre.

***N and K₂O double that of previous treatment.

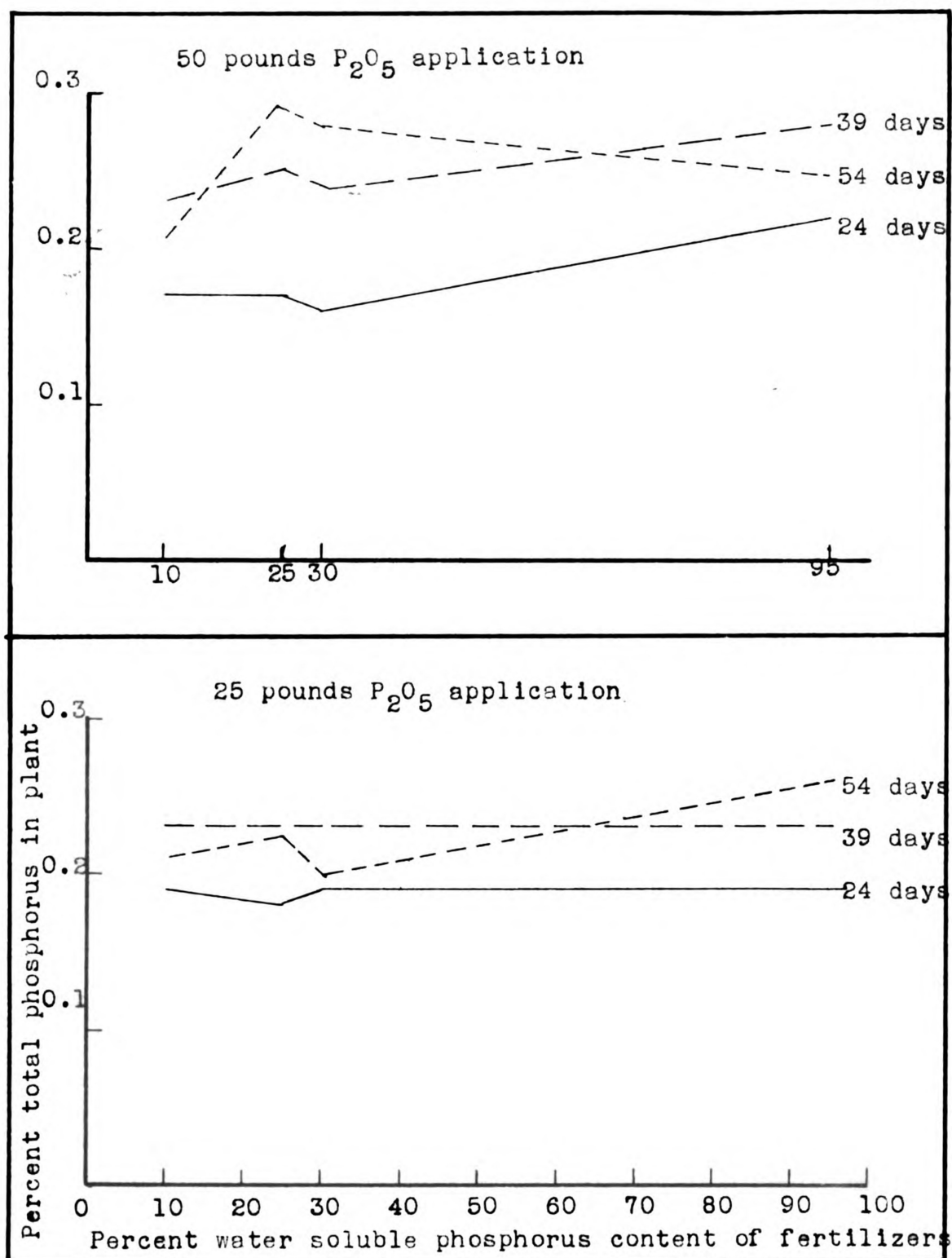
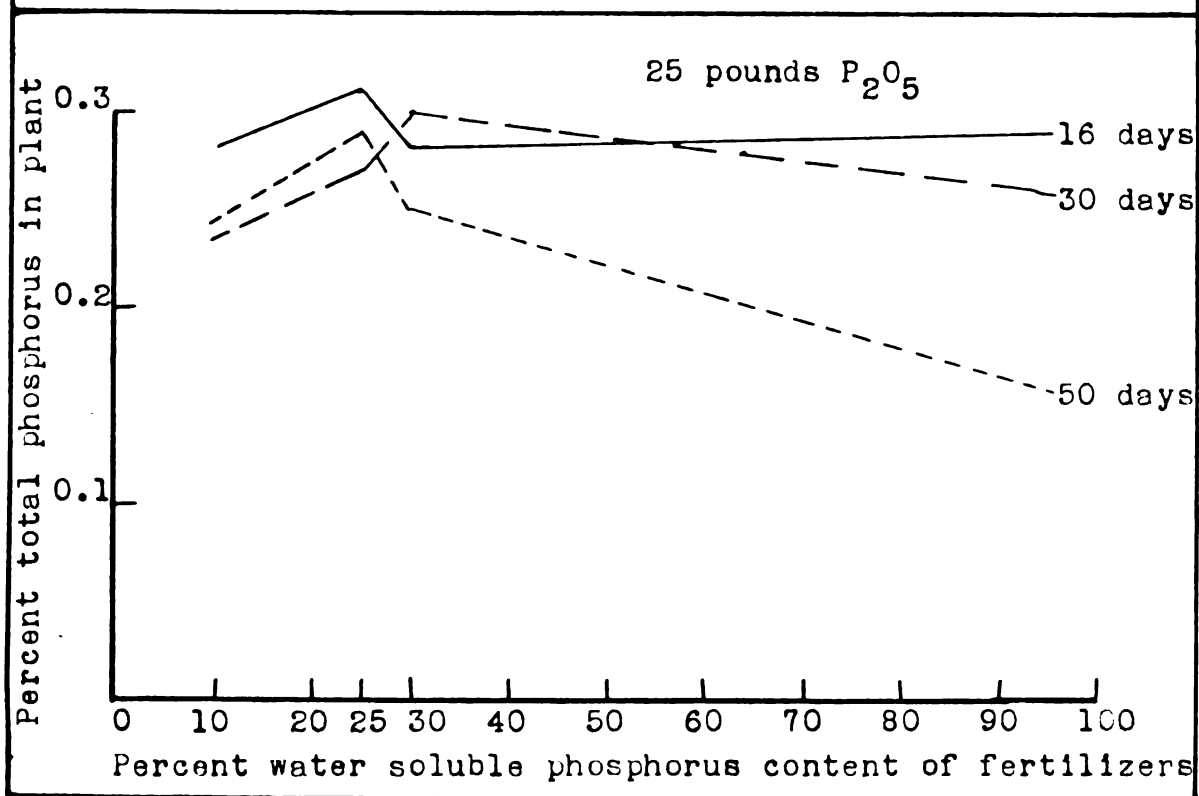
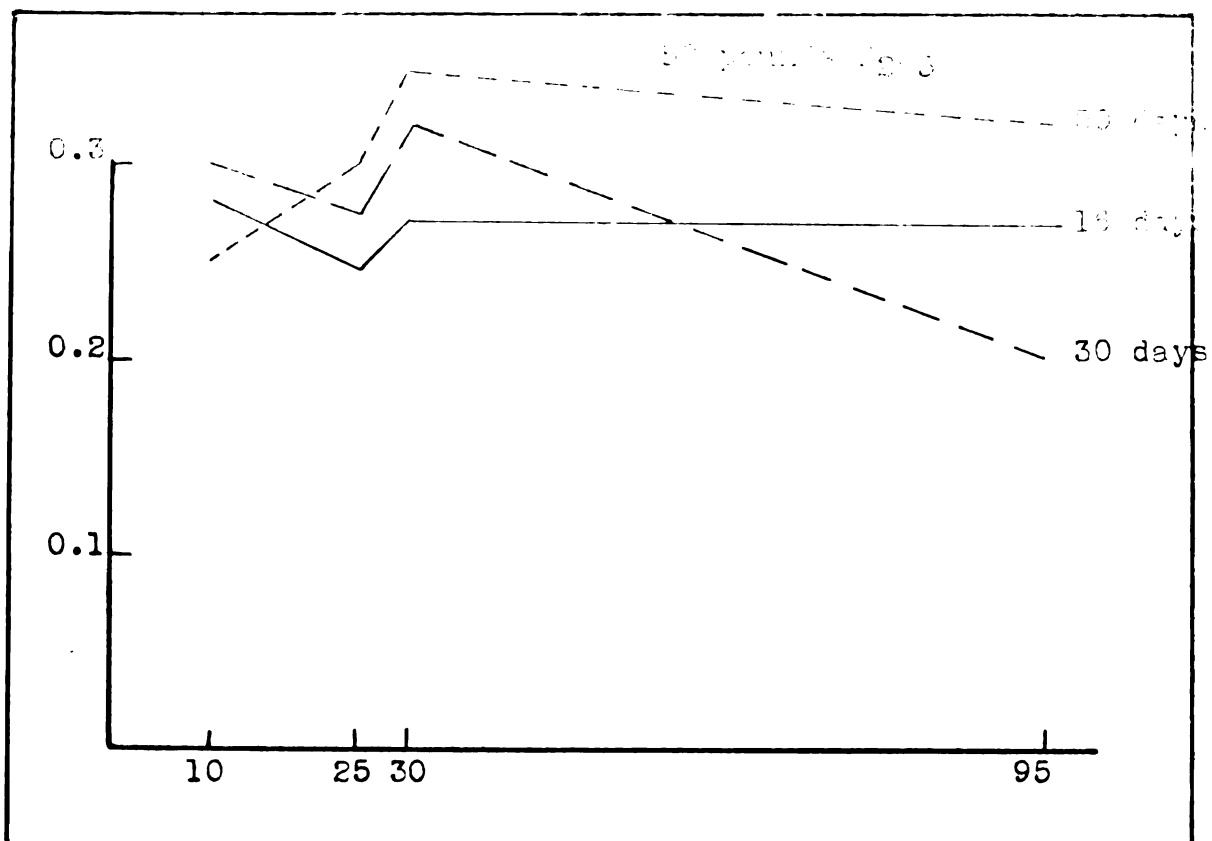


Figure 16. Effect of water solubility of fertilizer phosphorus on the total P content of corn grown on University Farm (Metea sandy loam).



Effect of water solubility of fertilizer phosphorus on the total P content of corn grown in W. K. Kellogg farm (Fox sandy loam)

It is interesting to note that water solubility of phosphorus had a marked effect on the uptake of phosphorus, especially at the early stage of growth of corn plants. The total phosphorus in plants generally increased with increase in water solubility of the fertilizer phosphorus applied. With a few exceptions, the relationship was true for both 1:1:1 and 1:2:2 fertilizers.

The second sample consisted of leaves only and was taken 39 days after planting. Here from 6 to 10 percent water solubility, a slight increase in total phosphorus of leaves, was obtained but increase in water solubility of the fertilizer from 10 to 30 percent did not show any corresponding increase in total phosphorus content of leaves.

In the third sample taken 54 days after planting, a decrease in the total phosphorus content of leaves was observed with an increase in the water soluble phosphorus content of the fertilizer.

The same general trend was observed in the case of 50 pounds of P_2O_5 application also. The best response to the water solubility of the fertilizer in terms of phosphorus uptake by plants was seen when the plants were young. With H Al NP-30 there was an increase in the uptake of phosphorus compared to the H Al NP-10. The highest amount of total phosphorus was found in plants treated with 50 percent water soluble 1:2:2 fertilizer. Above that there was a decrease in phosphorus uptake.

In the second sample, the plants grown in soils treated with H Al NP-30 and superphosphate were quite similar as far as the phosphorus uptake of plants was concerned. Similar observations could be made in the third sample also. In this case the water solubility of the fertilizer did not influence the uptake of phosphorus from 1:2:2 fertilizer treatments.

From Fox sandy loam, the first sample consisting of the above ground portion of the plant was taken 16 days after fertilization, whereas the second and third samples of leaves were taken 30 and 50 days respectively after fertilizer application. Here moisture was a limiting factor and as such the results were not in conformity with the previous findings.

With 25 pounds P_2O_5 per acre, the highest total phosphorus content of plants was found with plants treated with fertilizers with medium water soluble phosphorus contents. There was a slight variation between phosphorus uptake of plants treated with the H Al NP.

In the second sample the phosphorus content of leaves with H Al NP-10 was lower than that found in the check. The H Al NP-30 gave the highest uptake of phosphorus.

The same trend was observed in the third sample also.

With 50 pounds P_2O_5 application, all three samples showed that the highest phosphorus content of plants resulted from the application of high alumina nitric phosphates with medium water soluble phosphorus content.

Tomatoes

Tomatoes were grown in Metea sandy loam and Coloma sandy loam soils. The yield of tomatoes in tons per acre is given in Table 16.

Response to phosphorus was obtained with all fertilizers applied at the 100 pounds P_2O_5 level. The total yield of grade 1 and grade 2 tomatoes indicates that yield was not much affected by the water soluble phosphorus content of the fertilizer. This condition can be noted from the fact there was not much variation in the yield with phosphate with water soluble phosphorus contents varying from 25 to 50 percent. However, a lower fruit yield was found when H Al NP-10 was used, compared with the other fertilizers listed. The H Al NP-30 was found to be as good as superphosphate for tomatoes.

The yield of tomatoes which received 200 pounds P_2O_5 application, was not very good. In fact, the yield was less than that found with the N- K_2O application.

The yield of tomatoes grown in Coloma sandy loam is given in Table 17. On this soil a marked response to phosphorus application was obtained. There was a significant increase in the yield at 5% level. The grade 3 tomatoes were only a very small quantity.

In this soil, three levels of 50, 100, and 300 pounds of P_2O_5 applications were made. In almost all cases the best yield of tomatoes both in quality and quantity, were obtained at the medium level of 150 pounds of P_2O_5 application.

Table 16.

Influence of high alumina nitric phosphates and other fertilizers on the yield and total phosphorus content of leaves of tomatoes grown in University Farm (Metea sandy loam)*

Fertilizer	Percent fertilizer P soluble in water	Pounds P ₂ O ₅ per acre	Tons, yield per acre ¹			Percent P in leaves		
			Grade 1 ***	Grade 2	Grade 3	Days after planting 14	Days after planting 15	35
21.5-0-21.5**	-	-	9.8	10.1	0.8	0.16	0.21	0.21
21.5-0-21.5***	-	-	12.5	11.8	1.2	0.22	0.20	0.20
14-14-14	10	100	12.2	10.7	1.7	0.28	0.22	0.22
14-14-14	10	200	14.3	8.1	1.6	0.18	0.33	0.33
10-10-10	25	100	13.4	10.9	1.2	0.19	0.20	0.20
10-10-10	25	200	12.4	12.0	1.2	0.22	0.26	0.26
15-15-15	30	100	12.3	11.3	0.9	0.14	0.22	0.22
15-15-15	30	200	10.8	13.5	1.1	0.21	0.25	0.25
14.5-14.5-14.5	95	100	12.2	12.2	1.3	0.20	0.29	0.29
14.5-14.5-14.5	95	200	13.6	13.6	0.9	0.24	0.30	0.30

* Average of three replications

** N and K₂O adjusted to 100 pounds per acre

***N and K₂O adjusted to 200 pounds per acre

****Grade 1 - 3 to 5 inches in diameter;

Grade 2 - 2 to 3 inches in diameter;

Grade 3 - culls

¹ F value - 2.09 N.S.

Table 17.

Influence of high alumina nitric phosphates and other fertilizers on the yield and total phosphorus content of leaves of tomatoes grown in Jackson Prison Farm (Goloma sandy loam)*

Fertilizer	Percent fertilizer P soluble in water	Pounds P ₂ O ₅ per acre	Tons, yield per acre**			Percent P in leaves	
			Grade 1 ***	Grade 2	Grade 3	Days after planting 14	Days after planting 35
21.5-0-21.5 ¹	-	50	11.5	3.7	0.1	0.27	0.28
21.5-0-21.5 ²	-	150	8.2	3.7	0.0	0.21	0.34
21.5-0-21.5 ³	-	300	6.4	3.0	0.2	0.28	0.33
14-14-14	10	50	8.4	3.2	0.1	0.31	0.32
14-14-14	10	150	8.2	3.4	0.2	0.38	0.25
14-14-14	10	300	9.2	2.8	0.2	0.34	0.30
10-10-10	25	50	8.1	4.0	0.3	0.19	0.28
10-10-10	25	150	9.1	3.8	0.2	0.30	0.30
10-10-10	25	300	7.2	3.2	0.0	0.23	0.25
15-15-15	30	50	10.2	3.9	0.2	0.22	0.24
15-15-15	30	150	10.3	3.8	0.0	0.22	0.25
15-15-15	30	300	6.3	3.7	0.3	0.20	0.21
14.5-14.5-14.5	95	50	9.1	4.1	0.1	0.15	0.19
14.5-14.5-14.5	95	150	10.7	3.9	0.1	0.31	0.36
14.5-14.5-14.5	95	300	7.7	4.3	0.6	0.25	0.35

* Average of three replications

** F value 2.1. Significant at 5% level.

***Grade 1, 3 to 5 inches in diameter; Grade 2, 2 to 3 inches in diameter; Grade 3, culls.

1 N and K₂O adjusted to 50 pounds per acre.

2 N and K₂O adjusted to 150 pounds per acre.

3 N and K₂O adjusted to 300 pounds per acre.

There was a considerable decrease in the yield with 300 pounds application of phosphorus. This may probably be due to the fact that the concentration of soil solution at this level became so high that the plants found it difficult to absorb water.

In the case of high alumina nitric phosphate application, water solubility of the fertilizer phosphorus influenced the yield of tomatoes. H Al NP-30 was more effective than H Al NP-10.

Though the H Al NP-10 gave yields lower than that given by other fertilizers, the yield obtained by the use of H Al NP-30 was comparable with that obtained by the application of superphosphate or the 10-10-10 fertilizers.

Phosphorus uptake: Two samples were taken for analysis. The first sample was taken two weeks after the application of fertilizer in the case of tomatoes grown in Metea sandy loam.

Here the total phosphorus content of leaf samples was highest with H Al NP-10 application. Then there was a gradual decrease in the total phosphorus content of leaves until the H Al NP-30 was reached. The H Al NP-30 and the 100 percent water soluble NPK fertilizer had the same effect on the uptake of phosphorus by plants.

But 200 pounds application gave different results. The lowest amount of total phosphorus was seen in plants treated with the 14-14-14 fertilizer. Here also the total phosphorus contents of leaves of plants treated with H Al NP-30 and NPK fertilizer was the same.

The second sample (Figure 17) showed a sharp increase in the phosphorus content of leaves treated with 14-14-14 fertilizer from that of the check. The lowest phosphorus uptake was with plants treated with H Al NP-30.

Some interesting results were obtained in the case of total phosphorus content of tomato leaves of plants grown in Coloma sandy loam.

The first sample was taken two weeks after fertilizer application. In the early stages of growth with 50 pounds application, the highest concentration of phosphorus was in the leaves of plants treated with H Al NP-10. There was not much difference between the amounts of total phosphorus found in plants grown with H Al NP-30 and superphosphate.

With 150 pounds application similar results were obtained. H Al NP-10 resulted in the highest total phosphorus content of leaves whereas the lowest amount was found with plants treated with H Al NP-30. There was an increase in the leaf phosphorus with an increase in the water solubility of fertilizer phosphorus from 30 to 95 percent.

The same trend in results was found in the 300 pound treatment also.

The second sample was taken 5 weeks after fertilization. In this case with 50 pounds application, there was a decrease in the leaf phosphorus from plants treated with H Al NP-10 to those with H Al NP-30.

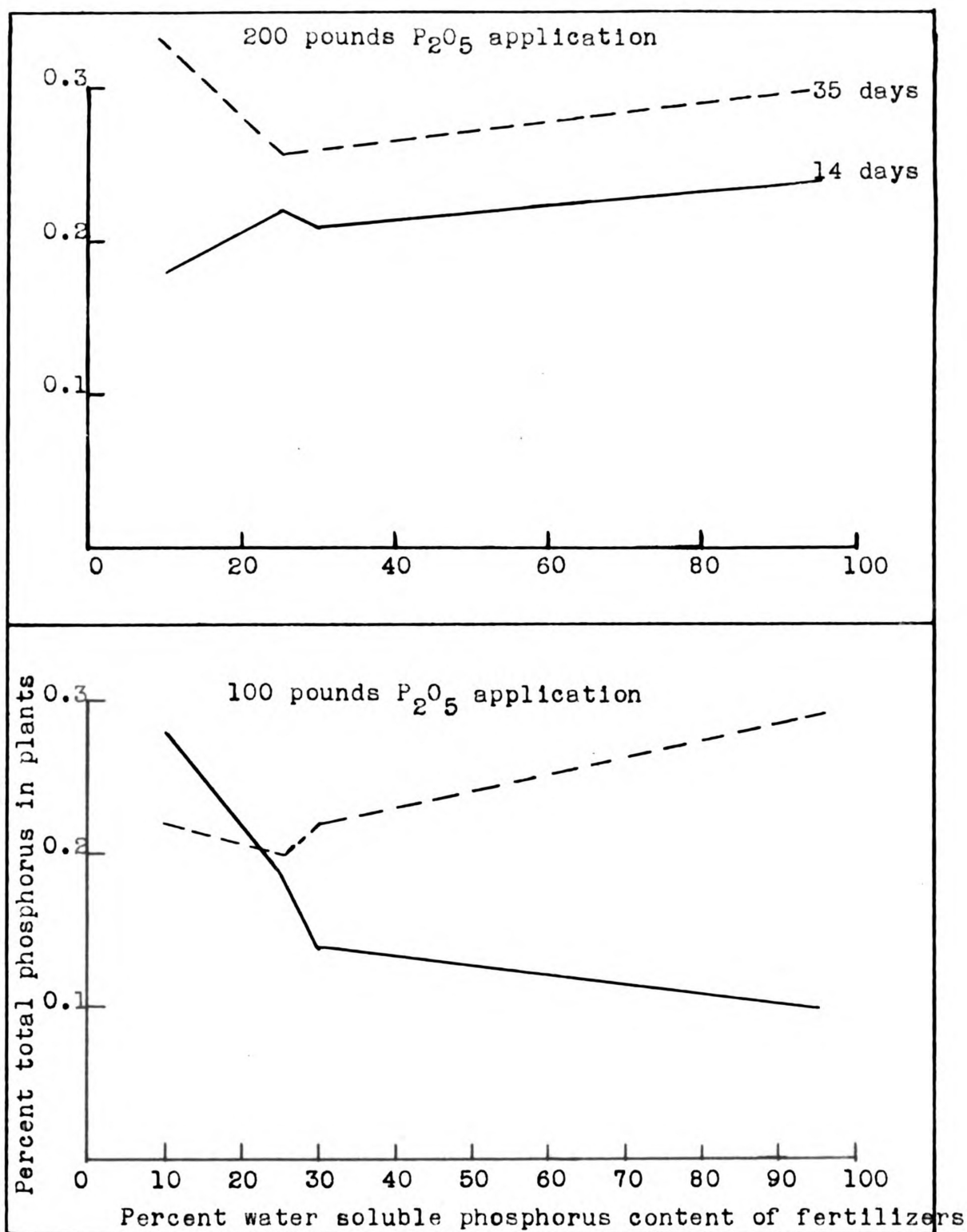


Figure 17. Effect of water solubility of fertilizer phosphorus on the total P content of tomatoes grown on University Farm (Metea sandy loam).

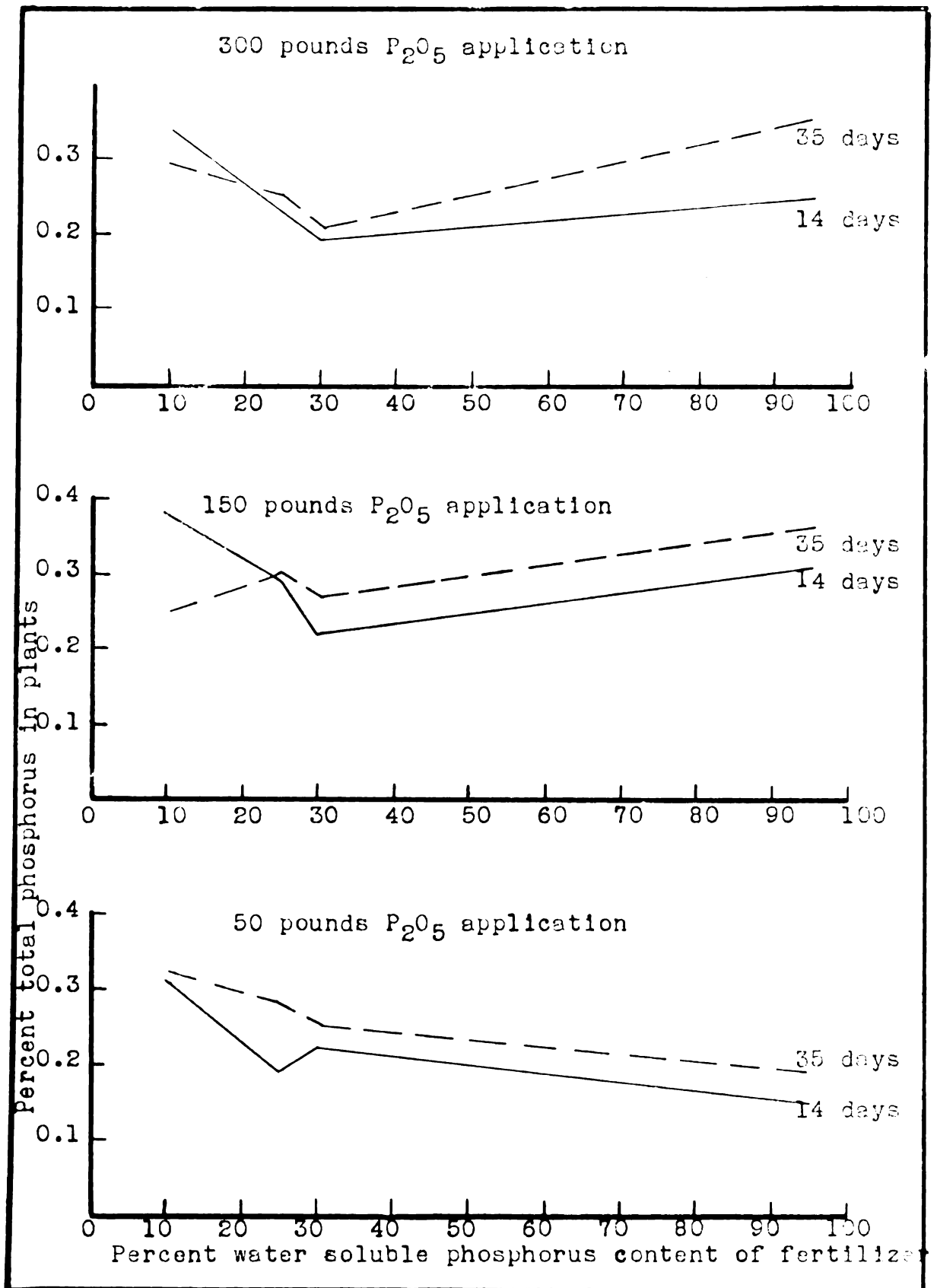


Figure 18. Effect of water solubility of fertilizer phosphorus on the total P content of tomatoes grown on W. K. Kellogg farm (Fox sandy loam).

However, with 150 pounds application, the total phosphorus in leaves was the lowest with H Al NP-10. With H Al NP-30 there was a slight increase in the phosphorus content of leaves. The highest concentration was with plants treated with 10-10-10 fertilizers and concentrated superphosphate.

The high concentration of 300 pounds application also produced some interesting variations in the total uptake of phosphorus by plants. Here the highest concentration of phosphorus was found with plants treated with superphosphate followed by the 10-10-10 fertilizer. The application of H Al NP-30 produced the lowest concentration of phosphorus.

In general, the total phosphorus in leaves of plants treated with 300 pounds P_2O_5 per acre was lower than that of those treated with 150 pounds P_2O_5 per acre application. The data on Table 18 show that the total yield of tomatoes also was lower in the case of plants treated with 300 pounds P_2O_5 application. This was particularly evident with H Al NP treatments. The osmotic effect of high concentration of soil solution may be responsible for the low phosphorus uptake and yield in this case.

It has been shown by several workers that aluminum is toxic to plants at high concentrations. It has been reported that the possible injurious effect of aluminum is due to the fact that soluble aluminum precipitates the phosphorus internally in plants. That aluminum is concentrated in the cortical and epidermal regions of the roots has been shown by Wright, Donahue and others. Practically no aluminum has been found in

leaf and stem.

So it is possible that in the case of high rates of alumina nitric phosphate applications, the decrease in the phosphorus concentration in leaves and the decrease in yield may be due to the fact that a part of the phosphorus absorbed by the roots is precipitated by aluminum that is also taken up by the plant, and made immobile. Since the aluminum concentration occurs at the cortex, a part of the absorbed phosphorus will not be able to enter into the vascular tissues and hence a reduction in the amount of phosphorus in leaves occurs. This reduction in the amount of phosphorus that the plants need for their metabolic processes manifests itself in a reduction in the fruiting capacity of the plants.

CONCLUSIONS

1. The chemical availability of phosphorus from high alumina nitric phosphates depends on the water soluble phosphorus content of the fertilizer, nature of the soil, and the time of contact between the soil and fertilizer. Laboratory studies indicate the following trends:
 - A. The availability of phosphorus increased with the increase in water soluble phosphorus content of the fertilizer.
 - B. The availability of phosphorus decreased with an increase in clay content of soil.
 - C. There was a decrease in the availability of phosphorus in soil with an increase in the organic matter content of the soil.
 - D. The high alumina nitric phosphates behaved differently in different soils.
 - E. The extractable phosphorus did not increase in proportion to the increase in rate of application.
 - F. Most of the soluble phosphorus that moved out of the fertilizer granules did so during the first 24 hours of incubation.
 - G. The phosphorus that diffused out of the fertilizer moved to a distance of 8 millimeters from the place of application.
2. The dry weight and phosphorus uptake of plants grown in the greenhouse on organic soil varied with variation in rate of

2. The dry weight and phosphorus uptake of plants grown in the greenhouse on organic soil varied with variation in rate of phosphorus application, pH, and method of placement of the fertilizer.
 - A. The dry weight of and phosphorus uptake by corn increased slightly with increase in water soluble phosphorus content of fertilizer tested. The high alumina nitric phosphate with low water soluble phosphorus content was not as effective in terms of measurement as the other fertilizers for corn.
 - B. The mixed placement of fertilizer resulted in higher yields than banded placement on acid organic soil.
 - C. Most vigorous growths of corn was obtained when the organic soil was limed to a pH of 5.4 to 6.5.
 - D. There was not much variation in terms of phosphorus uptake and dry weight of beans with different fertilizer treatments.
3. Water solubility of fertilizer phosphorus did not affect the yield of corn grown in sandy loam soils, appreciably. But for tomatoes there was a difference in yield with difference in water solubility of the fertilizer phosphorus.
 - A. The high alumina nitric phosphates were as effective a source of phosphorus as superphosphate and other commercial types of fertilizers for corn grown on two sandy soils. Increases in water soluble phosphorus contents of fertilizer did not affect the yield of corn appreciably.

B. The phosphorus uptake and yield of tomatoes increased as the water soluble phosphorus content of the fertilizer increased. High alumina nitric phosphates with medium water soluble phosphorus contents resulted in yields comparable to those obtained when concentrated superphosphate and other fertilizers were tested. In Coloma sandy loam, highest yields were obtained from the 150 pounds P_2O_5 per acre application, whereas in Metea sandy loam 100 pounds per acre of P_2O_5 was found to be adequate. In both soils high applications of fertilizers applied in banded placement reduced the yield of tomatoes.

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APPENDIX

Appendix - Table 1

Influence of high alumina nitric phosphates and other fertilizers on the heights of corn plants at different stages of growth grown in organic soils in the greenhouse*

Fertilizer	Percent P soluble in water	Method of place- ment	Pounds P ₂ O ₅ per acre	Tons lime per acre	Cm, height of plants		
					Number of days after planting		
					28	35	49
14-14-14	10	Mixed	50	0	40.0	52.2	69.8
			200	0	41.9	68.7	85.7
			400	0	44.3	69.0	81.9
		Banded	50	0	33.0	59.2	71.8
			200	0	40.8	63.6	75.9
			400	0	33.8	61.2	81.3
15-15-15	30	Mixed	50	0	31.8	61.6	78.4
			200	0	40.8	59.1	79.2
			400	0	44.7	70.7	79.7
		Banded	50	0	41.6	56.8	77.5
			200	0	32.0	63.6	91.9
			400	0	43.8	65.7	85.9
O-45-0	95	Mixed	200	0	38.6	60.4	82.9
21-53-0	100	Mixed	200	0	42.6	71.4	88.4
N -0- K	-	Mixed	200	0	25.9	44.4	59.8
14-14-14	10	Mixed	50	5	38.8	55.9	72.4
			200	5	43.2	69.1	93.6
			400	5	40.9	64.9	88.0
		Banded	50	5	38.8	54.7	76.7
			200	5	37.7	55.5	85.5
			400	5	40.6	66.3	93.1
15-15-15	30	Mixed	50	5	40.4	59.9	88.4
			200	5	42.6	72.7	80.8
			400	5	38.2	64.5	100.3
		Banded	50	5	41.4	59.7	95.2
			200	5	38.1	70.1	87.5
			400	5	40.2	67.7	92.8
O-45-0	95	Mixed	200	5	36.9	66.5	89.6
21-53-0	100	Mixed	200	5	33.8	66.1	84.1
N -0- K	-	Mixed	200	5	32.8	52.2	67.7

*Average of three pots (6 plants)

-Continued

Appendix - Table 1 - continued

Fertilizer	Percent P soluble in water	Method of place- ment	Pounds P ₂ O ₅ per acre	Tons lime per acre	Cm, height of plants		
					Number of days after planting		
					28	35	49
14-14-14	10	Mixed	50	10	31.4	55.1	79.1
			200	10	38.7	59.6	82.4
			400	10	37.1	64.8	93.2
		Banded	50	10	30.9	51.0	84.6
			200	10	35.1	56.3	80.4
			400	10	31.3	58.0	87.0
15-15-15		Mixed	50	10	33.4	51.6	67.3
			200	10	37.5	53.8	82.9
			400	10	33.6	57.1	78.7
		Banded	50	10	30.1	52.1	76.7
			200	10	34.6	56.7	75.3
			400	10	39.1	54.7	73.2
O-45-0		Mixed	200	10	46.1	63.6	85.9
21-53-0		Mixed	200	10	42.4	70.6	86.3
N -0- K		Mixed	200	10	28.9	47.3	61.8
14-14-14		Mixed	50	15	27.7	48.1	60.9
			200	15	30.6	48.1	67.7
			400	15	28.5	51.7	74.5
		Banded	50	15	24.7	46.5	63.5
			200	15	27.9	44.0	65.1
			400	15	28.9	49.3	71.9
15-15-15		Mixed	50	15	28.1	39.5	66.0
			200	15	27.8	46.9	71.9
			400	15	41.9	56.5	76.2
		Banded	50	15	28.7	48.1	71.1
			200	15	40.6	54.5	84.6
			400	15	40.1	64.4	89.6
O-45-0		Mixed	200	15	50.2	61.6	90.5
21-53-0		Mixed	200	15	42.8	44.4	85.0
N -0- K		Mixed	200	15	22.0	44.4	56.9

*Average of three pots (6 plants).

Appendix - Table 2

Effect of soil reaction, fertilizer placement and kind of phosphate fertilizer on the total phosphorus content of corn plants grown in an organic soil in the greenhouse (8 weeks after planting).

Fertilizer	Percent fertilizer P soluble in water	Method of place- ment	Pounds, P ₂ O ₅ per acre	Tons, lime per acre			
				0	5	10	15
				Percent, total phos- phorus			
14-14-14	10	Mixed	50	0.07	0.07	0.04	0.04
			200	0.13	0.12	0.10	0.10
			400	0.15	0.15	0.08	0.07
		Banded	50	0.15	0.13	0.07	0.09
			200	0.16	0.12	0.07	0.07
			400	0.11	0.07	0.06	0.05
15-15-15	30	Mixed	50	0.06	0.08	0.08	0.08
			200	0.09	0.09	0.09	0.07
			400	0.13	0.12	0.09	0.06
		Banded	50	0.07	0.03	0.06	0.06
			200	0.09	0.05	0.11	0.06
			400	0.10	0.10	0.08	0.08
0-49-0	95	Mixed	200	0.12	0.11	0.09	0.09
21-53-0	100	Mixed	200	0.07	0.07	0.09	0.11
15-0-15	-	-	-	0.07	0.07	0.01	0.01

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