FOLIAR APPLICATION OF PHOSPHATIC NUTRIENTS TO CERTAIN VEGETABLE CROPS

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Otmar Otto Silberstein

1950

FOLIAR APPLICATION OF PHOSPHATIC NUTRIENTS
TO CERTAIN VEGETABLE CROPS

By

OTMAR OTTO SILBERSTEIN

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

1950

THESIS

Acknowledgments

The author is indebted to Dr. S. H. Wittwer, of the Department of Horticulture, not only for suggesting a challenging problem, but also for guidance, encouragement, and assistance throughout the course of the work. Appreciation is further due Dr. L. F. Wolterink, of the Department of Physiology, for a splendid example of interdepartmental cooperation in giving his own time and effort, as well as permitting the use of his laboratory facilities, during all phases of the work involving the use of radioactive materials. The author also wishes to thank Dr. C. Redemann, of the Department of Agricultural Chemistry, for the preparation of several of the organic phosphorus compounds as well as for assistance in many chemical aspects of the problem. Appreciation is also expressed to Dr. W. S. Lundahl, of the Department of Biological Science, for the preparation of radioautographs.

The generosity of the Monsanto Chemical Company, of St. Louis, Missouri, and the Victor Chemical Company, of Chicago, Illinois, in supplying most of the chemicals tested in these trials is greatly appreciated.

"Of all soil constituents, phosphorus is the one about which the agronomists of different countries express the greatest fear of ultimate exhaustion. It is the major essential component whose deficiency in the soil is linked with the greatest number of disturbances in the health of animals and the element which offers the most striking and convincing demonstration of the close relationship between the chemical composition of the soil and the health and vigor of the plants and animals that live upon it."

Browne, C. A. "Some relationships of soil to plant and animal nutrition--the major elements." Yearbook of Agriculture, 1938. p. 806.

CONTENTS

FOLIAR APPLICATION OF PHOSPHATIC NUTRIENTS TO CERTAIN VEGETABLE CROPS

Introduction

The problem of supplying phosphorus to plants in sufficient quantities and at the time when it is most needed has been a predominant one in the recent history of agriculture. This element is generally the first of the so-called major plant food elements to become limiting when virgin soils are brought under cultivation, and its deficiency is today widespread throughout most soils of the United States, making it one of the leading factors responsible for reduced crop yields.

Not only are our soils low in total phosphorus, but a complex system of soil factors is keeping much of it chemically, physically, and biologically "fixed," so that only a small fraction of the total supply is within reach of plant roots and in utilizable form at a given time. Phosphatic fertilizers applied to the soil remain in an available form for only a relatively short time before they too become part of the phosphorus fractions unavailable to plants. One of the most difficult problems is to supply effective amounts of phosphorus to a growing crop, when it is impossible to work materials into the rhizosphere without injury, while materials broadcast on the surface do not penetrate the soil appreciably.

In an effort to keep plants supplied throughout the season, various means have been used, such as: conversion of phosphatic fertilizers to more soluble forms by acidulation, localized application to reduce the surface exposed to fixation processes, application of fertilizers in solution, and application of organic phosphates. The amount of phosphates applied to our soils has steadily increased, so that at the present time phosphate materials are leading all other plant food carriers in total tonnage used as well as total units of plant food supplied. This increasing phosphorus consumption may seriously hasten the time, even though in the very distant future, at which our national phosphorus supply will be critical, since our resources of this element are very limited. Therefore, from this viewpoint, search for a more efficient method of supplying phosphorus to plants seems to be very justified.

New organic insecticides of considerable phosphorus content also pose the question whether or not plants could eventually utilize the element supplied in this form. Furthermore, if one considers the success reported in the literature with foliage sprays of minor elements, nitrogen and magnesium, an attempt to solve the phosphorus problem from this angle seems imperative.

REVIEW OF LITERATURE

The old concept of impermeability of a continuous leaf cuticle has recently been revised (21). It was demonstrated in a series of photomicrographs that in the case of McIntosh apple leaves the walls of epidermal cells are made up of particles arranged in somewhat irregular layers, so that the walls cannot be considered uniform, solid structures. The cutin toward the exterior also does not form a continuous layer. By the use of certain stains it was shown that pectinaceous materials which have great water absorption power are present in all the walls of the epidermal cells and that the cuticle too is interspersed with these materials. In the cuticle these pectins extend vertically, whereas the cutinized areas run only parallel. This work then clearly indicates the presence of channels other than stomates and hydathodes by which materials may enter plants through foliage.

An earlier study (14) established the fact that the epidermis of tomato leaves is composed of undifferentiated cellulose; i.e., it does not become lignified, cutinized, or suberized. Based on these findings and other supplementary evidence, the authors conclude that increased transpiration brought about by certain copper sprays takes place directly through the epidermis walls. A reversion of the process for the uptake of solutions suggests itself readily.

The subject of nutrient sprays was recently briefly

and concisely reviewed (13). To this should be added the report (3) of successful control of magnesium deficiency by foliage sprays on apple trees growing on a soil of high potash level which failed to give response to soil application of magnesium. The advantages of foliage sprays are very evident from these papers: interference from soil factors is eliminated; immediate and direct control of a nutrient can be accomplished, which is of great importance, especially with nitrogen sprays; the amounts applied as sprays are usually much smaller than those applied to the soil. Some limitations of the method also are apparent: to maintain a desired nutrient level, repeated applications may be needed; single applications at higher concentrations tend to give injuries; generally, single applications are effective only in case of some minor elements.

Only very few reports were found in the literature pertaining directly to foliage application or "leaf feeding" of phosphorus compounds. In 1937 the work of Sankaran (22)* is quoted. He immersed phosphorus-deficient, excised leaves into four different solutions representing four treatments for periods of three to four days. The treatments were: 1. distilled water, 2. sucrose, 3. sodium phosphate and

---

* A copy of this thesis could not be obtained from the University of London without permission of the author. An attempt to locate the author has so far remained unsuccessful.

sucrose, and 4. sucrose, sodium phosphate, and ammonium nitrate. He found that respiration increased very considerably by treatment #3 and was further increased by #4. The magnitude of the increase depended on the physiological stage at which leaves had been removed from the original plants. The effect of treatments was greatest when the leaves normally contained most phosphorus and when respiration already was highest; i.e., when leaves were youngest. During respiration protein hydrolysis occurred, but less in leaves which also received ammonium nitrate.

A single foliage application of various starter solutions to tomato plants at transplanting time gave responses only to nitrogen (23), and similar findings are reported (15) as a result of attempts to spray various vegetables with different fertilizer solutions; again no uptake of phosphorus was observed, while nitrogen was taken up.

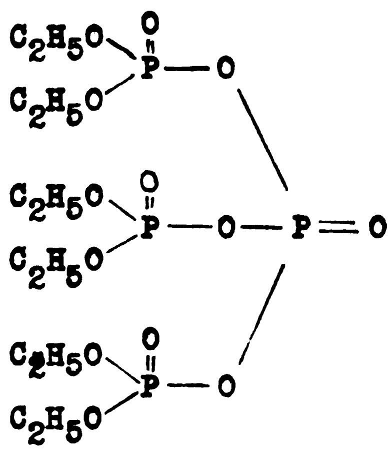
Positive responses from the use of phosphatic foliage sprays are indirect and are reported (30) following the use of phosphorus-containing insecticides on potatoes. After observing increases in yield beyond that due to insect control, a nutritional test was conducted the following season, involving four treatments which were applied nine times for a total of 1,000 gallons per acre: 1. DDT, 2 lbs. per 100 gallons, 2. DDT, 2 lbs. per 100 gallons, and phosphoric acid, 1 pint per 100 gallons, 3. DDT, 2 lbs. per 100 gallons, and phosphatic insecticide, 1 pint per 100 gallons.

Treatment #1 outyielded the control by 10 per cent, while treatments #2 and #3 outyielded the control by 25 per cent and 20 per cent, respectively. The increase in yield above insect control is attributed to the fact that the plants stayed green longer than those which did not receive phosphatic sprays. It must, however, be pointed out that much of the benefit derived from the phosphorus sprays may have come from that portion of the spray which went directly on the soil or dripped or was washed from the plants subsequently. It is estimated (6) that in applying urea to apple trees, only 25 per cent of the applied material enters the leaf, while the rest finds its way into the soil.

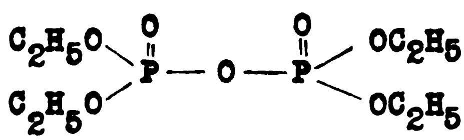
Organic phosphatic insecticides of the type referred to above are hexa ethyl tetra phosphate (HETP) or tetra ethyl pyro phosphate (TEPP), which are presently used for pest control on numerous crops, while other new organic phosphates are still being tested (2). Very recently tests were conducted (20) with a new systemic insecticide of considerable phosphorus content. The material bis (bis dimethylamino phosphonous) anhydride is taken in by plants after spray application and plants remain toxic to aphids from two to five weeks. That the material is translocated within the plants is evident from the fact that new tissue which had not been sprayed also becomes toxic; however, translocation has so far been observed only in an upward direction. Furthermore, it has been possible to demonstrate

the presence of the material by a specific chemical test. Nothing is yet known concerning the ultimate fate of the material or its components after loss of toxicity. If the material undergoes gradual hydrolysis, it is very possible that the nitrogenous as well as the phosphorus fractions become involved in plant metabolism.

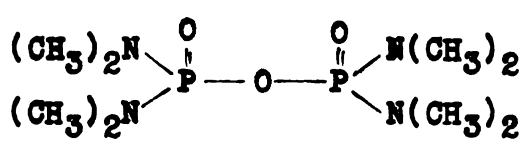
Following are the structural formulae for the insecticides mentioned above to show certain similarities; from them some possible decomposition products may also be postulated.

1. 

Hexa ethyl tetra phosphate (8)

2. 

Tetra ethyl pyrophosphate (8)

3. 

Bis (bis dimethyl amino phosphonous) anhydride (20)

Organic phosphates have also been tested as possible fertilizing materials, mainly in an effort to overcome the soil fixation problem. Phytic-, nucleic-, saccharose phosphoric, glycerophosphoric, and hexose di- and monophosphoric acids were studied (26) and found to be good sources of phosphorus to plants even under sterile conditions; i.e., with the possibility of microbial decomposition prior to uptake eliminated. Phytin was found to be utilizable by red clover (9), and oats assimilated it more readily than inorganic phosphorus compounds (28).

In a series of experiments by different workers it was found that compounds such as calcium glycero-, calcium glycol-, calcium sorbitol-, and calcium glucose phosphates can be leached 75-95 per cent from a soil of supposedly high fixing power (24). However, when the same materials were leached from three different soil types including the one above, it was found (11) that the amount of fixation was greatest for clay loam and that it increased in time; some of the organic materials became biologically fixed more slowly than inorganic under certain conditions. These results led to further investigations (17), in which it was found that tri-ethyl, trimethyl, and calcium diethyl phosphates can be recovered better than 80 per cent from a Cecil clay loam. Since some of these organic phosphates penetrate the soil very readily, remain in solution, and can be taken up by roots, measures were taken during the experimental work to

prevent soil contamination with test compounds.

Some extremely interesting observations on the movement and accumulation of phosphorus in plants have been made with the aid of the radioactive isotope $_{15}P^{32}$.[1] For tomatoes grown in nutrient solution it was found (1) that P* could be detected in the tops of 6 ft. tall plants forty minutes after the plants were transferred to a solution containing the radioactive isotope. After a four-hour absorption period, the concentration of P* was greatest in the top portions of plants and at all plant heights it was always greater in the leaves than in the stems. Green fruits absorbed more than ripe fruits, in which the active material was to be found mostly in the pulp and along the outer layer, while in the green fruits it accumulated mostly in seeds and all other tissue. If the plants were kept under phosphorus-deficient conditions for three days prior to transfer to the P* containing solution, small fruits had the greatest capacity for phosphate absorption, and if the plants were kept under phosphorus-deficient conditions after return from the labelled solution, the concentration of P* in the leaves decreased while it increased in the fruits.

Root-absorbed P* has recently been traced also in corn plants (18), where again the greatest accumulation was noted in different meristematic regions. The same

---

1) The symbol P* will be used to represent the radioactive isotope both in the review of literature and during the description of experimental work.

authors, furthermore, report (19) very briefly on some work with tomatoes in which again the greatest concentration of P* occurred in the apical leaves and internodes.

Other translocation studies are reported in which a P* labelled compound was injected into the leaves of bean plants (5). The movement of the material was found to follow a diurnal rhythm; the material migrated first dowaward, reaching a maximum in the root system toward evening, while the maximum upward movements occurred around noon, not quite coinciding with the light maximum.

Another method of introducing P* into plant foliage was used in work with squash (7). Leaves were treated either when they were suffering from a water deficit or under vacuum infiltration. Under these conditions the labelled material tended to move toward the nearest phosphorus pool; i.e., it moved toward the growing tip if an upper leaf was treated but toward the roots if a lower leaf was treated, while from a middle leaf the movement was simultaneous both in the upward and downward directions.

Apparently, the downward movement of phosphorus in plants does not end at root apices, for it was shown (10) that if wheat seedlings are grown with a split root system half of which is in a P*-containing nutrient solution while the other half is in a non-active solution, there occurs a slow exudation of P* from the roots into the inactive solution.

P* has also been used to determine accurately the percentage of phosphatic fertilizer utilized by some plants from the soil (25). Previously, in determining fertilizer efficiency, the phosphorus content of fertilized plants was compared with that of non-fertilized plants and the difference was considered as coming from the fertilizer. With tracer technique, however, it is shown that fertilized plants take up considerably more soil phosphorus, probably due to a more extensive root system. Generally, it was found that with increased phosphorus application the amount of fertilizer P used increases, but the percentage used decreases; furthermore, most of the fertilizer P is taken up early in the season. Under the condition described only 22 per cent of the fertilizer P was recovered by the plants, even though the material had been applied as a liquid. Lower rates of utilization from various sources were reported (4) when a mixture of orchard grass and ladino was grown as test crop; potatoes are reported to recover from 4.2 to 14.55 per cent of phosphorus applied as superphosphate (12).

The general objective of the investigations reported in this paper was to test phosphorus-containing compounds in their effectiveness as nutrient sprays to the foliage of plants.

GENERAL EXPERIMENTAL METHODS

The following sequence of tests was conducted:

Experiment I: Determination of non-toxic ranges. (Tomatoes).

Experiment II: Determination of optimum ranges. Effectiveness of single applications. (Tomatoes).

Experiment III: Effectiveness of repeated applications. (Tomatoes).

Experiment IV: Translocation of foliar-applied P*. (Tomatoes and corn).

Experiment V: Effectiveness of repeated applications on corn and beans.

Experiment VI: Field trial. (Tomatoes).

Experiments I-III were conducted during fall and winter of 1949 in the Plant Science Greenhouse; the remainder were conducted in spring and summer of 1950.

Plant material: As is evident from the above, the major portion of the work was conducted with tomatoes (variety, Bonny Best), while corn (variety, Golden Cross) and beans (variety, Tendergreen) were employed only to a limited extent. By this choice of plant material, mono- and dicotyledons as well as three families of great horticultural and botanical importance were represented. Corn and tomatoes are known to be heavy feeders, with a great need for phosphorus. Seeds of the same stock number were used in all trials in an effort to obtain uniform plant material.

Plants were generally grown on raised benches in 4-inch pots which were set into sand at an even spacing. Watering was done either with a hose or through rubber tubing attached to a watering can by directing a slow stream carefully at the surface of the growing medium. By this method no chemicals could be washed from the foliage.

Chemicals: Compounds were usually applied on the basis of P content and amounts used were calculated to give desired concentrations of millimoles of P. Concentrations during the first two experiments varied, but subsequently 25 millimoles of P per liter were found to be satisfactory for the greatest number of chemicals. All materials were applied in aqueous solution, with Dreft serving as a spreader at a rate of one half gram per liter.

Method of application: When materials were applied as sprays, small (200 ml.) or 1 liter "Sure-Shot" sprayers were used. If material was applied by dipping, the solution was usually in a shallow dish, at least two inches deep, and plants were immersed into it without completely inverting the pot. Dipping time was about five to seven seconds, depending on the size of plant.

Whatever the method of application, contamination of soil and pots with dipping solution was prevented by either completely covering the soil surface as well as pots, or in the case of application by dip, by leaving the plants on their sides until the foliage was completely dry.

Exceptions to these general procedures, as well as more detailed discussion of methods, will be presented as they occurred in each experiment.

Experiment I

This trial was of a preliminary nature with the objective of finding non-toxic concentration ranges within which some of the chemicals could be used. Went (27) used sucrose at a concentration of 10 per cent on tomatoes, while optimum concentrations for urea on tomatoes range from 0.45-0.75 per cent (16). On the other hand, the concentration of phosphoric acid used by Wolfenbarger (30) on potatoes was only about 0.06 per cent. In this trial concentrations of 1, 2.5, and 5 per cent by weight were used. Those which proved non-toxic at 5 per cent were also tested at 10 per cent levels. Solutions of the three lower concentrations were applied by spraying, while plants were dipped in the 10 per cent solutions. All materials were applied without spreader.

Test material consisted of tomato plants of unknown variety and origin which happened to be available in the greenhouse. Since the purpose of the experiment was to determine toxicity or injuriousness, no precautions against soil contamination were taken. On each plant one leaf was kept covered with a pliofilm bag during treatment to determine whether or not toxic effects would also appear on portions not sprayed; however, no such translocation of toxicity was observed. Treatments were applied on October 7, 1949, and the plants were under observation until October 20.

Table I summarizes the concentrations of the various materials as well as the observations made. Based on these results, it was decided to conduct further tests within a range of 25-150 millimoles of P per liter. Some non-injurious compounds were tested at higher concentrations.

Experiment II

The purpose of this phase of the investigation was to determine possible optimum concentrations and at the same time determine the effectiveness of the compounds after one application in overcoming phosphorus deficiency in young tomato plants.

Plants were grown in a low P medium, and single applications of test chemicals made to their foliage. Treated plants were compared with a group of plants receiving complete fertilization (Control A) and with another group of plants receiving no P fertilization (Control B). All plants received the same applications of nitrogen and potassium as well as minor elements. Involved in this test

TABLE I. Concentrations of Phosphate Compounds and Relative Toxicities on Tomato Plants.
(Concentrations expressed as millimoles of P per liter)

Material[1]	Concentration of solutions in per cent of commercial compound			
	1	2.5	5	10
H_3PO_4	86.6*	217.0**	433.0***	
KH_2PO_4	73.6	183.9	367.8	735.6**
EAP	71.9	179.8*	359.5**	
n-PAP	63.5	158.7*	317.3**	
n-BAP	55.1 (*)	137.7*	275.3**	
GPA	20.3	50.3*	101.6**	
K-GP	30.2	75.5	151.0	302.0**
Ca-GP	46.6	93.2	93.2[2]	
ETEAP	21.2	52.9	105.8	211.6
TPG	19.2	47.9	95.8	191.6
Vapotone	Extremely toxic at all concentrations			

(*) very slight injury
* slight injury
** serious injury
*** very severe injury

[1] A complete list of all compounds, their phosphorus content, source, and abbreviations used to represent them is given in the appendix.

[2] Material only 2 per cent soluble.

were eleven chemicals at three different concentrations, which were applied with and without spreader, giving sixty-six different treatments and two controls, as outlined above. These treatments were replicated three times, using single plants as replicates, for a total of 204 plants. Height measurements of plants were taken at the time of treatment and at the end of the experiment, at which time fresh weights were also determined. Plants were harvested twenty days after treatment.

Tomato seeds were sown in vermiculite on September 29, 1949, and after emergence the seedlings were watered with a solution of 1 oz. of "Take-Hold" per ten quarts of water.* On November 2 the seedlings were transplanted into 4-inch pots into a low phosphorus medium consisting of four parts of muck to one of sand, and grown in a greenhouse maintained at 50° F. night temperature. Additional potassium was supplied as KCl in a solution containing 1 oz. per ten quarts; copper and manganese were supplied by an application of a solution containing the corresponding sulphates in 0.1 per cent concentration. At the time of treatment all plants also received an application of

---

*Supplemental nutrient solutions were prepared conveniently by dissolving the amounts stated in a ten-quart watering can. A rate of 1 oz. per ten quarts gives approximately a 0.3 per cent solution on a weight basis. Analysis of "Take-Hold" is 11-52-17.

ammonium nitrate solution (½ oz. per ten quarts) and another application of KCl. The group of plants designated as Control A received an application of KH_2PO_4 (1½ oz. per ten quarts) instead of the last KCl application, which provides approximately the same potassium level in addition to the phosphorus supply.

Chemicals were applied by dipping, which was found to give the most uniform coverage for small plants. The soil surface of the pots was completely covered with heavy cotton padding fitted closely around the stems of the plants; these cotton pads were removed after the plants had completely dried.

All chemicals were applied at three concentrations, one of which was 50 millimoles, which was hoped to give an index of their relative efficiency; the other two concentrations were either higher or lower, depending on the performance of the chemical in Experiment I.

The results of this trial are summarized in Table II, which gives the average increase in height of three plants. Only those concentrations and chemicals are given which did not result in injury. The data were analyzed statistically, amd significant differences listed.

It is evident (Table II) that the majority of treatments were not significantly lower than the fertilized control which was exceeded by three treatments, but they were also not significantly higher than the no-P control.

TABLE II. The Effects of Single Foliage Applications of Test Compounds on Height Increments of Phosphorus Deficient Tomato Plants

Material	Millimoles of P per liter	Average increase in height of 3 plants in mm	
		with spreader	without spreader
H_3PO_4	75	44 (*)	***
	50	52.3	**
	25	48	**
KH_2PO_4	200	41	40
	100	46	41.3
	50	46	34
EAP	150	***	**
	100	**	*
	50	47.3	*
MAP	150	***	**
	100	**	*
	50	45	*
GPA	50	42.3	**
	25	50	52.3
	12.5	38	29.7
K-GP	200	35.3	42.3
	100	43.3	45.3
	50	42.3	36
Ca-GP	93	35.3	42.3
	50	38	44
	25	42.3	36
ETEAP	200	45	39.7
	100	46	38
	50	40.3	44.7
Control A	--	47.7	48.3
Control B	--	33.0	38.0

Differences necessary for significance between treatments (5%)--14.75.

It is further evident that there was a definite effect from the use of a spreader. By its use the applied solutions form a uniform film and drop formation is prevented. Irregular distribution of the applied solution is probably the cause of the greater amount of injury from some of the compounds used without spreader. But from the data it also appears that in all cases in which the compound contained Ca or K an addition of the spreader made the lowest concentrations used most effective, while without spreader the highest concentrations gave best results. In general, the lower concentrations gave best results.

Experiment III

The purpose of the experiment was to determine the effectiveness of repeated applications of some of test chemicals. Tomato plants were again grown in a low phosphorus medium, similar to that described in Experiment II. Chemicals were again applied by dipping with and without spreader, and with and without an intermittent dip into water, to find whether there was any benefit to the plants from re-dissolving material deposited on the exterior of the leaves. Most chemicals were applied at only one concentration, and treated plants were again compared with Controls A and B as described previously.

Involved in this test were thirteen chemicals, of which three were applied at two concentrations and one at three concentrations, which together with Controls A and B gave a total of twenty treatments, each at four methods of application and with six single plant replications. The four methods of application were:

1. no spreader
2. no spreader with intermittent water dip
3. with spreader
4. with spreader and intermittent water dip

First treatments were applied on January 14, 1950, and were repeated three times at weekly intervals; intermittent water dips began on January 18 and were also repeated at weekly intervals. After immersion, the plants were kept on their side for about one hour, until the foliage had dried, to prevent soil contamination.

Height measurements of individual plants were taken at the beginning and conclusion of the experiment, and height increments compared. Results are summarized in Table III. The following compounds were found injurious:

n-BAP at 50 millimoles per liter
n-PAP at 50 millimoles per liter
EAP at 50 millimoles per liter
MAP at 50 millimoles per liter
Fr 1-6 at 150 millimoles per liter
Fr 1-6 at 300 millimoles per liter

TABLE III. Increases in Height of Tomato Plants as a Result of Four Weekly Applications of Various Test Chemicals

Material	Concentration[1]	Method of application 1	2	3	4	Means
H_3PO_4	25	31.3	31.8	39.0	34.0	34.0
KH_2PO_4	50	30.8	27.7	39.7	31.8	32.5
KH_2PO_4	100	28.3	29.7	33.8	33.8	31.4
KAMP	--[2]	34.7	30.8	31.0	27.8	31.1
GPA	50	30.3[3]	33.7[3]	26.7	33.5	31.1
K-GP	50	36.8	28.7	27.7	28.0	30.3
K-GP	100	27.3	23.7	35.0	28.0	28.5
Ca-GP	50	20.5	28.2	23.8	21.2	23.4
ETEAP	50	31.0	29.2	27.7	29.2	29.3
ETEAP	100	25.8	25.7	30.0	26.2	26.9
TPG	10	25.8	26.0	27.8	26.3	26.5
Fr 1-6	75	29.7[3]	25.8[3]	29.5[3]	27.5[3]	28.1
Control A	--	45.8	36.5	40.7	37.0	40.0
Control B	--	27.2	27.0	23.2	24.0	25.4
Means		30.4	28.9	31.1	29.2	29.9

Least Significant Differences	.05	.01
Material	3.6	4.8
Method of Application	1.9	2.6
Chemical x Method of Application	6.6	8.9

1) Concentration in millimoles of P per liter.
2) Saturated solution.
3) Very slight injury.

Experiment IV

At this point it was thought desirable to establish by the use of radioactive phosphorus that material applied to the foliage by the methods previously described actually enters the plants and is translocated and accumulated in meristematic regions.

The experiment consisted of two phases. First, a study was made of the movement of foliage-applied material to the roots of corn and tomato plants; and secondly, the movement of material was traced from the foliage to newly set fruits of tomato plants.

Part 1. Tomatoes were seeded on January 31, 1950, and transplanted into vermiculite in 4-inch pots on February 15. Plants were watered with a solution containing ½ oz. of "Take-Hold" per two gallons of water at ten-day intervals until time of treatment. Corn was seeded on February 15 directly into 4-inch pots of vermiculite and was then thinned to two plants per pot. They were maintained on the same nutrient solution.

The dipping solution containing P* was the usual solution containing 25 millimoles of H_3PO_4 per liter which had been enriched with 0.3 ml. of $H_3P^*O_4$. Since the test was designed to be of a qualitative nature, no determination of the activity of the solution was made.

On March 28 ten tomato plants and ten pots containing two corn plants each were dipped into the above dipping solution. Heavy cotton padding was again used to prevent contamination of the vermiculite growing medium. Plants were harvested 6, 12, 24, 36, 48, 96, and 106 hours following treatment.

At harvesting, the top portions of the plants were discarded and the crown of the root, including the top one inch of the root system, was separated from the other root tissue. The rest of the root tissue was washed free of vermiculite and dried between blotting paper at a temperature of about 80° C. Dried roots were then ground up in a hand mortar and radioactivity determined with a Geiger Mueller tube on samples weighing about 40 milligrams. From these samples counts per second per milligram of dryweight were calculated. The results are presented in a graph (Fig. 1), and illustrated by radioautographs (Fig. 2 and 3).

<u>Part 2</u>. Tomato plants used were started at the same time as those in Part 1 but were subsequently transplanted into greenhouse soil into 8-inch pots. On May 5 the first and second flower clusters were removed and the third flower cluster on three plants was pruned to three blossoms which were either completely or partially open. These clusters were then sprayed with 25 ppm of p-chloro phenoxy acetic acid, which induced simultaneous fruit set in all blossoms. On May 10 the plants were sprayed with a solution of 25 millimoles per liter of H_3PO_4, which had been enriched with

0.01 ml. of $H_3P^*O_4$. The flower clusters were covered with small pliofilm bags, and pot surface and pots were completely covered with layers of absorbent cotton and wrapped with paper. Fruits were harvested from these plants at twelve-hour intervals up to 106 hours after treatment. After harvesting, the fruits were cut into three sections and dried under an electric heat lamp. The dried tissue was ground up in a hand mortar and activity again determined on samples weighing about 40 mg. The schedule for harvesting fruits together with results is given in the following Table IV.

TABLE IV. Movement of P* into Young Tomato Fruits Following Application to the Foliage

Plant	Fruits on one cluster					
	1		2		3	
	Hours 1)	Counts 2)	Hours	Counts	Hours	Counts
A	10	.034	46	.093	83	.108
B	22	.052	59	.099	94	.062
C	35	.055	70	.066	106	.061

1) hours after treatment
2) counts per second per milligram of dry weight

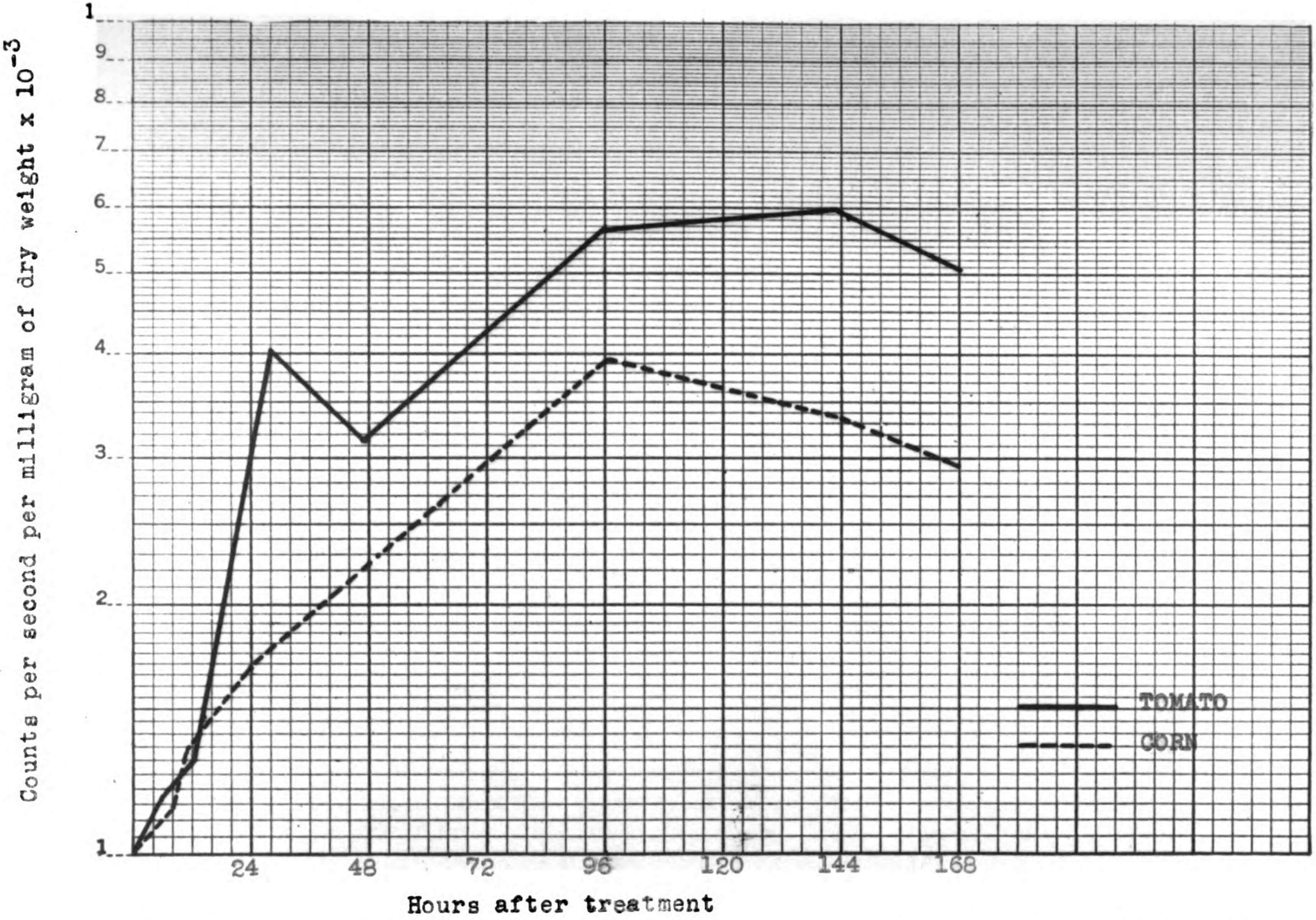


Fig. 1. Accumulation of P* in the roots of corn and tomato plants following application of $H_3P^*O_4$ to the foliage.

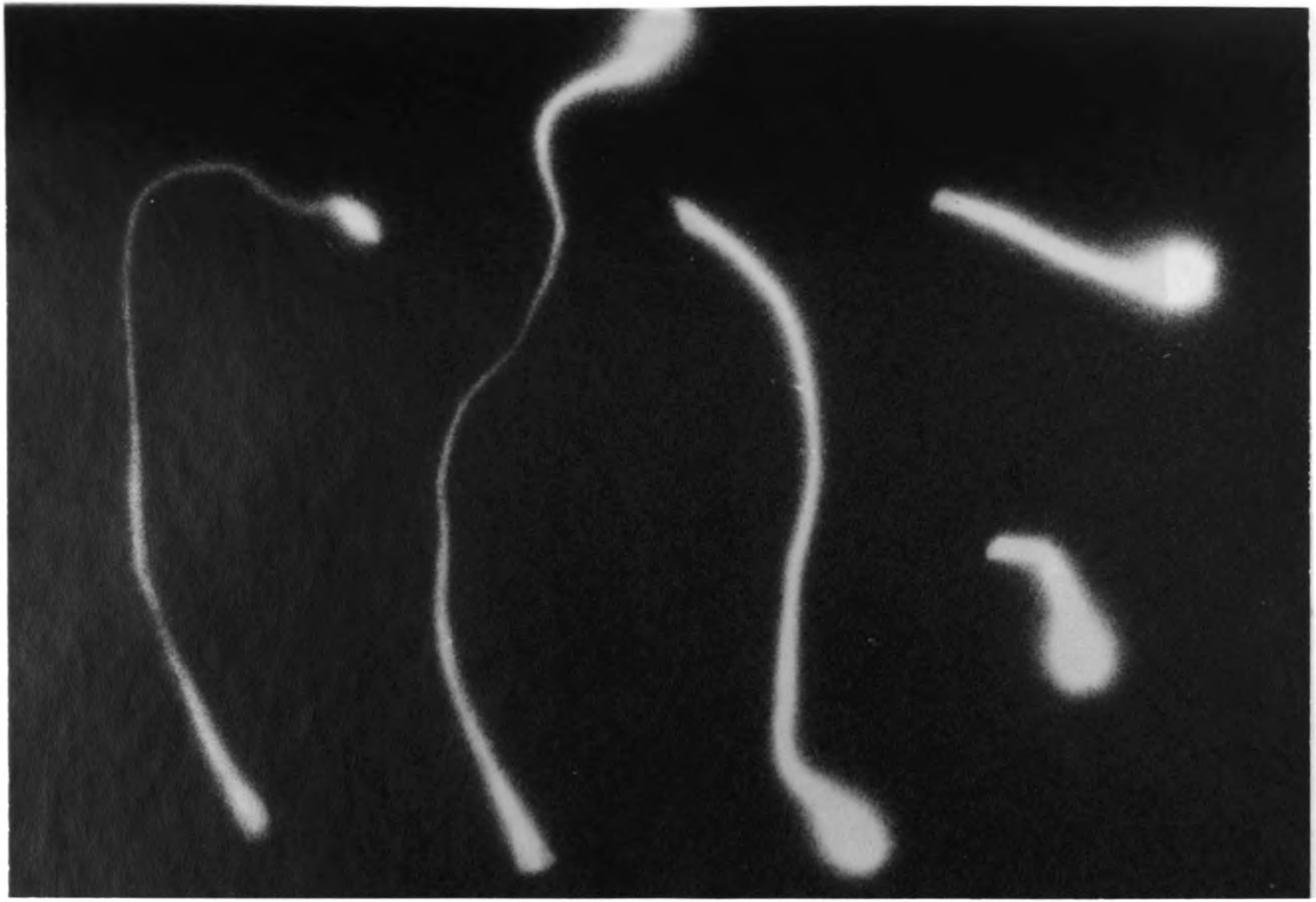


Fig. 2. Radioautograph of anker root tips of a corn plant harvested 29 hours after application of $H_3P^*O_4$ to the foliage. Apparent swelling of the tips is due to greater accumulation of active material. (Greatly enlarged).

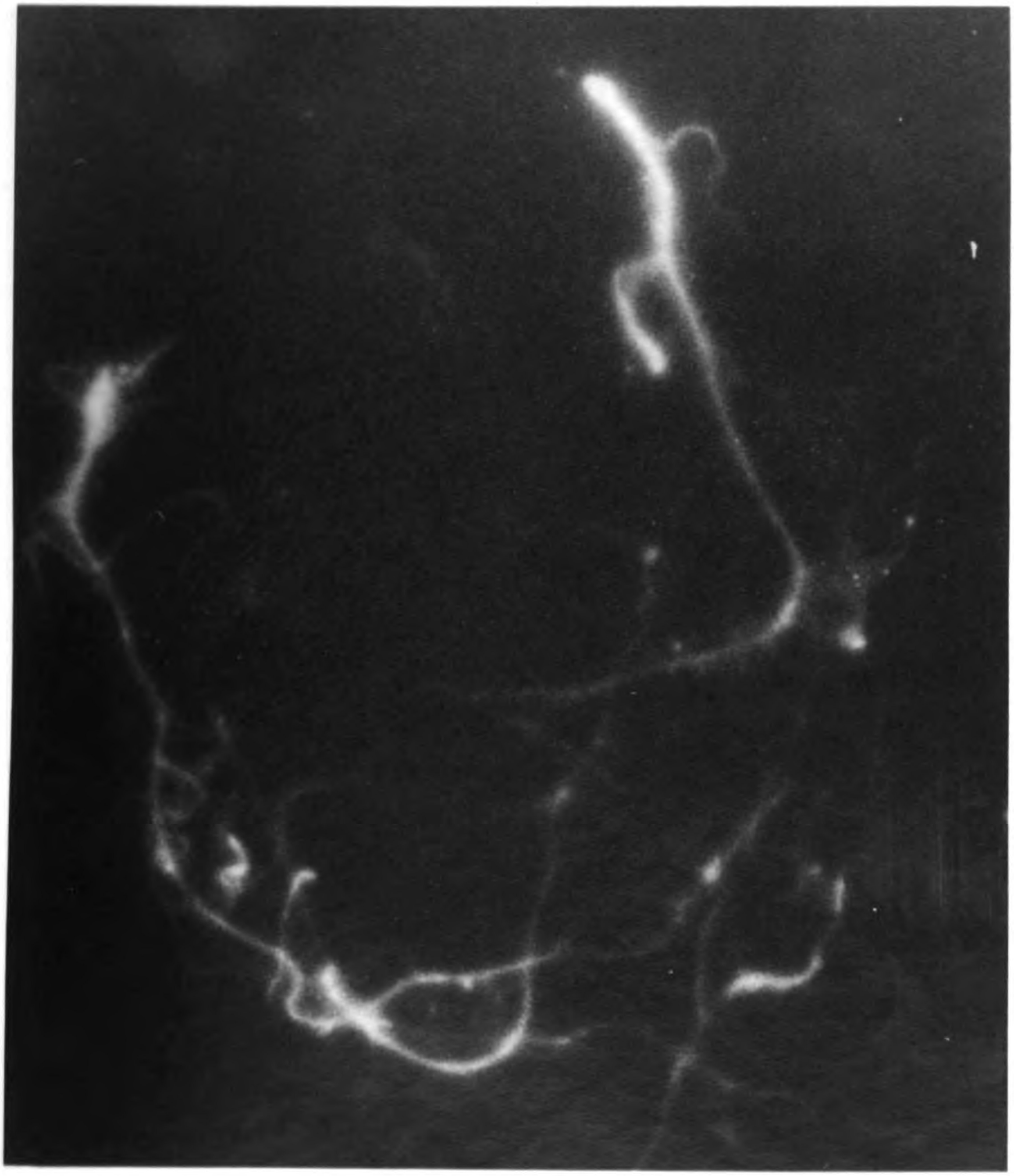


Fig. 3. Radioautograph of a portion of roots of a tomato plant harvested 46 hours after application of $H_3P^*O_4$ to the foliage. (Greatly enlarged).

Experiment V

The purpose of this trial was to test some of the chemicals on plants other than tomatoes. Beans and corn were chosen as test plants. To eliminate further any interference from spray material contaminating the growing medium, two plants were grown per pot; one plant was treated by dipping in the usual way while the other plant was left as a control. Under these conditions any material that might come in contact with the growing medium would be available to both plants. With single plants in individual pots treated plants may have gained some advantage from phosphatic materials that reached the growing medium despite precautions taken.

On June 13 corn and beans were seeded directly into sand in pots and later thinned to two uniform plants per pot. Cotyledons were removed from the beans immediately after germination to reduce the amount of stored material available to the seedlings and all plants were supplied with a three salt nutrient solution containing no phosphorus.* Beginning July 16 the plants were dipped three times into

---

* Solution contained:	$MgSO_4.7H_2O$	23 millimoles
	KNO_3	23 millimoles
	NH_4NO_3	40 millimoles

Solution was applied four times daily; pots were watered intermittently with plain water to prevent salt accumulations. Minor elements were contained in sufficient quantities in the sand.

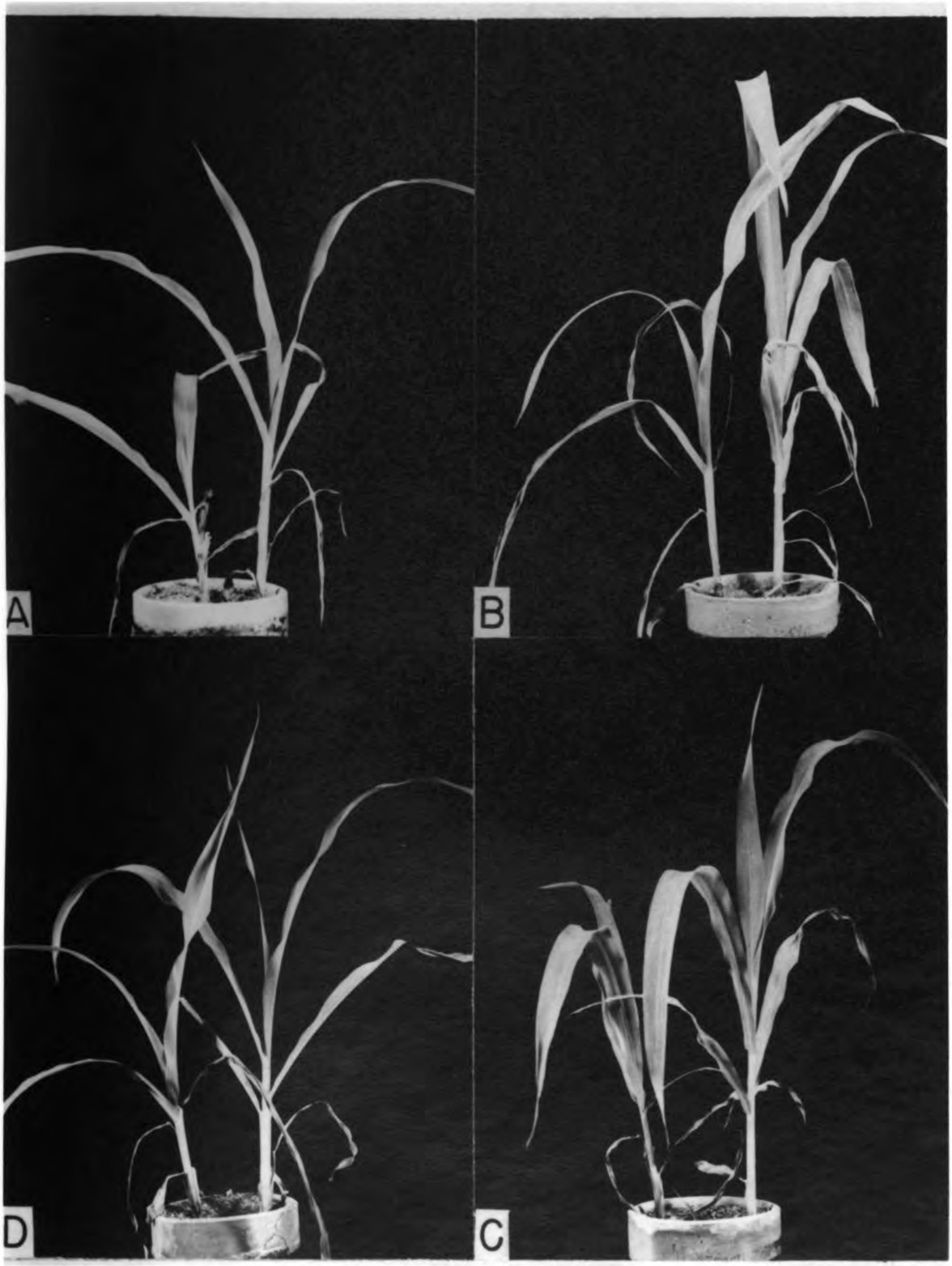


Fig. 4. Response of phosphorus-deficient corn plants to three foliage applications of: A. Phosphoric acid, B. "Take-Hold", C. Potassium glycerophosphate, D. Mono ammonium phosphate. Right plant: treated; left plant: control (no treatment).

TABLE V. The Effect of Repeated Foliage Applications of Test Compounds on the Percentage Increases in Fresh Weights of Bean and Corn Plants.[1] (Each figure based on six plants).

Compound	Beans	Corn
H_3PO_4	115	160
$NH_4H_2PO_4$	161	135
$MgHPO_4$	25	29
KH_2PO_4	108	120
$Na_2H_2P_2O_7$	50	50
T-H	157	233
MAP	190	108
EAP	31	119
GPA	25	189
Na-GP	39	158
K-GP	82	76
Mg-GP	-6.0	38

All compounds used at 25 millimoles of P per liter.

1) Per cent increase over control plants grown in the same pot.

solutions of various chemicals at weekly intervals. All compounds were applied with the usual spreader, and six plants of each crop were treated with the same compound. Height measurements were taken at the time of treatment and at the conclusion of the experiment. Final fresh weights of top portions of plants were also taken. However, in Table V only the fresh weight differences are listed, and in Fig. 4 are illustrated some of the corn plants involved in the test.

Experiment VI

The purpose of this part of the investigation was to test a limited number of chemicals under field conditions.

Tomato plants were grown in the field at high and low phosphorus levels and received four repeated spray applications of four different chemicals. On half of the area the soil was covered at the time of spraying while on the other half the spray material was allowed to get on the soil. These treatments were further interacted with hormone cluster spray, to see whether the additional phosphorus supply would help the plants overcome exhausting effect of a heavy load of early fruit.

Seeds were sown in the greenhouse on March 18, 1950, and the seedlings transplanted into 4-inch pots on

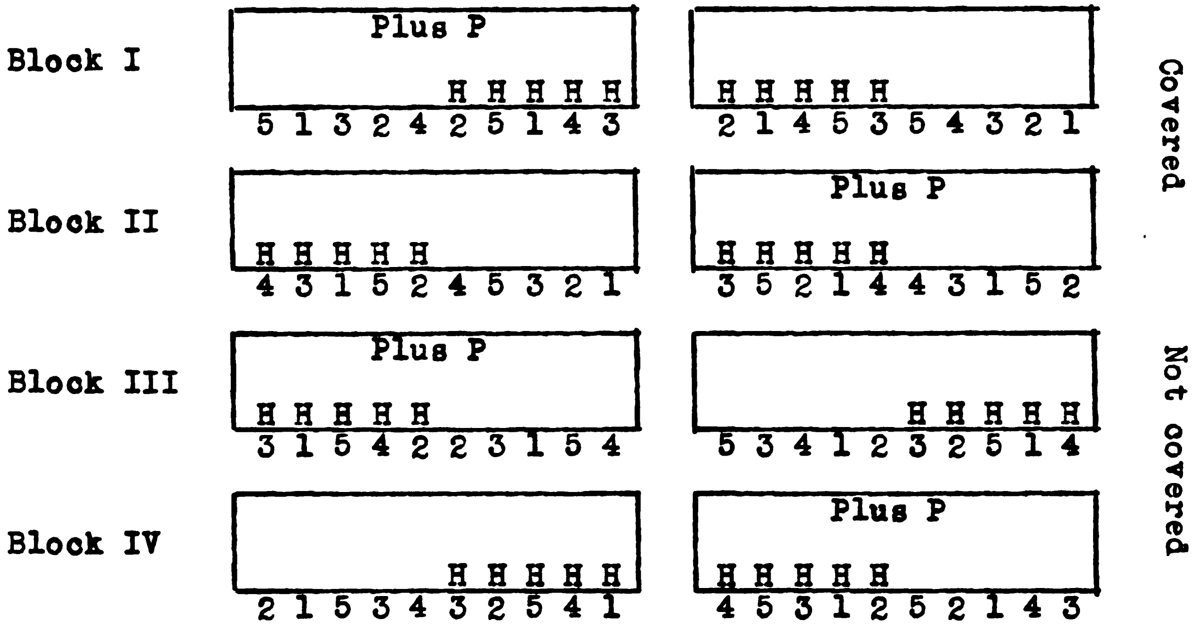
April 22. The growing medium was a mixture of two parts of greenhouse soil to one part of muck. The plants were moved to a cold frame on May 15 and transplanted to the field on May 27 at a spacing of 3 ft. x 5 ft. in rows of five plants each. A detailed description of the experimental layout is given in Fig. 5, while Table VI gives treatment dates and amounts of solution applied.

TABLE VI. Dates of Treatment and Amounts of Spray Solution Applied to Eighty Field Grown Tomato Plants

Date	Amount of Solution Applied per Treatment (Average for 80 plants)
June 4	2.8 liters
June 10	3.5 "
June 17	5.7 "
June 26	7.2 "
Total	19.2 liters

At the concentration used for phosphoric acid, glycerophosphoric acid, and urea ortho phosphate 14.9 grams of phosphorus were applied to eighty plants, which is approximately 2.73 lbs. of P_2O_5 per acre or less than 14 lbs. of 0-20-0 per acre.

Fig. 5. Experimental Design of Field Plots.



Soil type: Hillsdale sandy loam.

Fertility levels: The entire area received:

KCl (60%)	200 lbs./acre
NH_4NO_3	200 lbs./acre

Plus P plots received in addition:

Superphosphate (45%)	300 lbs./acre

Hormone treatment (H): 80 ppm alpha-orthochlorophenoxypropionic acid to clusters on June 5, 9, 14, and 20.

Spray treatments:

No.	Compound	Conc. in m-moles of P/liter
1	H_3PO_4	25
2	GPA	25
3	UOP	25
4	Pl-MP	100
5	Control	No treatment

All compounds applied with spreader using 2½ gallon hand sprayers, a separate sprayer for each compound.

Ground covering: Heavy paper bags were spread under the plants at treatment time covering the soil completely. Notches were cut out for stems; bags were left under plants until paper and plants were completely dry.

Harvesting of fruits began on July 12 and as expected was confined mostly to hormone-treated plants. Figures 6-10 in the Appendix present graphically the accumulative totals for the various treatments up to August 9. Total yields as of August 15, considered to be early yields, were subjected to statistical analysis, and the results are summarized in Table VII.

TABLE VII. The Effect of Foliage-applied Sprays of Phosphatic Compounds on Early Yield of Field Tomatoes

Treatments	Average yields	
	In ounces per 20 plants[1)]	In tons per acre
H_3PO_4	740	3.35
GPA	675	3.06
UOP	513	2.33
Pl-MP	473	2.14
Control	640	2.80

1) Difference needed for significance at 1 per cent level--19.0.

DISCUSSION

From the results of the experiments herein reported it is apparent that plants benefit from phosphorus in certain forms applied to their foliage, both under conditions of deficiency as shown by the greenhouse tests and also as a supplement to phosphorus applied to the soil as shown in the field trial. The study involving P* shows definitely that the material is absorbed and translocated, and that it accumulates in meristematic regions. However, the study does not prove directly that the material becomes actually involved in the various metabolic processes. Such proof could only be established by separation of the plant phosphorus into its various fractions and determining the activity within each fraction. Such a study would be of great interest. The growth and yield responses obtained, however, suggest that the materials are utilized by the plants.

The fact that the materials can be applied best at a very low concentration is of greatest importance. It is known from work with nutrient solutions that phosphorus is needed not so much in large concentrations as it is needed in a continuous supply. Also it is known that within plants the concentration of soluble phosphorus is generally low and that increases in supply generally result in greater dilution by growth, unless other factors become limiting. From this viewpoint the effects of low concentrations are, therefore, not surprising. Since the materials are supplied in such small amounts, the responses they produce indicate a vastly greater efficiency of this method of supplying phosphorus than by soil treatments. This is best shown by the results of the field trial as illustrated in the following Table VIII.

TABLE VIII. The Effect of Phosphoric Acid Foliage Spray on Early Yield of Tomatoes.
(Figures are totals in ounces for forty plants).

Soil Treatment	Treated	Control	Percent increase over control
Superphosphate added	1521	1356	12.1
No superphosphate added	1440	1203	19.9
Percent increase due to superphosphate	10.3	12.7	

According to this table, an application of 135 lbs. of P_2O_5 per acre to the soil gave an increase of 12.7 per cent in yield. However, four spray applications totalling 2.73 lbs. of P_2O_5 per acre gave an increase of 19.9 per cent under the same experimental conditions. Since the yield data did not show any significant differences due to covering the ground, it must be concluded that the increase in yield resulted from the nutrients taken in by the foliage.

From the overall yield data it was also apparent that there was no significant interaction between hormone treatment and phosphorus supply, although the expected hormone response in earliness is evident in Figures 6-10. This is in agreement with results already reported from hormone treatments on early field tomatoes (29).

Of the four chemicals tested in the field plastic meta phosphate gave the lowest yields. This compound was used at a higher concentration because in preliminary tests with corn seedlings it was found completely non-injurious. This compound also has a very high sodium and potassium content and interference by these ions is very possible. The poor results with urea ortho phosphate may be explained by the fact that nitrogen content of this compound is double its phosphorus content. It is, therefore, possible that this material would give better results when its nitrogen supply does not tend to provide an excess. There is also a further possibility that the material is injurious when sprayed directly on blossoms, as indicated by a blossom and fruit set count early in the season.

A question which arises whenever new spray materials are used concerns their effect on quality of the product. Therefore, during the third and fourth picking a total of about 400 fruits was collected from the various treatments and compared with fruits from the controls. No differences were observed in the amount of cracking, color and thickness of flesh, and fullness of locules.

It is to be expected that plants of different species and probably also of different variety will respond differently to various chemicals. An indication of this was obtained in Experiment V, when young corn and bean plants were treated with twelve different compounds. From Table V it can be seen that magnesium-containing compounds (magnesium-glycero phosphate and mono magnesium phosphate) gave the poorest results in both crops. This is probably directly related to the solubility of these compounds. Generally, beans responded best to inorganic phosphates; the only organic compound to give good response was methyl acid phosphate. On corn almost all compounds gave good results, especially "Take-Hold," which is a mixture of monopotassium and diammonium phosphate.

From the above another potential of leaf feeding, namely, as a method in plant nutrition becomes apparent. In certain experiments it is very often desirable to provide plants with a high level of a nutrient, and often this is impossible without interference from another ion. By using organic compounds, or acids and bases directly, interference in plant metabolism from inorganic ions can be eliminated.

There is reason to believe that the use of phosphatic sprays is sound also from the economic viewpoint. While the cost of chemicals may be the same if normal fertilizers can be used, the amounts applied are so much smaller that they may tend to justify repeated application. The possibility of combining phosphatic sprays with regular pest control spray schedules also should be investigated, as well as the possibility of using dusting materials.

An investigation into the responses of all types of agricultural crops to phosphorus sprays seems also justified.

SUMMARY

1. A series of phosphorus-containing compounds were tested for their efficiency in supplying P to plants when applied to their foliage. A concentration of 25 millimoles of P per liter was found to be satisfactory for most compounds when applied with a spreader.

2. In greenhouse trials young tomato, bean, and corn plants grown under P deficiency conditions gave growth responses to most treatments as indicated by increases in height and fresh weight compared with non-treated control plants.

3. The movement of P* applied to the foliage was traced from the foliage to roots of corn and tomato plants and from the foliage to young tomato fruits.

4. In a field trial phosphoric acid and glycerophosphoric acid when applied to the foliage gave increases in early yields of tomatoes of 10-19 per cent at low and high soil phosphorus levels, respectively. The amount of P applied as spray responsible for this increase was equivalent to 2.73 lbs. of P_2O_5 per acre.

CONCLUSIONS

Based on the findings reported, it is felt that phosphatic materials applied to the foliage of plants can be of nutritional benefit to such plants. Results indicate that solutions containing 25 millimoles of P per liter as H_3PO_4 are non-injurious when applied with a spreading agent such as Dreft, and that repeated applications may bring responses in growth and yield. Further investigations are definitely warranted.

BIBLIOGRAPHY

1. Arnon, D. I., P. R. Stout, and F. Sipos. Radioactive phosphorus as an indicator of phosphorus absorption of tomato fruits at various stages of development. Amer. Jour. Bot. 27: 791-798. 1940.
2. Ball, H. J., and T. C. Allen. Insecticidal tests for some new organic phosphates. Jour. Econ. Ent. 42: 394-396. 1949.
3. Biddulph, O. Diurnal migration of injected radio phosphorus from bean leaves. Amer. Jour. Bot. 28: 348-352. 1941.
4. Blaser, R. E. and C. McAuliff. Utilization of phosphorus from various fertilizer materials. I. Orchard grass and ladino clover in New York. Soil Sci. 68: 145-150. 1949.
5. Bould, C. and J. Tolhurst. Report on the use of foliage sprays for the control of magnesium deficiency in Apples. Bristol Univ. of Agr. Res. Sta. Ann. Report 1948. p. 51-58. 1949.
6. Boynton, D. Foliar nitrogen sprays for fruit tree. 79th Ann. Rep. Mich. Sta. Hort. Soc. 81-84. 1949.
7. Colwell, R. N. The use of radioactive phosphorus in translocation studies. Amer. Jour. Bot. 29: 798-806. 1942.

8. Frear, D. E. H. Chemistry of Insecticides, fungicides, and herbicides. p. 100. D. Van Nostrand Co., New York, N. Y. 1948.

9. Heck, A. F. and A. L. Whiting. Assimilation of phosphorus from phytin by red clover. Soil Sci. 24:17-30. 1927.

10. Hevesy, G. Interaction between the phosphorus atoms of the wheat seedling and the nutrient solution. Ark. Bot. 33:(2). 1946.

11. Hilbert, G. E., L. A. Pink, M. S. Sherman, and T. H. Treamearne. Organic phosphates I. Fixation studies with three different soil types. Soil Sci. 46: 409-418. 1938.

12. Jacob, W. C., C. H. VanMiddelem, E. L. Nelson, C. D. Welch and N. S. Hall. Utilization of phosphorus by potatoes. Soil Sci. 68:113-120. 1949.

13. Jones, R. J. and H. T. Rogers. New fertilizers and fertilizer practices. Advances in Agronomy 1:39-76. 1949.

14. Krausche, K. K. and B. E. Gilbert. Increase in transpiration rates of tomato leaves due to copper sprays. Plant Phys. 12:853-860. 1937.

15. Matskow, F. F. Extra radical nutrition of plants. Dokl. Akad. Nauk, U.S.S.R. 66:733-736. 1949.

16. Mayberry, B. D. and S. H. Wittwer. The use of urea sprays on vegetable crops. Abstracts of paper to be presented at A.I.B.S. Meetings, Columbus, Ohio, Sept. 11-13, 1950.

17. Pink, L. A., M. S. Sherman, and F. A. Allison. The behavior of soluble organic phosphates added to soils. Soil Sci. 51:351-365. 1941.

18. Rabideau, G. S., W. G. Whaley and C. Heimsch. The absorption and distribution of radioactive phosphorus in two maize inbreds and their hybrid. Amer. Jour. Bot. 37:93-99. 1950.

19. __________. The absorption and distribution of radioactive phosphorus by tomato plants at various developmental stages. Amer. Jour. Bot. 36:801. 1950. (Abstract).

20. Ripper, W. E., R. M. Greenslade, and G. S. Hartley. A new systemic insecticide bis (bis dimethylamino phosphonous) anhydride. Bul. Ent. Res. 40:481-501. 1950.

21. Roberts, E. A., M. D. Southwick, and D. H. Palmiter. A microchemical examination of McIntosh apple leaves showing relationship of cell wall constituents to penetration of spray solutions. Plant Phys. 23:557-569. 1948.

22. Sankaran, R. Thesis. University of London. 1936. As quoted by G. F. Gregory. Mineral nutrition of plants. Ann. Rev. Biochem. 6:557-578. 1937.

23. Sayre, C. B. Starter solutions for tomato plants. New York State Agr. Exp. Sta. Bul. 706. 1943.

24. Spencer, V. E. and R. Stewart. Soil penetration of some organic and inorganic phosphates. Soil Sci. 38:65-79. 1934.

25. Spinks, J. W. T., H. G. Dion, M. Reade, and J. E. Dehm. Study of fertilizer uptake using radioactive phosphorus III. Sci. Agr. 28:309-314. 1948.

26. Weissflog, J. and H. Mengdehl. Studien zum Phosphor Stoffwechsel in der hoeheren Pflanze. IV. Aufnahme und Verwertbarkeit organischer Phosphorsaeureverbindungen durch die Pflanze. Planta 19: 182-241. 1933.

27. Went, F. W. and M. Carter. Growth response of tomato plants to applied sucrose. Amer. Jour. Bot. 35: 95-106. 1948.

28. Whiting, A. L. and A. F. Heck. Assimilation of phosphorus from phytin by oats. Soil Sci. 22:477-494. 1926.

29. Wittwer, S. H., H. Stallworth, and M. J. Howell. The value of a hormone spray for overcoming delayed fruit-set and increasing yields of outdoor tomatoes. Amer. Soc. Hort. Sci. Proc. 51:371-380. 1948.

30. Wolfenbarger, D. O. Nutritional value of phosphatic insecticides. Jour. Econ. Ent. 41:818-819. 1949.

APPENDIX

LIST OF COMPOUNDS TESTED

Symbol used in text	Compound[1]	% P[2]
Inorganic		
1. H_3PO_4	Ortho phosphoric acid	37.2
2. KH_2PO_4	Mono potassium phosphate	17.8
3. $NH_4H_2PO_4$	Mono ammonium phosphate	23.5
4. $MgHPO_4 \cdot 3H_2O$	Mono magnesium phosphate	17.8
5. $Na_2H_2P_2O_7 \cdot 6H_2O$	Sodium acid pyro phosphate	9.4
6. T-H	"Take-Hold" (11-52-17)	7.4
7. Pl-MP	Plastic Meta phosphate	29.2
8. KAMP	Potassium acid metaphosphate	
Organic		
9. MAP	Methyl acid phosphate	29.6
10. EAP	Ethyl acid phosphate	23.6
11. n-PAP	n-Propyl acid phosphate	19.7
12. n-BAP	n-Butyl acid phosphate	16.9
13. AAP	Amyl acid phosphate	15.7
14. GPA	Glycerophosphoric acid	6.5
15. Na-GP	Sodium glycerophosphate	19.0
16. K-GP	Potassium glycerophosphate	9.5
17. Ca-GP	Calcium glycerophosphate	14.8
18. Mg-GP	Magnesium glycerophosphate	16.5
19. ETEAP	Ethyl triethanolamine phosphate	6.8

Symbol used in text	Compound[1]	% P[2]
20. U-OP	Urea orthophosphate	19.9
21. TPG	Tetra phospho glucosate	5.9
22. Fr 1-6	Fructose 1-6, diphosphate (Ca-Salt)	11.1

---

[1] Compounds 2-6, inclusive, were obtained from Victor Chemical Co. For further information on these compounds see: Product List, Victor Chemical Co., Chicago, Ill.

Compounds 7, and 9-19, inclusive, were obtained from Monsanto Chemical Co. For further information on these compounds see: Monsanto Chemicals and Plastics, 28th ed.; also Alkyl phosphoric acids. Technical Bul. 120. Monsanto Chemical Co., St. Louis, Mo.

Compound 21 was obtained from W. Hearing Co., Houston, Texas.

Compounds 1, 8, and 22 were obtained from the Department of Agricultural Chemistry, Michigan State College, E. Lansing, Michigan.

[2] Calculated from purity of compound and chemical composition.

The following graphs show the response (in terms of early yield) of field grown tomatoes to repeated phosphatic foliage sprays. Each graph represents the results obtained by applying four sprays of one compound under four different experimental conditions. These experimental conditions are indicated by the following symbols:

H plus P -Hormone cluster spray; superphosphate to soil
H minus P -Hormone cluster spray; no superphosphate to soil
plus P -Superphosphate to soil
minus P -No superphosphate to soil

Each graph is based on eighty plants; each line represents total yield of twenty plants.

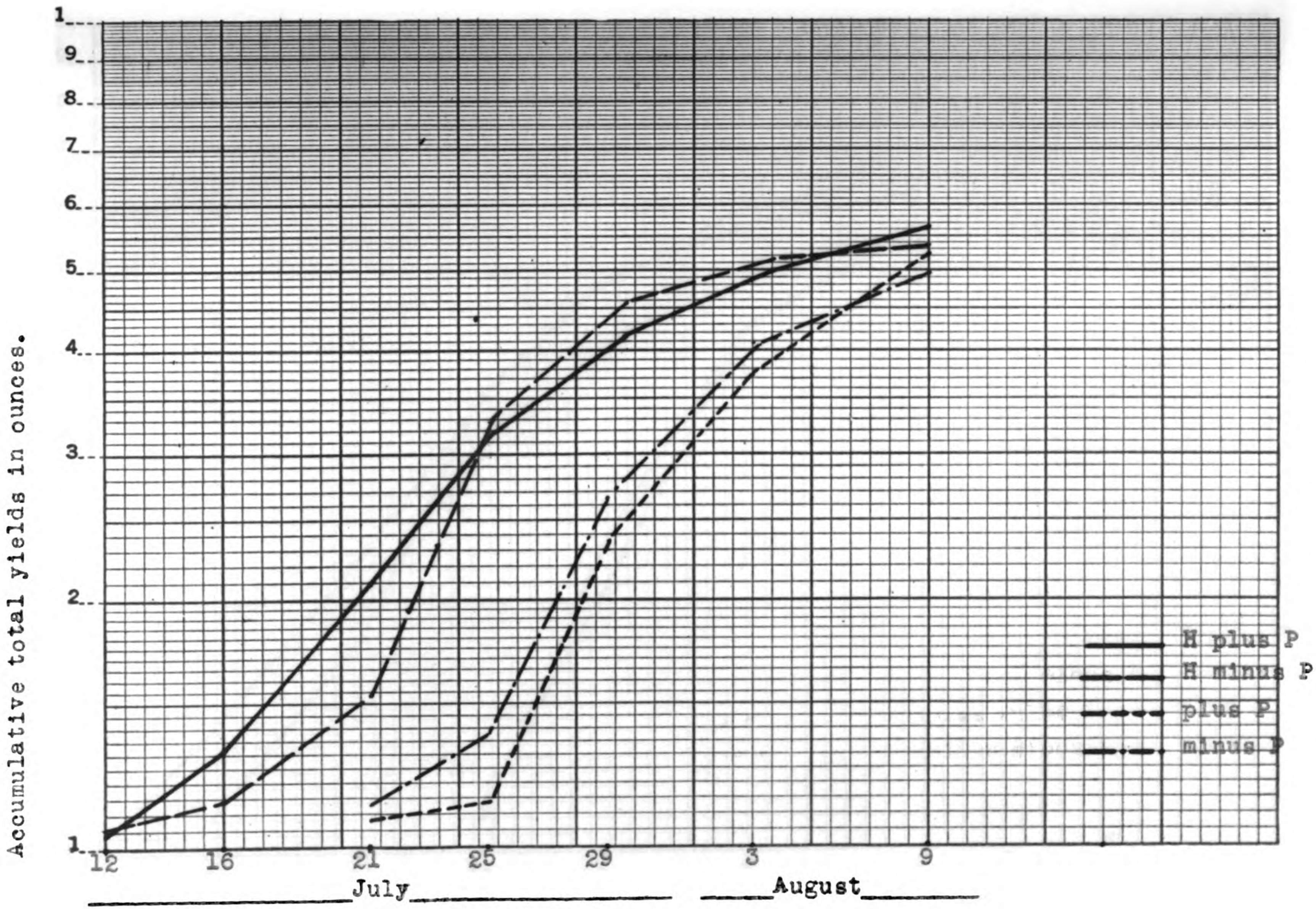


Fig. 6. Treatment 5. Control (no foliage spray).

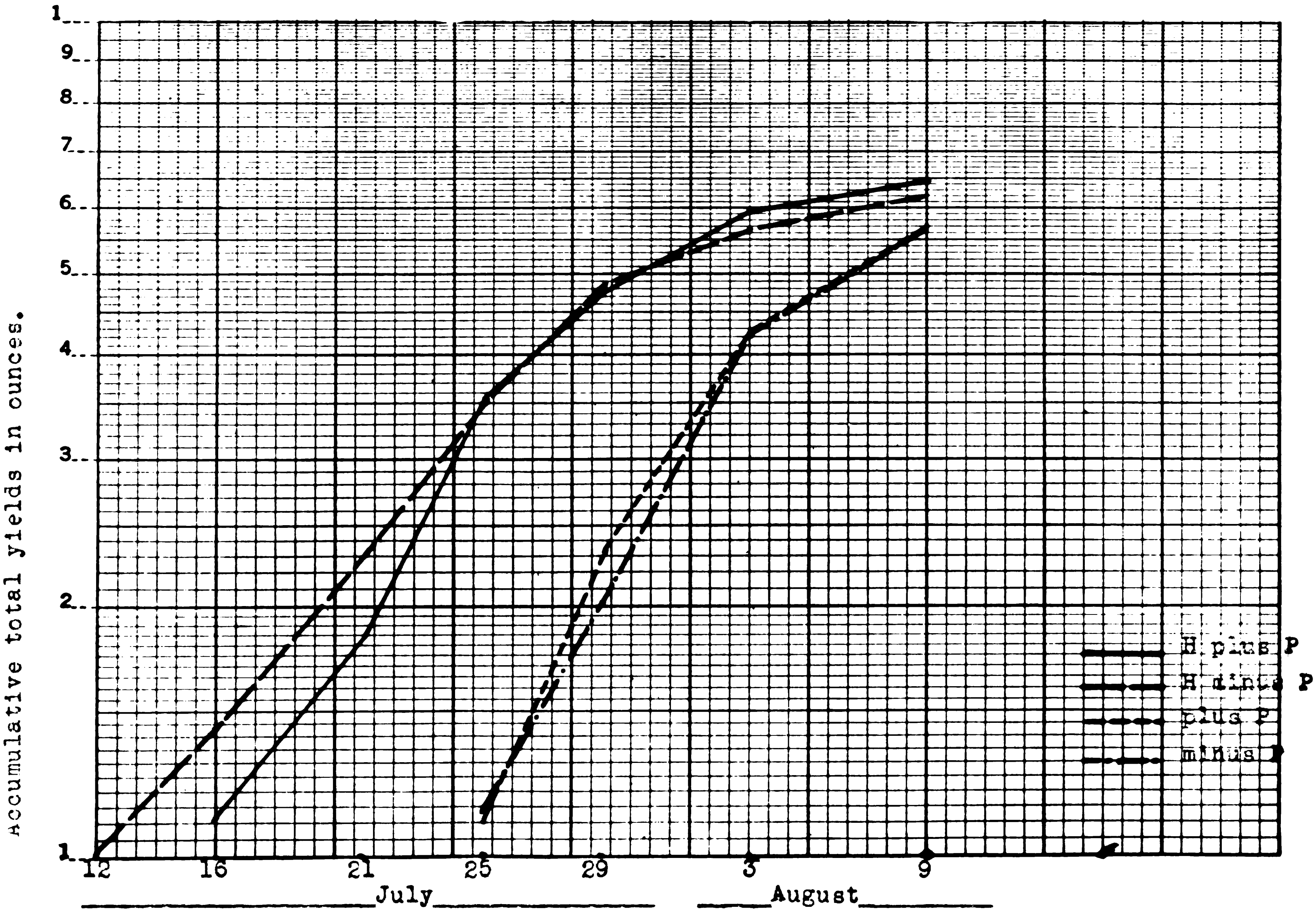


Fig. 7. Treatment 1. Phosphoric acid.

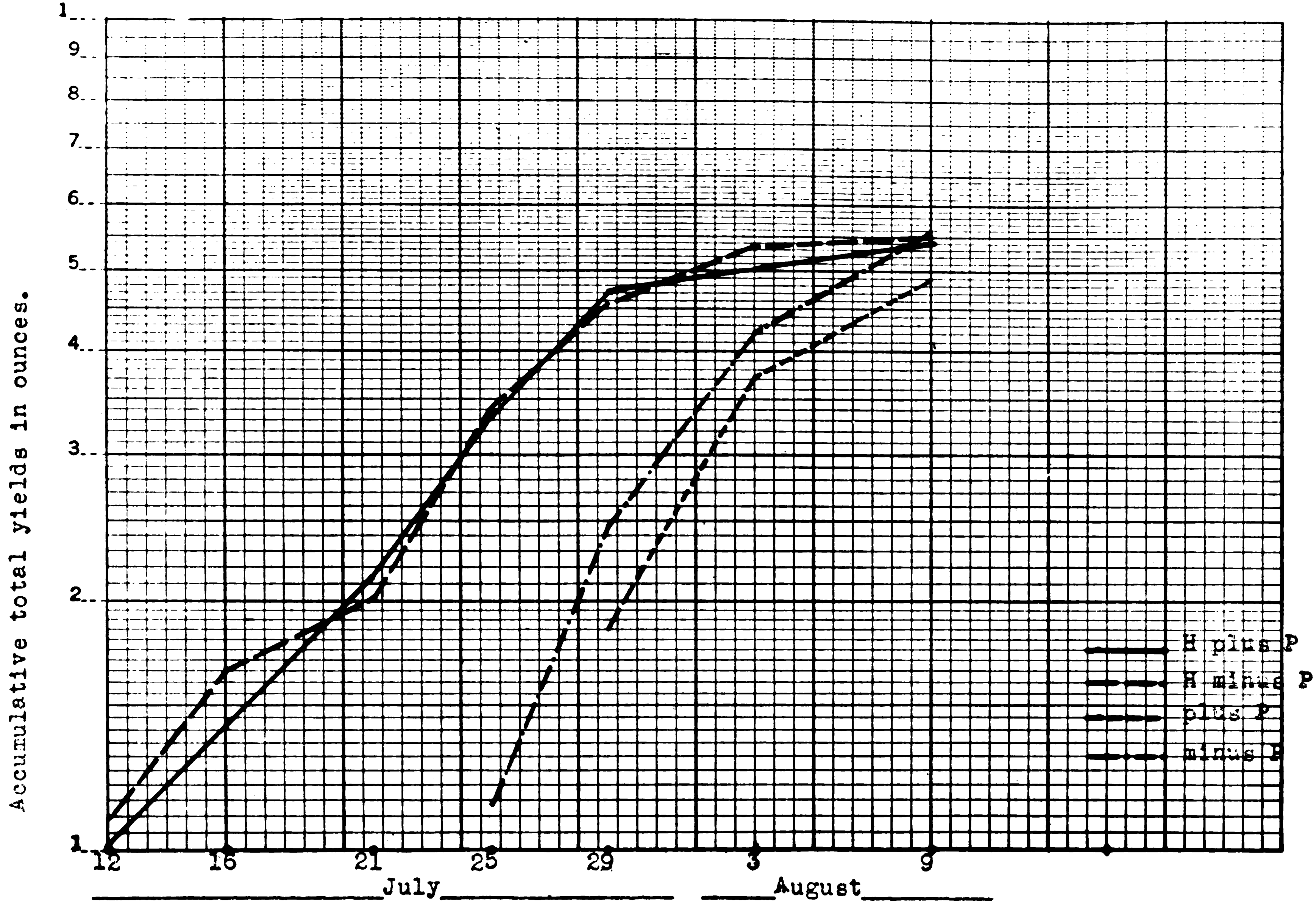


Fig. 8. Treatment 2. Glycerophosphoric acid.

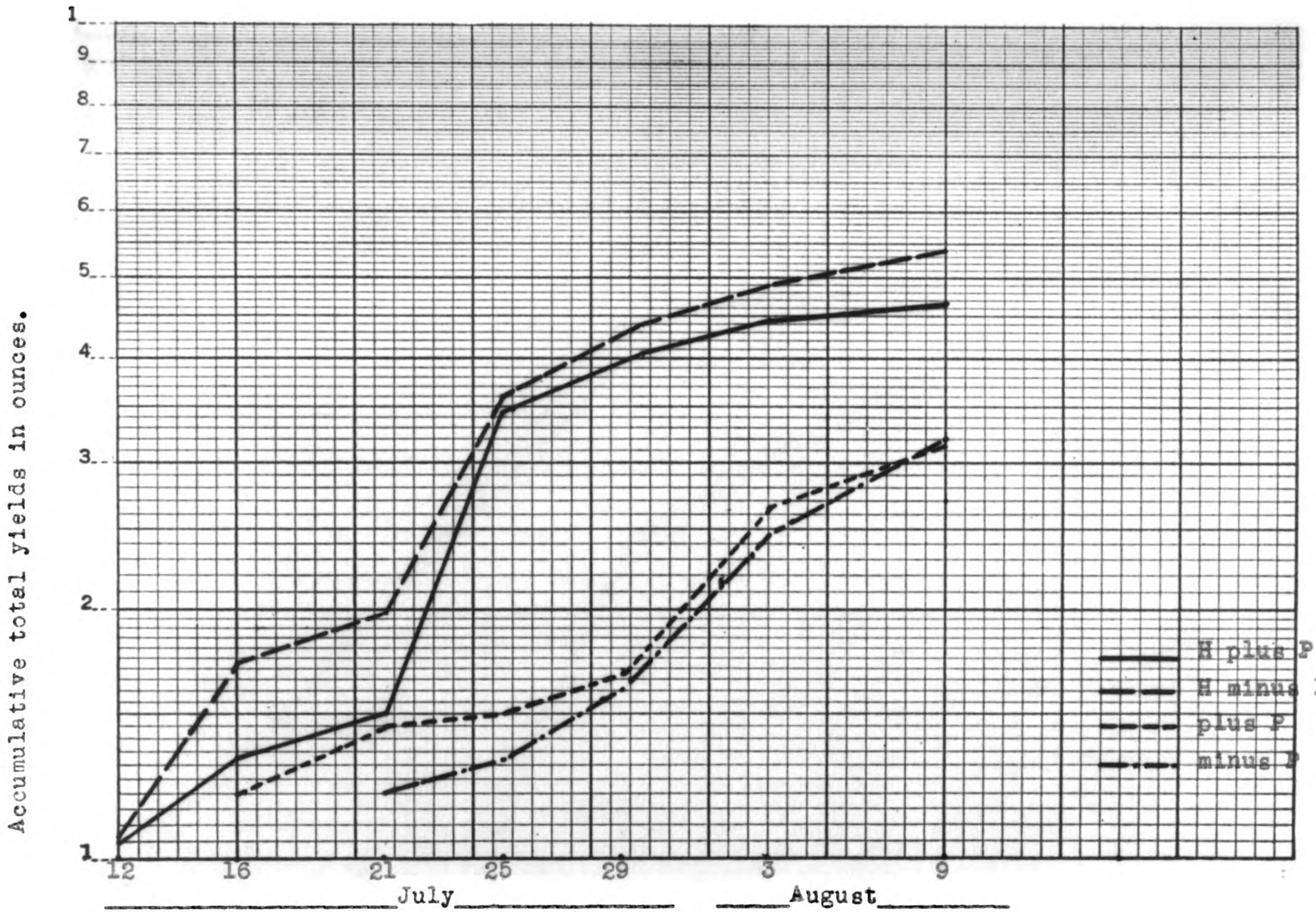


Fig. 8. Treatment 3. Urea ortho phosphate.

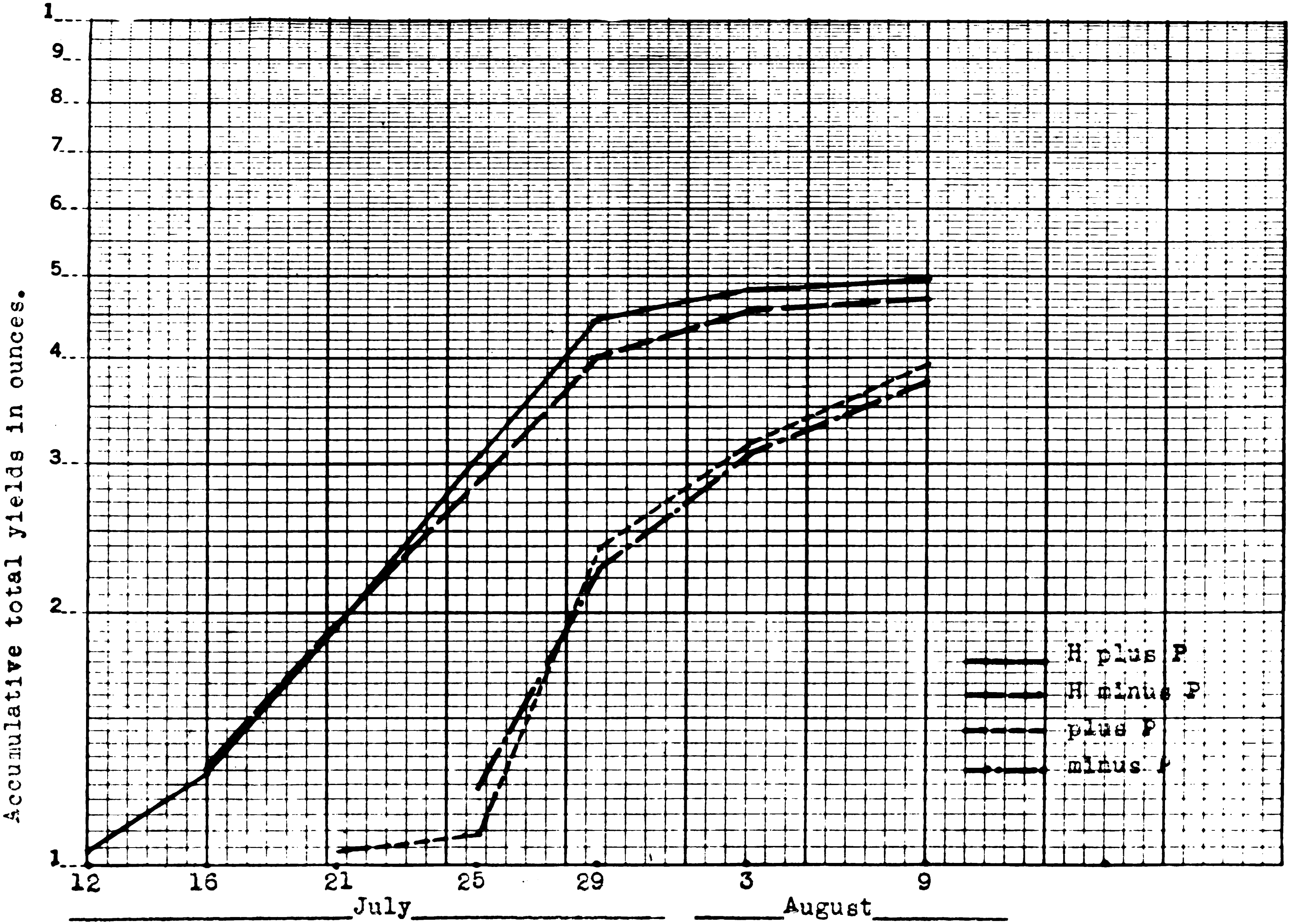


Fig. 10. Treatment 4. Plastic meta phosphate.