THE EFFECT OF VARIED LEVELS OF NITROGEN, PHOSPHORUS, POTASSIUM, AND BORON IN SOIL ON THE YIELD AND CHEMICAL COMPOSITION OF GREENHOUSE TOMATOES

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Many commercial growers of greenhouse tomatoes are attempting, by the use of soil and tissue tests, to control the nutrient status of their soils. Their large capital investment makes it important that all scientific aids available be used to help them obtain maximum yields. Fertilizer costs are secondary to high yields of marketable fruit.

Many of the growers in Michigan do their own soil testing with the Spurway Simplex Soil Testing Kit (32).

The question arises regarding the most desirable nutrient levels or range of levels in soils for the elements required by tomatoes. Since the Spurway procedure for soil testing is commonly used in this area, it appeared that a nutrient level problem on the tomato, using this testing procedure, would have practical as well as scientific value.

Accordingly this investigation was undertaken to provide further information regarding the proper range of concentrations of nitrogen, phosphorus, potassium, and boron in soils for greenhouse tomatoes. The interrelationships of varying levels of these elements were also studied. Chemical analyses of the plant tissues were made to determine the effect of treatment on the chemical composition of the plants.

EXPERIMENTAL

Soil Testing Procedure

In this study soil testing was carried out on air dry soil according to the rapid methods of Spurway (32). Only his "active" tests were used. Briefly, this consisted of extracting the soil with approximately 0.018 N acetic acid, using a 1:4 ratio by weight of soil to extracting solution. Tests for nitrogen, phosphorus, and potassium were run on the filtered extract. Nitrates were determined by use of a sulfuric acid solution of diphenylamine. Phosphorus was estimated by use of an ammonium molybdate solution with stannous chloride as the reducing agent. The sodium cobaltinitrite procedure was used for potassium determinations. The colors or turbidities developed in the above tests were compared with those of standard solutions carried through the same procedures. All soil test results are expressed as parts per million in the soil extract.

Methods of Soil Analysis

Mechanical analyses of the soils were determined by the hydrometer method proposed by Bouyoucos (5). Base exchange capacity was determined by leaching with neutral ammonium acetate as suggested by Peech, et al. (26). The procedure followed for the determination of exchangeable potassium was essentially that of Lawton (16). This is a colorimetric method which utilizes hexanitrodiphenylamine (dipicrylamine).

The carbon train technique was used for determining carbon. Per cent organic matter was estimated by multiplying the per cent carbon by the factor 1.724, assuming that organic matter is 58 per cent carbon.

All pH measurements of the soils were made potentiometrically, using a Macbeth alternating current pH meter with glass electrodes.

Calibration of the Fertilizer "Fixing Power" of Soil

Two experiments were conducted which involved the maintenance of nitrogen, phosphorus, and potassium at constant levels in the soil. The problem arose as to the amount of the various C.P. reagents needed in order to obtain the desired levels in the soil. These amounts were determined by means of a tumbler experiment set up in the laboratory. One hundred and fifty gram samples of the screened, air dry soil to be used later in the greenhouse experiment were placed in 24 glass tumblers. Twelve treatments, in duplicate, were applied. They included varied amounts of the nitrogen, phosphorus, and potassium reagents. The amount of each reagent used progressed by treatment from zero nitrogen, phosphorus, or potassium to treatments including sufficient quantities of each to bring the soil tests to a value higher than any level desired for that element in the future experiment. Lime was added to the Oshtemo soil in the tumblers at a rate equivalent to one ton per acre. The nitrate and potassium salts were added in solution, while the calcium carbonate and primary monocalcium phosphate were added as dry salts due to their low solubilities. The treatments were mixed thoroughly into the soils which were then brought to their moisture equivalent with distilled water and allowed to incubate at room temperature for ten days. Additional distilled water was added as needed to keep the soils at the desired moisture content during incubation.

At the end of the incubation period the soil was removed from the tumblers, air dried, and tested for available nitrogen, phosphorus, and potassium according to the Spurway procedure.

Using the results obtained, calibration curves were plotted for each of the three elements concerned. The test results were plotted as the ordinate and the milligrams of the respective salts added as the abscissa. By using these graphs the amount of a particular reagent required to bring any given amount of this soil to a desired nutrient level was readily calculated. During the experiments, when soil tests indicated that a nutrient level had dropped, the calibration curves were also used to calculate the amount of a reagent necessary to restore the soil to its proper level.

Plan of Greenhouse Experiments

Greenhouse experiments were conducted with tomato plants grown in closed bottom, glazed, earthenware jars. Surface soils of five common Michigan soil types were collected. The soils were air dried and screened through a three-eighths inch mesh rotary type screen before using.

During the growing period soil moisture was maintained at approximately moisture equivalent by additions of distilled water.

Descriptions of Soils Used

The following soils were used and the descriptions are essentially the same as given in the respective county soil survey reports published by the United States Department of Agriculture:

1. Oshtemo loamy sand: A soil type with a yellowish-brown surface layer of loamy sand which occurs on nearly level land. Very little clay is present in the subsoil and loose dry sand or sand and gravel extend to depths of several feet. This soil is naturally very drouthy, is low in organic matter, and is strongly acid in reaction. Surface soil of this type was obtained from the Rose Lake Wildlife Experimental Farm, Clinton County, Michigan.

2. Brookston silt loam: A soil developed on heavier materials of the flat basin lands, valleys, and depressions which were originally wet and swampy. It has a very dark gray or nearly black surface layer which is rich in organic matter and ranges from 6 to 10 inches in thickness. The surface layer grades into a gray or yellowish-gray layer, 4 to 8 inches thick, which is more coherent and has a higher clay content. Beneath this is found steel gray or bluish-gray plastic or sticky clay, slightly mottled with yellow and rust-brown. The substratum consists of clayey glacial till containing more or less lime. This soil is relatively high in natural fertility when drained. The Brookston used was from the Michigan State College farm, Ingham County, East Lansing, Michigan.

3. Thomas loamy sand: The surface layer of this soil is black loamy sand, high in organic matter, and contains a considerable amount of light colored fine sand. At a depth of about 12 inches the surface layer grades into a thin layer of gray sandy clay which contains some fine gravel and some small shells or fragments of shells. Below 15 inches light brown, yellow, and gray plastic clay occurs. The soil is naturally poorly drained and is alkaline throughout the profile. Soil of this type was obtained near Saginaw Bay in Tuscola County, Michigan.

4. Wisner sandy loam: This soil consists of very dark gray sandy loam to a depth of 4 inches. Between 4 and 8 inches the material is lighter in color, and gray clay loam occurs at 8 to 15 inches. Small fragments of shells are present in the surface layers. A plastic clay, colored with light gray, yellow, and yellowish-brown, occurs at depths greater than 15 inches. It is naturally poorly drained and is alkaline throughout the profile. Surface soil of this type was obtained from the Wiergorski farm, Tuscola County, near Wisner, Michigan.

5. Miami loam: Under cultivation this soil type has a surface layer of light grayish-yellow loam which extends to an average depth of 12 inches. The subsoil, which ranges from 12 to 16 inches in thickness, is dull yellowish-brown heavy clay. The substratum is light grayish-yellow or light gray heavy calcareous glacial till. Soil of this type was

obtained from Tuscola County, about 6 miles northeast of Caro, Michigan.

A summary of some of the physical and chemical properties of these soils is shown in Table 1.

TABLE 1.—Some physical and chemical properties of the soils used.

Soil type	Particle size distribution			% organic matter	Original pH	Base exchange capacity (4)
	% sand (1)	% silt (2)	% clay (3)			
Oshtemo loamy sand	83.2	11.9	4.9	0.92	4.43	3.5
Brookston silt loam	28.0	64.8	7.2	5.06	6.10	22.7
Thomas loamy sand	88.0	10.9	1.1	6.89	7.00	20.4
Wisner sandy loam	58.0	39.0	3.0	5.96	7.40	13.9
Miami loam	49.8	47.0	3.2	2.29	7.25	10.2

(1) 1.0-0.05 mm.
(2) 0.05-0.002 mm.
(3) < 0.002 mm.
(4) milliequivalents per 100 grams of soil.

Analytical Procedures

The plant materials analyzed were oven dried at 90 to 95°C., then ground in a small Wiley Mill to pass through a 20 mesh seive. Before grinding, the tomato fruit was thinly sliced, placed on enamel trays and dried in the oven.

A one gram sample of the oven dried material was placed in a porcelain crucible, and 1 ml. of 1:1 H_2SO_4 was added followed by 3 ml. of distilled water to moisten the sample. It was then dried in an oven and ashed overnight in a muffle furnace at approximately 550°C. After cooling, the ash was moistened with a few drops of distilled water, followed by 3 ml. of concentrated HCl. This mixture was heated to boiling, diluted with a few ml. of distilled water and filtered. The filtrate was collected in a 50 ml. volumetric flask which was brought to volume with small, successive washings of the residue. The solution was thoroughly mixed and stored in a tightly stoppered, soft glass bottle.

Phosphorus, potassium, calcium, and magnesium were determined on aliquots of the plant ash extract. To determine phosphorus a colorimetric method using ammonium molybdate and the Fiske-Subbarow (10) reducing agent was followed. Potassium was determined colorimetrically by a modification of the method suggested by Lawton (16), which uses hexanitrodiphenylamine. For determining calcium a 10 ml. aliquot of the extract was precipitated as oxalate and then titrated with standardized $KMnO_4$. The titan yellow procedure, proposed by Peech and English (25), was followed for the magnesium determinations.

Total nitrogen was determined on the dried material according to the Kjeldahl-Gunning procedure (1).

SOME EFFECTS AND INTERRELATIONSHIPS OF NITROGEN, PHOSPHORUS, AND POTASSIUM LEVELS ON TOMATOES.

Agricultural scientists have recognized for nearly a century the mutual effect of one element upon another in the nutrition of plants. In this period, especially during the past three decades, a great volume of literature has accumulated on the subject. Thomas (35), in 1932, published an extensive review of literature regarding ionic antagonisms relative to plant nutrition giving particular emphasis to the reciprocal effects of nitrogen, phosphorus, and potassium. Prior to that time considerable attention had been devoted to the development of physiologically balanced nutrient solutions with the objective of discovering the optimum ratios between various nutritive elements.

Investigations into the interrelationship of nitrogen, phosphorus, and potassium have been generally approached by the use of nutrient solutions. Plants were grown either directly in such solutions or in sand cultures with frequent applications of nutrient solutions. Plant yields correlated with chemical analyses of plant tissues from plants grown under many different nutrient conditions have provided considerable insight into the interrelation between essential plant nutrients.

In recent years workers have emphasized the importance of maintaining the proper concentration and balance of available nutrient elements in the soil for the production of maximum crop yields. Spurway (33), in considering the available nutrients in soils, stresses the importance of "level and balance" for maximum production. This investigator points out that the same crop yield may be produced under many conditions of unbalanced fertility, but he suggests fertilizing in such a way as to both raise the level of the required nutrients and to bring them into better physiological balance for the plant.

The technique of foliar analysis has been valuable in studying and interpreting various interrelationships between nutrient elements. Salter and Ames (29), in 1928, suggested studying the availability of soil nutrients by means of chemical analyses of plants. Since that time there has been considerable interest in this technique as an aid in determining fertilizer needs.

Lundegardh (17) has pointed out that the fundamental concept of foliar analysis is that the amouht of nutrient salts absorbed by the plants reflects the availability of these salts in the soil under the actual growing conditions of the plant.

Thomas (36,37,38,39,40) has adopted the foliar analysis technique in the study of nutrient relationships of several crops. In the interpretation of such analyses, he recognizes the importance of two factors, "quantity" and "quality". For maximum growth each element must be above its critical concentration and at the same time be in proper balance with all other elements. This concept of nutrient element balance is essentially in harmony with the concepts of Shear, Crane, and Myers (30) who have conducted extensive investigations on the nutrition of tung trees.

Macy (21) and Ulrich (41) proposed the use of foliar analysis to determine the "critical percentage" or "critical concentration" of the various elements in plants. If plants showed a concentration below these critical values they would be expected to respond to an application of that element.

There is need for further research regarding desirable nutrient levels and nutrient relationships in both field and greenhouse soils. Much work remains to be done with regard to these relationships for specific crops. This is especially true with intensively grown crops such as greenhouse tomatoes.

Nitrogen, Phosphorus, and Potassium Levels on Oshtemo Loamy Sand

Experimental: A 5x5x5 factorial greenhouse experiment using Oshtemo loamy sand was conducted during the spring of 1948. Single plants, started in flats, were grown in 2-gallon glazed jars filled with 8 kilograms of screened, air dry soil. Nutrient levels in the soil extract were maintained at 0, 25, 50, 100 and 200 ppm of NO_3, 0, $2\frac{1}{2}$, 5, 10, and 25 ppm of phosphorus, and 0, 15, 30, 45, and 60 ppm of potassium. These nutrient levels are indicated by subscripts throughout this discussion. In all cases the zero level was the original soil with no addition of the element concerned. The untreated Oshtemo soil was extremely low in all three nutrients.

Because the Oshtemo soil had a pH of 4.4 an amount of precipitated $CaCO_3$ equivalent to one ton per acre was added to each jar. Manganese sulphate and magnesium sulphate, each equivalent to 100 pounds per acre, and sodium tetraborate ($Na_2B_4O_7$) equivalent to 5 pounds per acre were also applied to all jars. A summary of the varied treatments is given in Table 2.

Seeds of the Master Marglobe (Stokes) variety were planted in flats on January 3, 1948. Oshtemo loamy sand which received 200 pounds per acre of 2-16-8 fertilizer was used in the flats. The treatments were thoroughly mixed into the soil on January 9 to 12. Sufficient distilled water was added at this time to bring the soil in each jar to its moisture equivalent which was approximately 12 per cent moisture.

On February 7 the plants were transplanted from the flats to the jars. The roots of each plant were washed free of soil when transplanted. At this time the plants were uniform in size, about three inches in height, and had started their second pair of true leaves. All plants were a normal green color and healthy in appearance.

The soils were tested frequently during the growth of the crop and additional nutrients were applied as needed to maintain the original levels.

The fruits were picked as they ripened. When the experiment was terminated on July 6 the remaining green fruits were picked and included in the total yields.

TABLE 2.—A summary of the nitrogen, phosphorus, and potassium treatments applied to Oshtemo loamy sand.

Nutrient level	C.P. reagent used	Gm. added per jar	Pounds per acre equivalent
N_0	NH_4NO_3	0.00	0.0
N_{25}	"	1.43	357.5
N_{50}	"	2.86	715.0
N_{100}	"	5.72	1430.0
N_{200}	"	11.44	2860.0
P_0	$Ca(H_2PO_4)_2 \cdot H_2O$	0.00	0.0
$P_{2\frac{1}{2}}$	"	3.90	976.0
P_5	"	5.87	1466.5
P_{10}	"	8.82	2206.0
P_{25}	"	14.32	3580.0
K_0	K_2SO_4	0.00	0.0
K_{15}	"	2.56	640.0
K_{30}	"	4.80	1200.0
K_{45}	"	8.96	2240.0
K_{60}	"	13.12	3280.0

Results and Discussion:

Conductivity and pH of the Soil: Many of the fertilizer applications in this study were extremely high. To obtain information regarding the effect of total soluble salt concentrations on plant growth, conductivity measurements were made on soil samples collected at the time of transplanting. Conductivity was measured with a Solu-Bridge, type RD, manufactured by Industrial Instruments Inc., Jersey City, New Jersey. To 50 grams of air dry soil, 100 ml. of distilled water was added and the mixture was stirred for 5 minutes. After settling for 2 minutes the liquid was decanted and conductivity was determined on the decanted liquid.

These results, presented in Table 3, show that at the time of sampling the nitrogen, phosphorus, and potassium fertilizers had little consistent effect on the pH of the soil, but they had a marked influence on the conductivity values. The potassium sulphate and ammonium nitrate treatments caused noticeable increases in the conductivity values but the phosphate treatments did not.

The only plants in the experiment which showed any indication of an excessive soluble salt concentration were those that received the highest application of ammonium nitrate. The specific conductivity of the decanted liquid from soil which received this treatment varied from 50 to 70×10^{-5} mhos at the low potassium levels to 100 to 140×10^{-5} mhos at the highest levels of potassium. Within

TABLE 3.—The effect of treatment on conductivity and pH of Oshtemo loamy sand.

Treatment	Conductivity of soil solution *	pH	Treatment	Conductivity of soil solution *	pH
$N_0P_0K_0$	12	6.6	$N_{25}P_0K_0$	17	6.4
$N_0P_0K_{15}$	19	6.5	$N_{25}P_0K_{15}$	30	6.2
$N_0P_0K_{30}$	26	6.4	$N_{25}P_0K_{30}$	38	6.2
$N_0P_0K_{45}$	54	6.3	$N_{25}P_0K_{45}$	60	6.2
$N_0P_0K_{60}$	69	6.3	$N_{25}P_0K_{60}$	75	6.1
$N_0P_{2\frac{1}{2}}K_0$	13	6.7	$N_{25}P_{2\frac{1}{2}}K_0$	25	6.3
$N_0P_{2\frac{1}{2}}K_{15}$	21	6.6	$N_{25}P_{2\frac{1}{2}}K_{15}$	31	6.2
$N_0P_{2\frac{1}{2}}K_{30}$	32	6.5	$N_{25}P_{2\frac{1}{2}}K_{30}$	43	6.1
$N_0P_{2\frac{1}{2}}K_{45}$	49	6.4	$N_{25}P_{2\frac{1}{2}}K_{45}$	47	6.1
$N_0P_{2\frac{1}{2}}K_{60}$	55	6.4	$N_{25}P_{2\frac{1}{2}}K_{60}$	58	6.3
$N_0P_5K_0$	12	6.7	$N_{25}P_5K_0$	20	6.2
$N_0P_5K_{15}$	28	6.5	$N_{25}P_5K_{15}$	30	6.2
$N_0P_5K_{30}$	29	6.4	$N_{25}P_5K_{30}$	43	6.1
$N_0P_5K_{45}$	49	6.3	$N_{25}P_5K_{45}$	50	6.1
$N_0P_5K_{60}$	58	6.4	$N_{25}P_5K_{60}$	73	6.1
$N_0P_{10}K_0$	12	6.6	$N_{25}P_{10}K_0$	31	6.1
$N_0P_{10}K_{15}$	19	6.5	$N_{25}P_{10}K_{15}$	40	6.1
$N_0P_{10}K_{30}$	30	6.4	$N_{25}P_{10}K_{30}$	61	6.0
$N_0P_{10}K_{45}$	46	6.3	$N_{25}P_{10}K_{45}$	50	6.0
$N_0P_{10}K_{60}$	60	6.4	$N_{25}P_{10}K_{60}$	65	6.2
$N_0P_{25}K_0$	13	6.4	$N_{25}P_{25}K_0$	24	6.1
$N_0P_{25}K_{15}$	20	6.3	$N_{25}P_{25}K_{15}$	33	6.0
$N_0P_{25}K_{30}$	30	6.3	$N_{25}P_{25}K_{30}$	44	6.0
$N_0P_{25}K_{45}$	50	6.2	$N_{25}P_{25}K_{45}$	66	6.0
$N_0P_{25}K_{60}$	65	6.2	$N_{25}P_{25}K_{60}$	86	5.9

* Specific conductivity x 10^5 mhos at 25°C.

TABLE 3.—(continued) The effect of treatment on conductivity and pH of Oshtemo loamy sand.

Treatment	Conductivity of soil solution *	pH	Treatment	Conductivity of soil solution *	pH
$N_{50}P_0K_0$	32	5.9	$N_{100}P_0K_0$	59	6.0
$N_{50}P_0K_{15}$	36	5.9	$N_{100}P_0K_{15}$	46	6.1
$N_{50}P_0K_{30}$	47	5.9	$N_{100}P_0K_{30}$	71	6.0
$N_{50}P_0K_{45}$	84	5.9	$N_{100}P_0K_{45}$	85	6.1
$N_{50}P_0K_{60}$	84	6.0	$N_{100}P_0K_{60}$	84	6.1
$N_{50}P_{2\frac{1}{2}}K_0$	39	6.0	$N_{100}P_{2\frac{1}{2}}K_0$	35	6.1
$N_{50}P_{2\frac{1}{2}}K_{15}$	52	6.0	$N_{100}P_{2\frac{1}{2}}K_{15}$	70	6.0
$N_{50}P_{2\frac{1}{2}}K_{30}$	58	6.0	$N_{100}P_{2\frac{1}{2}}K_{30}$	73	6.1
$N_{50}P_{2\frac{1}{2}}K_{45}$	59	6.0	$N_{100}P_{2\frac{1}{2}}K_{45}$	84	6.0
$N_{50}P_{2\frac{1}{2}}K_{60}$	78	6.0	$N_{100}P_{2\frac{1}{2}}K_{60}$	96	6.0
$N_{50}P_5K_0$	36	6.0	$N_{100}P_5K_0$	61	6.1
$N_{50}P_5K_{15}$	43	6.0	$N_{100}P_5K_{15}$	62	6.1
$N_{50}P_5K_{30}$	53	5.9	$N_{100}P_5K_{30}$	73	6.1
$N_{50}P_5K_{45}$	62	6.0	$N_{100}P_5K_{45}$	89	6.0
$N_{50}P_5K_{60}$	65	6.1	$N_{100}P_5K_{60}$	85	6.0
$N_{50}P_{10}K_0$	37	5.9	$N_{100}P_{10}K_0$	44	6.1
$N_{50}P_{10}K_{15}$	42	6.0	$N_{100}P_{10}K_{15}$	55	6.1
$N_{50}P_{10}K_{30}$	47	5.9	$N_{100}P_{10}K_{30}$	67	6.0
$N_{50}P_{10}K_{45}$	70	5.9	$N_{100}P_{10}K_{45}$	72	6.0
$N_{50}P_{10}K_{60}$	95	5.9	$N_{100}P_{10}K_{60}$	95	6.0
$N_{50}P_{25}K_0$	29	6.0	$N_{100}P_{25}K_0$	44	6.1
$N_{50}P_{25}K_{15}$	45	6.0	$N_{100}P_{25}K_{15}$	47	6.1
$N_{50}P_{25}K_{30}$	50	5.9	$N_{100}P_{25}K_{30}$	65	6.0
$N_{50}P_{25}K_{45}$	60	5.9	$N_{100}P_{25}K_{45}$	75	6.0
$N_{50}P_{25}K_{60}$	87	5.9	$N_{100}P_{25}K_{60}$	95	6.0

* Specific conductivity x 10^5 mhos at 25°C.

TABLE 3.—(continued) The effect of treatment on conductivity and pH of Oshtemo loamy sand.

Treatment	Conductivity of soil solution *	pH	Treatment	Conductivity of soil solution *	pH
$N_{200}P_0K_0$	70	6.3	$N_{200}P_5K_{45}$	120	6.1
$N_{200}P_0K_{15}$	82	6.2	$N_{200}P_5K_{60}$	88	6.1
$N_{200}P_0K_{30}$	70	6.3	$N_{200}P_{10}K_0$	57	6.2
$N_{200}P_0K_{45}$	100	6.2	$N_{200}P_{10}K_{15}$	60	6.2
$N_{200}P_0K_{60}$	110	6.4	$N_{200}P_{10}K_{30}$	90	6.3
$N_{200}P_{2\frac{1}{2}}K_0$	71	6.3	$N_{200}P_{10}K_{45}$	140	6.0
$N_{200}P_{2\frac{1}{2}}K_{15}$	73	6.4	$N_{200}P_{10}K_{60}$	125	6.0
$N_{200}P_{2\frac{1}{2}}K_{30}$	77	6.2	$N_{200}P_{25}K_0$	72	6.2
$N_{200}P_{2\frac{1}{2}}K_{45}$	108	6.2	$N_{200}P_{25}K_{15}$	68	6.6
$N_{200}P_{2\frac{1}{2}}K_{60}$	110	6.2	$N_{200}P_{25}K_{30}$	65	6.2
$N_{200}P_5K_0$	67	6.2	$N_{200}P_{25}K_{45}$	88	6.0
$N_{200}P_5K_{15}$	50	6.3	$N_{200}P_{25}K_{60}$	130	5.9
$N_{200}P_5K_{30}$	100	6.2			

*Specific conductivity x 10^5 mhos at 25°C.

this range all plants showed similar toxicity symptoms. Since the lower values of this high nitrogen group were lower than the values obtained for some soils at lower nitrogen levels, where normal growth occurred, it was concluded that the toxicity was related to the actual NH_4 or NO_3 concentration rather than to the total soluble salt concentration.

Dry Weight and Fruit Yield: The dry weight and fruit yield per plant, as a result of each treatment, is presented in Table 4. Both factors were analyzed statistically by the analysis of variance. For both dry weight and fruit yield, the effects of nitrogen, phosphorus, and potassium levels were highly significant as were also the NP, NK, and PK interactions.

The levels of nitrogen were more influential on dry weight and fruit yields than were the levels of either of the other elements. There was a highly significant difference between each of the five levels of nitrogen on both factors. As Table 5 and Fig. 1 show, N_{50} resulted in the highest average dry weight. However, during the early stages of growth the plants at N_{25} were largest, as illustrated in Fig. 2. Part of this difference in final dry weight is attributed to the difficulty encountered in keeping the nitrogen level from dropping below 25 ppm when the plants were large and actively growing. There was a marked depression of growth where nitrogen levels were above 50 ppm in the soil extract, as Fig. 1 shows. Severe toxicity

TABLE 4.—The effect of treatment on dry weight and fruit yield of tomato plants.

Treatment	Dry weight of plant (gms.)	Yield of fruit (gms.)	Treatment	Dry weight of plant (gms.)	Yield of fruit (gms.)
$N_0P_0K_0$	6	55.5	$N_{25}P_0K_0$	35	377.2
$N_0P_0K_{15}$	8	39.4	$N_{25}P_0K_{15}$	47	442.7
$N_0P_0K_{30}$	6	64.3	$N_{25}P_0K_{30}$	50	261.2
$N_0P_0K_{45}$	7	76.3	$N_{25}P_0K_{45}$	34	366.3
$N_0P_0K_{60}$	11	51.4	$N_{25}P_0K_{60}$	49	207.3
$N_0P_{2\frac{1}{2}}K_0$	6	21.5	$N_{25}P_{2\frac{1}{2}}K_0$	28	70.2
$N_0P_{2\frac{1}{2}}K_{15}$	6	77.3	$N_{25}P_{2\frac{1}{2}}K_{15}$	84	555.9
$N_0P_{2\frac{1}{2}}K_{30}$	13	0.0	$N_{25}P_{2\frac{1}{2}}K_{30}$	96	599.0
$N_0P_{2\frac{1}{2}}K_{45}$	7	90.2	$N_{25}P_{2\frac{1}{2}}K_{45}$	70	941.3
$N_0P_{2\frac{1}{2}}K_{60}$	9	99.7	$N_{25}P_{2\frac{1}{2}}K_{60}$	82	784.9
$N_0P_5K_0$	3	84.6	$N_{25}P_5K_0$	19	220.1
$N_0P_5K_{15}$	9	93.2	$N_{25}P_5K_{15}$	84	513.2
$N_0P_5K_{30}$	8	63.2	$N_{25}P_5K_{30}$	99	721.4
$N_0P_5K_{45}$	7	50.2	$N_{25}P_5K_{45}$	78	945.2
$N_0P_5K_{60}$	7	88.5	$N_{25}P_5K_{60}$	85	625.4
$N_0P_{10}K_0$	7	59.1	$N_{25}P_{10}K_0$	21	68.7
$N_0P_{10}K_{15}$	8	102.6	$N_{25}P_{10}K_{15}$	75	940.0
$N_0P_{10}K_{30}$	10	96.4	$N_{25}P_{10}K_{30}$	77	979.4
$N_0P_{10}K_{45}$	6	74.7	$N_{25}P_{10}K_{45}$	81	878.3
$N_0P_{10}K_{60}$	9	81.4	$N_{25}P_{10}K_{60}$	43	925.0
$N_0P_{25}K_0$	5	0.0	$N_{25}P_{25}K_0$	30	177.8
$N_0P_{25}K_{15}$	9	99.5	$N_{25}P_{25}K_{15}$	78	949.8
$N_0P_{25}K_{30}$	7	193.9	$N_{25}P_{25}K_{30}$	91	650.7
$N_0P_{25}K_{45}$	6	128.4	$N_{25}P_{25}K_{45}$	82	1015.0
$N_0P_{25}K_{60}$	5	0.0	$N_{25}P_{25}K_{60}$	73	924.4

TABLE 4.—(continued) The effect of treatment on dry weight and fruit yield of tomato plants.

Treatment	Dry weight of plant (gms.)	Yield of fruit (gms.)	Treatment	Dry weight of plant (gms.)	Yield of fruit (gms.)
$N_{50}P_0K_0$	13	92.8	$N_{100}P_0K_0$	1	0.0
$N_{50}P_0K_{15}$	8	0.0	$N_{100}P_0K_{15}$	26	35.2
$N_{50}P_0K_{30}$	33	108.3	$N_{100}P_0K_{30}$	3	0.0
$N_{50}P_0K_{45}$	35	133.9	$N_{100}P_0K_{45}$	3	0.0
$N_{50}P_0K_{60}$	10	61.5	$N_{100}P_0K_{60}$	3	12.5
$N_{50}P_{2\frac{1}{2}}K_0$	26	102.2	$N_{100}P_{2\frac{1}{2}}K_0$	30	190.3
$N_{50}P_{2\frac{1}{2}}K_{15}$	92	465.1	$N_{100}P_{2\frac{1}{2}}K_{15}$	55	287.5
$N_{50}P_{2\frac{1}{2}}K_{30}$	93	615.3	$N_{100}P_{2\frac{1}{2}}K_{30}$	73	271.2
$N_{50}P_{2\frac{1}{2}}K_{45}$	106	425.6	$N_{100}P_{2\frac{1}{2}}K_{45}$	66	518.3
$N_{50}P_{2\frac{1}{2}}K_{60}$	84	628.7	$N_{100}P_{2\frac{1}{2}}K_{60}$	71	389.0
$N_{50}P_5K_0$	22	142.7	$N_{100}P_5K_0$	20	158.2
$N_{50}P_5K_{15}$	86	488.9	$N_{100}P_5K_{15}$	50	300.0
$N_{50}P_5K_{30}$	107	617.4	$N_{100}P_5K_{30}$	64	532.2
$N_{50}P_5K_{45}$	111	734.9	$N_{100}P_5K_{45}$	72	685.3
$N_{50}P_5K_{60}$	96	572.9	$N_{100}P_5K_{60}$	82	453.8
$N_{50}P_{10}K_0$	22	120.9	$N_{100}P_{10}K_0$	34	114.0
$N_{50}P_{10}K_{15}$	71	811.6	$N_{100}P_{10}K_{15}$	75	535.4
$N_{50}P_{10}K_{30}$	111	705.7	$N_{100}P_{10}K_{30}$	96	365.2
$N_{50}P_{10}K_{45}$	92	958.6	$N_{100}P_{10}K_{45}$	85	610.8
$N_{50}P_{10}K_{60}$	82	950.2	$N_{100}P_{10}K_{60}$	100	429.9
$N_{50}P_{25}K_0$	23	101.2	$N_{100}P_{25}K_0$	21	43.4
$N_{50}P_{25}K_{15}$	77	848.0	$N_{100}P_{25}K_{15}$	32	513.9
$N_{50}P_{25}K_{30}$	99	577.9	$N_{100}P_{25}K_{30}$	69	541.1
$N_{50}P_{25}K_{45}$	121	659.3	$N_{100}P_{25}K_{45}$	73	357.9
$N_{50}P_{25}K_{60}$	126	529.9	$N_{100}P_{25}K_{60}$	83	388.3

TABLE 4.—(continued) The effect of treatment on dry weight and fruit yield of tomato plants.

Treatment	Dry weight of plant (gms.)	Yield of fruit (gms.)	Treatment	Dry weight of plant (gms.)	Yield of fruit (gms.)
$N_{200}P_0K_0$	0	0.0	$N_{200}P_5K_{45}$	66	256.4
$N_{200}P_0K_{15}$	0	0.0	$N_{200}P_5K_{60}$	54	340.6
$N_{200}P_0K_{30}$	0	0.0	$N_{200}P_{10}K_0$	39	91.0
$N_{200}P_0K_{45}$	0	0.0	$N_{200}P_{10}K_{15}$	61	241.8
$N_{200}P_0K_{60}$	0	0.0	$N_{200}P_{10}K_{30}$	62	317.6
$N_{200}P_{2\frac{1}{2}}K_0$	42	120.9	$N_{200}P_{10}K_{45}$	31	43.6
$N_{200}P_{2\frac{1}{2}}K_{15}$	55	153.8	$N_{200}P_{10}K_{60}$	52	242.3
$N_{200}P_{2\frac{1}{2}}K_{30}$	51	328.2	$N_{200}P_{25}K_0$	24	28.8
$N_{200}P_{2\frac{1}{2}}K_{45}$	60	115.1	$N_{200}P_{25}K_{15}$	44	182.5
$N_{200}P_{2\frac{1}{2}}K_{60}$	53	353.5	$N_{200}P_{25}K_{30}$	50	521.5
$N_{200}P_5K_0$	40	110.8	$N_{200}P_{25}K_{45}$	15	153.7
$N_{200}P_5K_{15}$	55	215.8	$N_{200}P_{25}K_{60}$	45	265.9
$N_{200}P_5K_{30}$	24	63.6			

TABLE 5.—Analysis of variance of dry weight of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
Total	124	150,663.4	
N levels	4	62,046.2	15,511.6**
4 N_0 vs. $N_{25}+N_{50}+N_{100}+N_{200}$	1	46,214.5	46,214.5**
3 N_{25} vs. $N_{50}+N_{100}+N_{200}$	1	2,225.0	2,225.0**
2 N_{50} vs. $N_{100}+N_{200}$	1	10,956.8	10,956.8**
N_{100} vs. N_{200}	1	2,649.9	2,649.9**
P levels	4	28,883.6	7,220.9**
4 P_0 vs. $P_{2\frac{1}{2}}+P_5+P_{10}+P_{25}$	1	28,758.5	28,758.5**
3 $P_{2\frac{1}{2}}$ vs. $P_5+P_{10}+P_{25}$	1	25.8	25.8
2 P_5 vs. $P_{10}+P_{25}$	1	22.4	22.4
P_{10} vs. P_{25}	1	76.9	76.9
K levels	4	20,600.2	5,150.1**
4 K_0 vs. $K_{15}+K_{30}+K_{45}+K_{60}$	1	19,807.2	19,807.2**
3 K_{15} vs. $K_{30}+K_{45}+K_{60}$	1	630.8	630.8*
2 K_{30} vs. $K_{45}+K_{60}$	1	162.2	162.2
K_{45} vs. K_{60}	1	0.0	0.0
NP	16	13,736.8	858.6**
NK	16	12,963.4	810.2**
PK	16	4,733.2	295.8**
NPK (error)	64	7,700.0	120.3

* Significant at 5% point.
** Significant at 1% point.

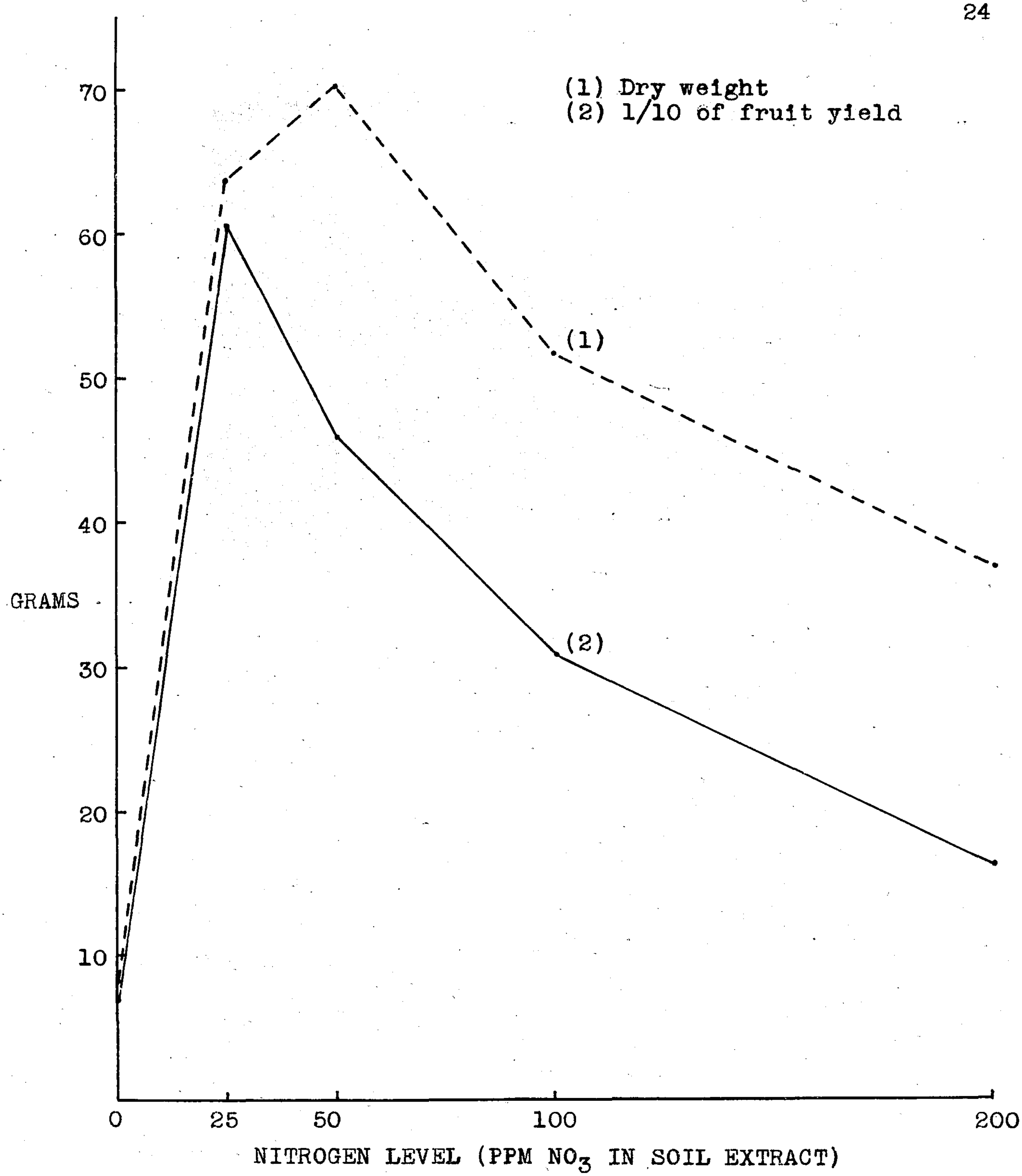

FIG. 1.—Effect of nitrogen levels on the average dry weight and fruit yield of tomatoes.

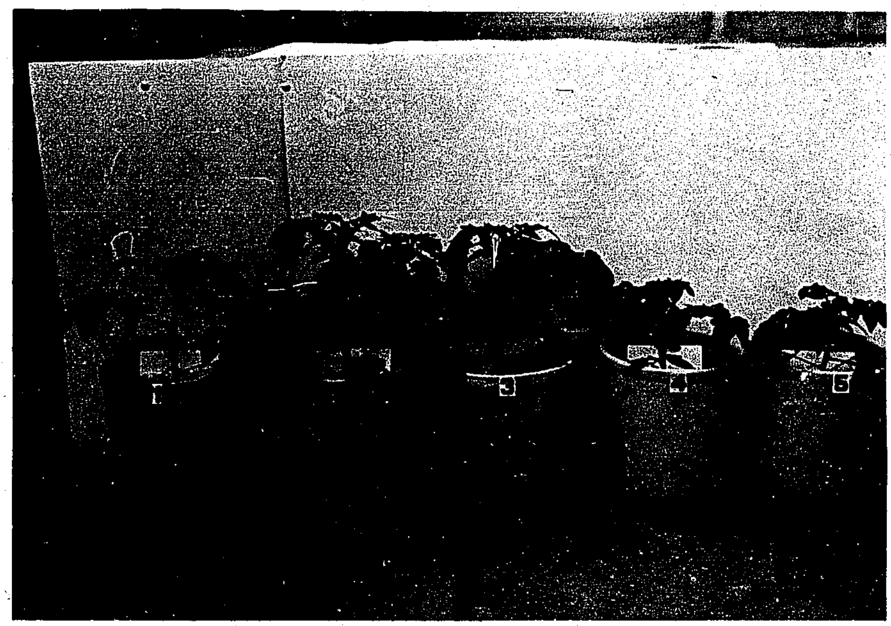

FIG. 2.—The effect of nitrogen levels on plants adequately supplied with phosphorus and potassium. Treatments are: 1-$N_0P_{10}K_{45}$, 2-$N_{25}P_{10}K_{45}$, 3-$N_{50}P_{10}K_{45}$, 4-$N_{100}P_{10}K_{45}$, 5-$N_{200}P_{10}K_{45}$.

symptoms occurred at the N_{200} level. The plants were extremely stunted in growth, had a soft, semi-wilted appearance, and were deep green in color. This is illustrated in Fig. 2, jar 5.

Symptoms of nitrogen starvation occurred only on those plants that received the N_0 treatment. Six weeks after transplanting, the color of all plants in this group began to fade from green to light yellow. The symptoms appeared on the older leaflets first and progressed to the younger ones. Where there was only a moderate deficiency the leaflets were uniformly light green in color. In the advanced stages, however, the veins were distinctly purple in color while the interveinous tissue remained a faded yellow. During this advanced stage of nitrogen starvation the plants had a very tough, wiry texture in comparison to plants which received nitrogen. The occurrence and severity of these symptoms were unrelated to phosphorus and potassium treatments. The marked difference obtained between the N_0 and N_{25} treatments is apparent from Fig. 3.

FIG. 3.—Plants on the left received no nitrogen while those on the right received the N_{25} treatment. Both groups received various phosphorus and potassium treatments.

Fruit yields were closely related to the size of plants in this experiment. Fig. 1 and Table 6 show that N_{25} resulted in the highest fruit yield per plant and that no nitrogen, as well as excessive nitrogen, resulted in decreased fruit production.

A marked response to phosphorus was obtained in this experiment. When dry weights are considered, the only significant difference between levels was between none and some phosphorus. This is shown in Table 5 and Fig. 4. Levels of $P_{2\frac{1}{2}}$, P_5, P_{10}, and P_{25} were equally effective in production of dry weight. Fruit yields were also increased by phosphorus treatments. As Table 6 and Fig. 4 show, P_5, P_{10}, and P_{25} resulted in the highest yields, yet these three levels were equally effective.

Distinct phosphorus starvation symptoms occurred within ten days after transplanting on all plants that did not receive phosphorus fertilizer. These plants were spindling, stunted, and dark green with distinct purpling of the under side of the leaves. The purpling extended over both the veins and the interveinous tissue. As the roots became better established, many of the phosphorus starved plants lost their purple color and grew to a fair size. Symptoms similar to these have been described by MacGillivray (20) and Cook and Millar (8) for phosphorus starvation of tomatoes.

A definite NP interaction was present in this experiment. Increased amounts of phosphorus tended to counteract

TABLE 6.—Analysis of variance of fruit yield of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
Total	124	10,974,223.5	
N levels	4	4,685,941.7	1,171,485.4**
4 N_0 vs. $N_{25}+N_{50}+N_{100}+N_{200}$	1	1,948,065.8	1,948,065.8**
3 N_{25} vs. $N_{50}+N_{100}+N_{200}$	1	1,640,861.8	1,640,861.8**
2 N_{50} vs. $N_{100}+N_{200}$	1	825,282.2	825,282.2**
N_{100} vs. N_{200}	1	271,731.9	271,731.9**
P levels	4	1,746,054.3	436,513.6**
4 P_0 vs. $P_{2\frac{1}{2}}+P_5+P_{10}+P_{25}$	1	1,594,656.3	1,594,656.3**
3 $P_{2\frac{1}{2}}$ vs. $P_5+P_{10}+P_{25}$	1	95,815.4	95,815.4**
2 P_5 vs. $P_{10}+P_{25}$	1	39,690.7	39,690.7
P_{10} vs. P_{25}	1	15,891.9	15,891.9
K levels	4	1,541,390.4	385,347.6**
4 K_0 vs. $K_{15}+K_{30}+K_{45}+K_{60}$	1	1,502,232.5	1,502,232.5**
3 K_{15} vs. $K_{30}+K_{45}+K_{60}$	1	13,895.1	13,895.1
2 K_{30} vs. $K_{45}+K_{60}$	1	8,616.9	8,616.9
K_{45} vs. K_{60}	1	16,645.8	16,645.8
NP	16	690,314.8	43,144.7**
NK	16	855,183.7	53,449.0**
PK	16	647,019.5	40,438.7**
NPK (error)	64	808,319.1	12,630.0

** Significant at 1% point.

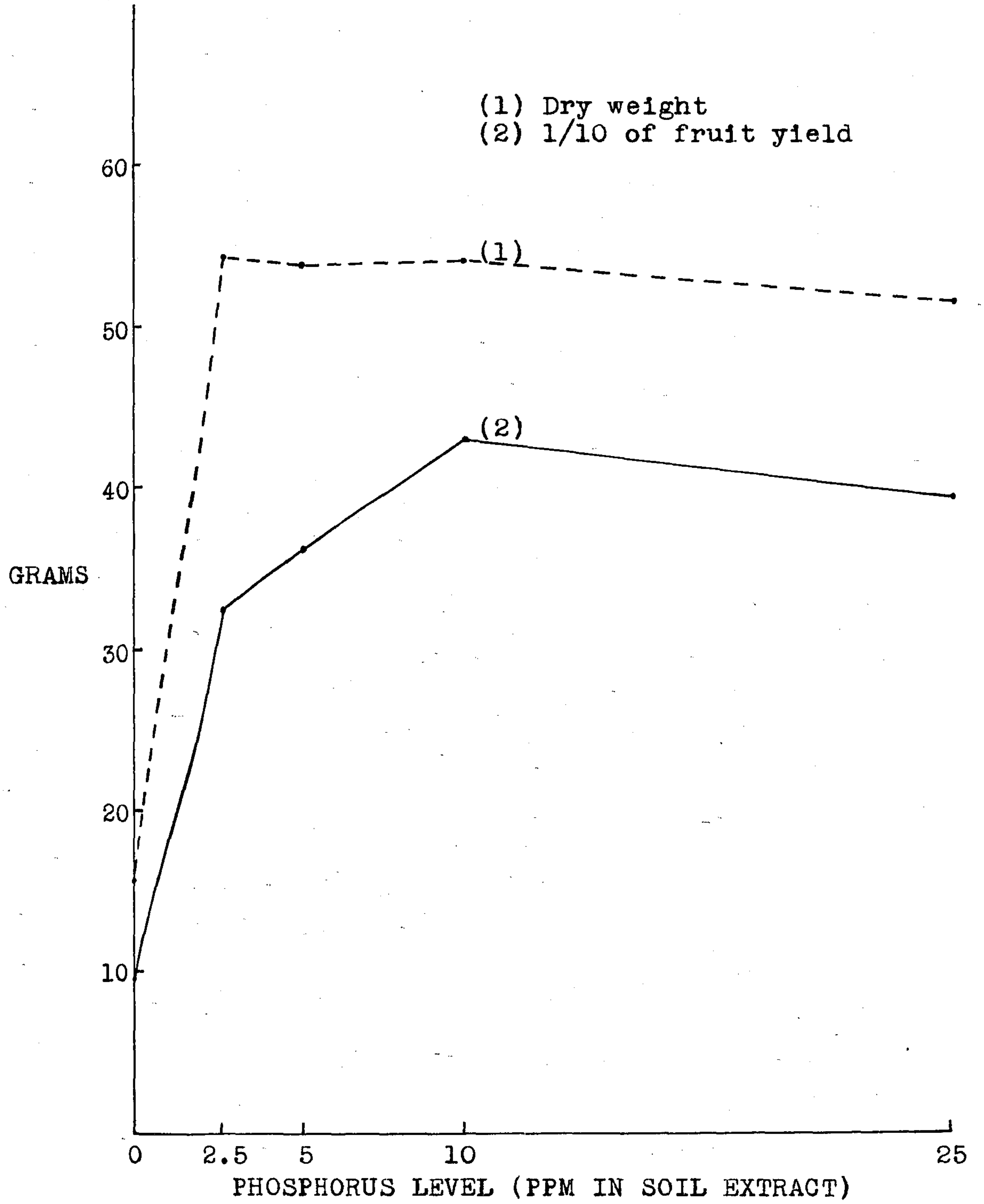

FIG. 4.—Effect of phosphorus levels on the average dry weight and fruit yield of tomatoes.

the toxic effects of excessive nitrogen. It can be seen in Fig. 5 that in the presence of excessive nitrogen, at least during the early stages of development, growth was consistently improved by the higher phosphate levels. Similar results have been reported by Emmert (9). This investigator, studying the nutrition of the tomato, found that the effects of nitrogen are governed by the levels of phosphorus in the plant. His experiments also showed that there is a tendency for the harmful effects of high nitrates in the growth medium to be offset by the presence of a high phosphorus level.

FIG. 5.--The effect of increased phosphorus levels in the presence of adequate potassium and excessive nitrogen. Treatments are: 1-$N_{200}P_0K_{30}$, 2-$N_{200}P_{2\frac{1}{2}}K_{30}$, 3-$N_{200}P_5K_{30}$, 4-$N_{200}P_{10}K_{30}$, 5-$N_{200}P_{25}K_{30}$.

A marked NP interaction was also present at low phosphorus levels. At P_0 the phosphorus deficiency symptoms occurred earlier and became more severe as nitrogen was increased. The plants in Fig. 6 present a good example of the inverse relationship of these two elements. The potassium

FIG. 6.—The effect of increased nitrogen levels in the absence of adequate phosphorus and potassium. Treatments are: 1-$N_0P_0K_0$, 2-$N_{25}P_0K_0$, 3-$N_{50}P_0K_0$, 4-$N_{100}P_0K_0$, 5-$N_{200}P_0K_0$.

levels had no apparent influence on this relationship. As the experiment progressed the plants that received N_0P_0 lost their purple color, developed normally to the limit of their available nitrogen supply, and produced a single small fruit on each plant. These plants were essentially the same size as the others within the N_0 group. In this case nitrogen was the most limiting growth factor.

Where moderate amounts of nitrogen were applied without the addition of phosphorus the plants eventually lost their purple leaf colorations, made more growth than where nitrogen was lacking, and produced a few fruits. However, where the nitrogen level was kept at 100 or 200 ppm, in the presence of very low available phosphorus, the plants continued to show extreme phosphorus deficiency symptoms throughout the study. The five plants within the $N_{200}P_0$ group made little growth and died before the experiment was completed. Fig. 7 illustrates these relationships.

FIG. 7.—The effect of increased nitrogen levels in the absence of adequate phosphorus. Treatments are: 1-$N_0P_0K_{60}$, 2-$N_{25}P_0K_{60}$, 3-$N_{50}P_0K_{60}$, 4-$N_{100}P_0K_{60}$, 5-$N_{200}P_0K_{60}$. This picture was taken two months later than the one in Fig. 6.

Statistical analyses of dry weight and fruit yield data showed that the NP interaction was highly significant in both groups of data. A segregation of the 16 degrees of freedom of each of these interactions is shown in Tables 7 and 8 respectively. The combinations of levels which caused the significant NP interaction are indicated in these tables. With the combinations designated as significant it can be concluded that the plants responded differently to nitrogen levels in the presence of the phosphorus levels concerned. In considering these interactions one must be cautioned that these data represent the results of only one crop of tomatoes grown on one particular soil type with extreme treatments applied. Nevertheless, they do show the harmful effect of excessive nitrogen, especially when it occurs in the absence of adequate phosphorus.

Fertilizing with potassium resulted in significant increases in both dry weight and fruit yield. During the early stages of growth, those plants which received K_{45} were larger than those at any other potassium level, as indicated in Fig. 8. It can be seen from Tables 5 and 6 and Fig. 9 that nearly all of the variance with both factors at time of harvest was between K_0 and the average of the other four levels. As the fruit yield data show, potassium levels greater than K_{15} were not effective in causing further increases in yield. The dry weights were greatly increased with the addition of the first increment of potassium, and

TABLE 7.—A statistical analysis of NP interaction of dry weight of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
NP	16	13,736.8	858.6**
[4 $N_0-N_{25}-N_{50}-N_{100}-N_{200}$] [4 $P_0-P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	7,284.7	7,284.7**
" [3 $P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	0.01	0.01
" [2 $P_5-P_{10}-P_{25}$]	1	10.1	10.1
" [$P_{10}-P_{25}$]	1	2.4	2.4
[3 $N_{25}-N_{50}-N_{100}-N_{200}$] [4 $P_0-P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	2,502.7	2,502.7**
" [3 $P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	47.5	47.5
" [2 $P_5-P_{10}-P_{25}$]	1	179.2	179.2
" [$P_{10}-P_{25}$]	1	662.7	662.7*
[2 $N_{50}-N_{100}-N_{200}$] [4 $P_0-P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	371.3	371.3
" [3 $P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	51.4	51.4
" [2 $P_5-P_{10}-P_{25}$]	1	32.9	32.9
[$P_{10}-P_{25}$]	1	1,653.8	1,653.8**
[$N_{100}-N_{200}$] [4 $P_0-P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	169.3	169.3
" [3 $P_{2\frac{1}{2}}-P_5-P_{10}-P_{25}$]	1	307.2	307.2
" [2 $P_5-P_{10}-P_{25}$]	1	360.2	360.2
" [$P_{10}-P_{25}$]	1	101.3	101.3

* Significant at 5% point.
** Significant at 1% point.

TABLE 8.—A statistical analysis of NP interaction of fruit yield of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
NP	16	690,314.9	43,144.7**
[4 N_0-N_{25}-N_{50}-N_{100}-N_{200}] [4 P_0-$P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	349,880.6	349,880.6**
" [3 $P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	10,880.5	10,880.5
" [2 P_5-P_{10}-P_{25}]	1	7,052.1	7,052.1
" [P_{10}-P_{25}]	1	4,318.9	4,318.9
[3 N_{25}-N_{50}-N_{100}-N_{200}] [4 P_0-$P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	141.9	141.9
" [3 $P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	4,062.2	4,062.2
" [2 P_5-P_{10}-P_{25}]	1	33,458.5	33,458.5
" [P_{10}-P_{25}]	1	3,042.1	3,042.1
[2 N_{50}-N_{100}-N_{200}] [4 P_0-$P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	91,259.3	91,259.3**
" [3 $P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	24,948.4	24,948.4
" [2 P_5-P_{10}-P_{25}]	1	35,960.9	35,960.9
" [P_{10}-P_{25}]	1	46,303.7	46,303.7
[N_{100}-N_{200}] [4 P_0-$P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	59,426.3	59,426.3*
" [3 $P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}]	1	6,736.5	6,736.5
" [2 P_5-P_{10}-P_{25}]	1	3,735.1	3,735.1
" [P_{10}-P_{25}]	1	9,107.9	9,107.9

* Significant at 5% point.
** Significant at 1% point.

FIG. 8.—The effect of increased potassium levels in the presence of adequate nitrogen and phosphorus. Treatments are: 1-$N_{25}P_{2\frac{1}{2}}K_0$, 2-$N_{25}P_{2\frac{1}{2}}K_{15}$, 3-$N_{25}P_{2\frac{1}{2}}K_{30}$, 4-$N_{25}P_{2\frac{1}{2}}K_{45}$, 5-$N_{25}P_{2\frac{1}{2}}K_{60}$.

there was some indication of further benefit from the second increment. Amounts above this level resulted in no further increase in growth. The plants tolerated the two higher levels but they did not require them.

Deficiency symptoms of potassium occurred only on those plants that did not receive potassium fertilizer. These symptoms appeared within three weeks after transplanting. Plants which showed potassium starvation were drawfed in appearance, had unusually short internodes, and were yellow at the tips and margins of the leaflets. These

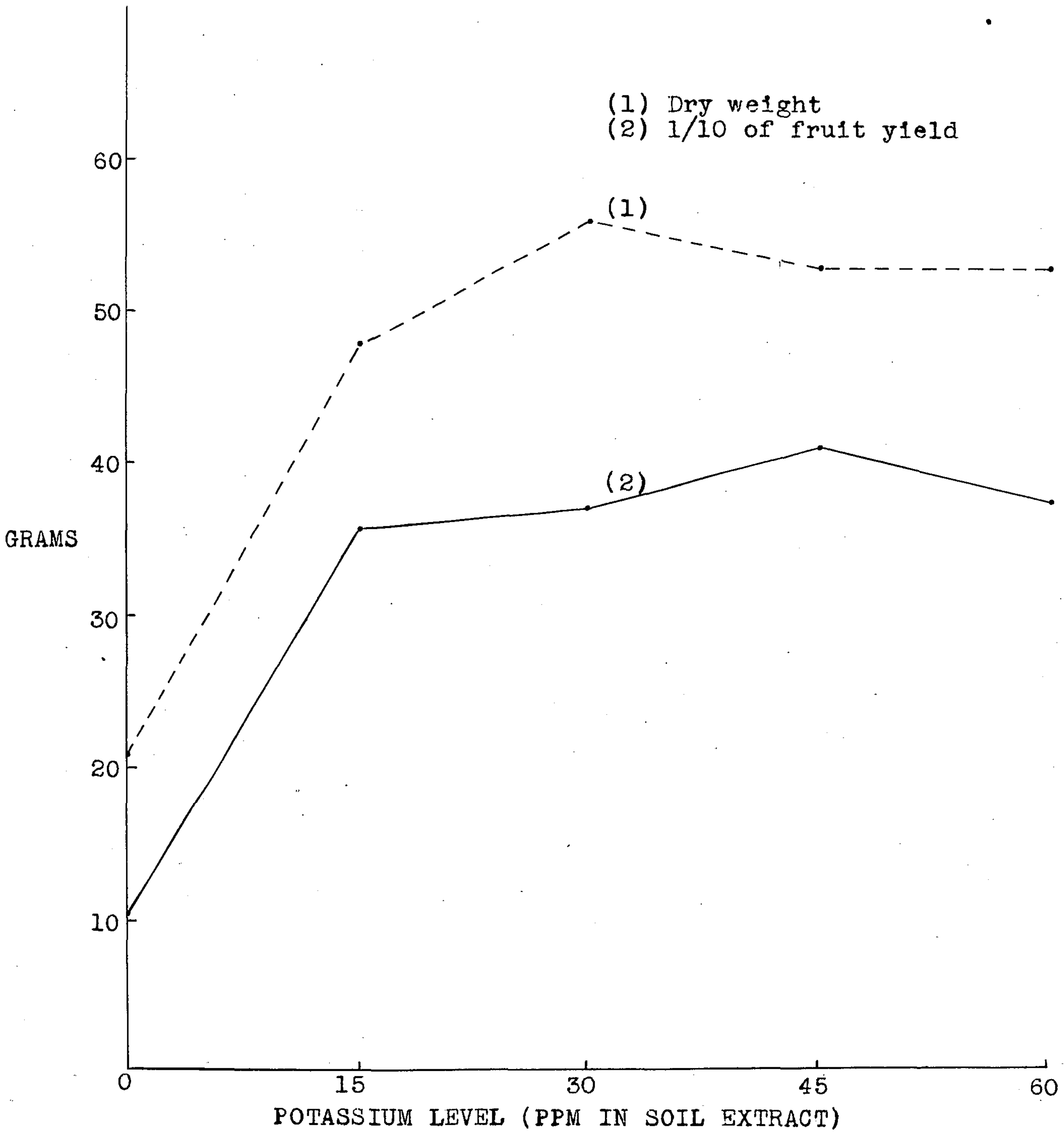

FIG. 9.—Effect of potassium levels on the average dry weight and fruit yield of tomatoes.

deficiency symptoms started on the older leaflets and progressed to the younger ones as the deficiency became more severe. When potassium starvation occurred at high nitrogen levels, white spots were found in conjunction with the marginal yellowing of the leaflets. These spots were similar to those described by Cook and Millar (8) as characteristic of potassium starvation on clover and alfalfa. The condition is apparently caused by a low potassium and high nitrogen relationship since legumes are generally high in nitrogen and this disorder occurred on the tomatoes only in the presence of high nitrogen.

Symptoms of potassium deficiency on older plants are considerably different from those on young plants. A normal mature plant that becomes deficient in potassium shows a yellow mottling of the interveinous tissue on the older leaflets, while the veins remain green. The mottling starts at the edges and progresses inwardly. This is illustrated in Fig. 10.

There were highly significant potassium interactions with both nitrogen and phosphorus in this study. It was observed that potassium deficiency symptoms occurred earlier and with greater severity on plants with high phosphorus and (or) with high nitrogen. The plant which showed the most severe symptoms of starvation received the $N_{200}P_{25}K_0$ treatment. The phosphorus-potassium relationship is shown in Fig. 11.

Statistical breakdowns of the PK interactions for dry

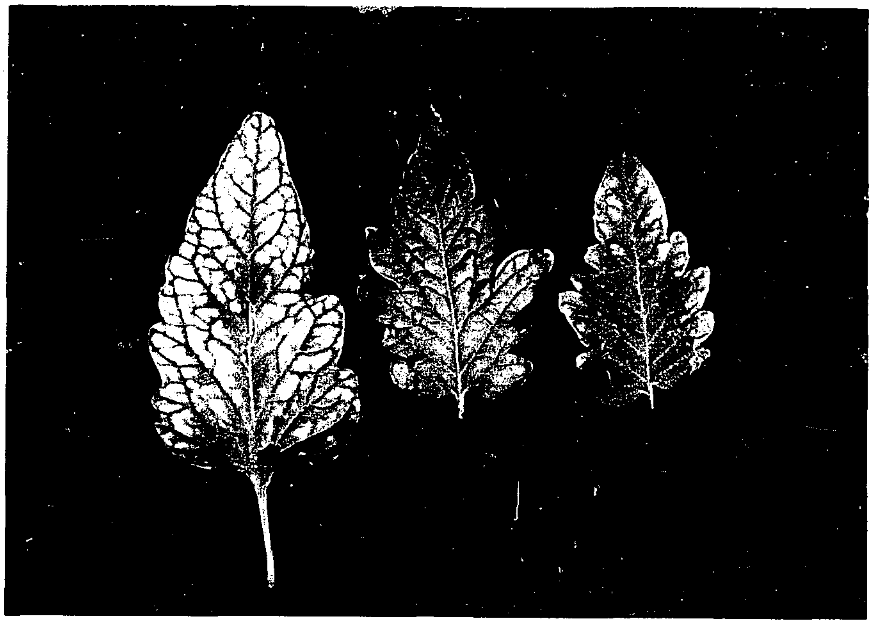

FIG. 10.—Tomato leaflets showing potassium deficiency symptoms at different stages of growth. The leaflets on the left developed the symptoms at fruiting time. In the center is a younger one from the same plant. On the right is an older leaflet from a young plant.

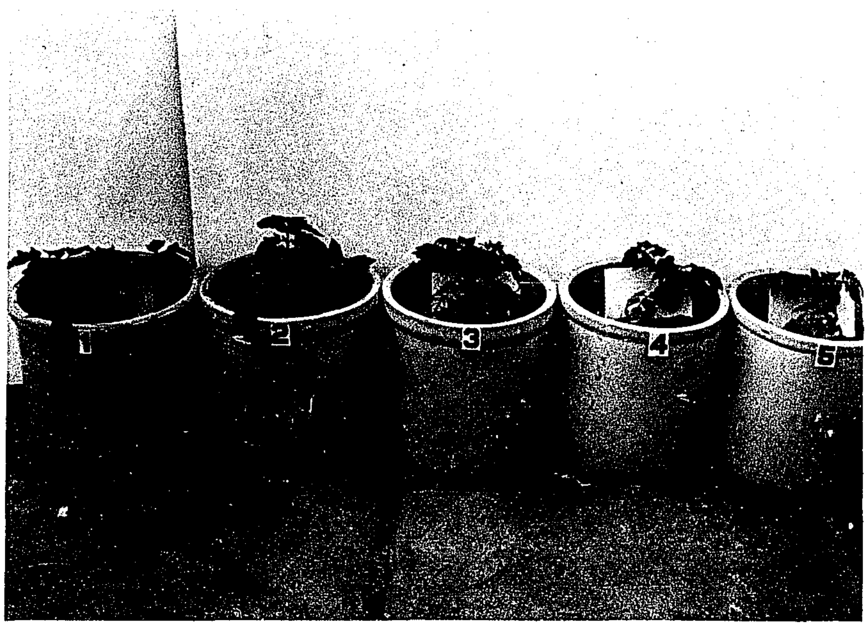

FIG. 11.—The effect of increased phosphorus levels on the severity of potassium deficiency symptoms. Treatments are: 1-$N_{25}P_0K_0$, 2-$N_{25}P_{2\frac{1}{2}}K_0$, 3-$N_{25}P_5K_0$, 4-$N_{25}P_{10}K_0$, 5-$N_{25}P_{25}K_0$.

weight and fruit yield into their individual degrees of freedom are presented in Tables 9 and 10 respectively. With both groups of data it can be seen that this interaction was significant at the 1% point only when the extreme levels were involved.

Statistical analyses of the NK interactions showing a breakdown into their individual degrees of freedom for dry weight and fruit yields are presented in Tables 11 and 12 respectively. These data show the combinations of treatments which resulted in significant interactions. With both factors the significant interactions occurred where K_0 was involved. In other words, the plants responded differently to nitrogen levels at K_0 than they did at higher levels of potassium.

The data from this experiment emphasize the importance of maintaining proper nutrient balance in the soil for maximum production of tomatoes. Low nutrient levels which were well balanced gave much better results than did high levels which were unbalanced in one or more elements. For example, high nitrogen in the absence of adequate phosphorus resulted in death of the plants, yet when both elements were low they grew fairly well and produced a few fruit. Another unbalanced condition was observed within the N_0 group when both phosphorus and potassium were high. Plants which received N_0K_{60} with intermediate phosphorus levels showed no toxicity symptoms nor did those which received N_0P_{25} with

TABLE 9.—A statistical analysis of PK interaction of dry weight of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
PK	16	4,733.2	295.8**
[4 P_0-$P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	3,333.4	3,333.4**
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	252.1	252.1
" [2 K_{30}-K_{45}-K_{60}]	1	0.03	0.03
" [K_{45}-K_{60}]	1	4.5	4.5
[3 $P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	48.8	48.8
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	70.9	70.9
" [2 K_{30}-K_{45}-K_{60}]	1	7.5	7.5
" [K_{45}-K_{60}]	1	17.6	17.6
[2 P_5-P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	36.5	36.5
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	16.0	16.0
" [2 K_{30}-K_{45}-K_{60}]	1	325.4	325.4
" [K_{45}-K_{60}]	1	35.3	35.3
[P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	7.2	7.2
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	208.0	208.0
" [2 K_{30}-K_{45}-K_{60}]	1	273.1	273.1
" [K_{45}-K_{60}]	1	96.8	96.8

* Significant at 5% point.
** Significant at 1% point.

TABLE 10.—A statistical analysis of PK interaction of fruit yield of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
PK	16	647,019.6	40,438.7**
[4 P_0-$P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	409,409.1	409,409.1**
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	7,937.2	7,937.2
" [2 K_{30}-K_{45}-K_{60}]	1	1,438.1	1,438.1
" [K_{45}-K_{60}]	1	470.3	470.3
[3 $P_{2\frac{1}{2}}$-P_5-P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	23,686.5	23,686.5
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	17,152.2	17,152.2
" [2 K_{30}-K_{45}-K_{60}]	1	5,292.3	5,292.3
" [K_{45}-K_{60}]	1	7,202.9	7,202.9
[2 P_5-P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	51,884.7	51,884.7*
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	67,889.4	67,889.4*
" [2 K_{30}-K_{45}-K_{60}]	1	17,928.1	17,928.1
" [K_{45}-K_{60}]	1	17,978.2	17,978.2
[P_{10}-P_{25}] [4 K_0-K_{15}-K_{30}-K_{45}-K_{60}]	1	717.8	717.8
" [3 K_{15}-K_{30}-K_{45}-K_{60}]	1	3,393.1	3,393.1
" [2 K_{30}-K_{45}-K_{60}]	1	11,032.4	11,032.4
" [K_{45}-K_{60}]	1	3,607.3	3,607.3

* Significant at 5% point.
** Significant at 1% point.

TABLE 11.—A statistical analysis of NK interaction of dry weight of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
NK	16	12,963.4	810.2**
$[4\ N_0-N_{25}-N_{50}-N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	4,196.3	4,196.3**
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	165.0	165.0
" $[2\ K_{30}-K_{45}-K_{60}]$	1	12.3	12.3
" $[K_{45}-K_{60}]$	1	8.0	8.0
$[3\ N_{25}-N_{50}-N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	307.1	307.1
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	337.6	337.6
" $[2\ K_{30}-K_{45}-K_{60}]$	1	572.5	572.5*
" $[K_{45}-K_{60}]$	1	16.1	16.1
$[2\ N_{50}-N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	3,635.9	3,635.9**
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	590.3	590.3*
" $[2\ K_{30}-K_{45}-K_{60}]$	1	32.1	32.1
" $[K_{45}-K_{60}]$	1	707.3	707.3*
$[N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	1,562.4	1,562.4**
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	806.0	806.0*
" $[2\ K_{30}-K_{45}-K_{60}]$	1	11.3	11.3
" $[K_{45}-K_{60}]$	1	3.2	3.2

* Significant at 5% point.
** Significant at 1% point.

TABLE 12.—A statistical analysis of NK interaction of fruit yield of tomato plants grown on Oshtemo loamy sand.

Source	D.F.	S.S.	Mean square
NK	16	855,183.8	53,449.0**
$[4\ N_0-N_{25}-N_{50}-N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	287,220.5	287,220.5**
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	4,915.5	4,915.5
" $[2\ K_{30}-K_{45}-K_{60}]$	1	4,325.0	4,325.0
" $[K_{45}-K_{60}]$	1	874.9	874.9
$[3\ N_{25}-N_{50}-N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	201,836.5	201,836.5**
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	180.9	180.9
" $[2\ K_{30}-K_{45}-K_{60}]$	1	34,556.8	34,556.8
" $[K_{45}-K_{60}]$	1	30,175.2	30,175.2
$[2\ N_{50}-N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	160,563.6	160,563.6**
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	91.2	91.2
" $[2\ K_{30}-K_{45}-K_{60}]$	1	7,695.0	7,695.0
" $[K_{45}-K_{60}]$	1	2,317.6	2,317.6
$[N_{100}-N_{200}]$ $[4\ K_0-K_{15}-K_{30}-K_{45}-K_{60}]$	1	42,457.0	42,457.0
" $[3\ K_{15}-K_{30}-K_{45}-K_{60}]$	1	3.1	3.1
" $[2\ K_{30}-K_{45}-K_{60}]$	1	24,688.9	24,688.9
" $[K_{45}-K_{60}]$	1	53,282.2	53,282.2*

* Significant at 5% point.
** Significant at 1% point.

intermediate potassium levels. But the plant which received $N_0P_{25}K_{60}$ showed definite symptoms of nutritional unbalance as can be seen in Fig. 12, jar 4. When these

FIG. 12.—The effect of high phosphorus and potassium levels both with and without nitrogen. Treatments are: 1-$N_0P_0K_0$, 2-$N_0P_{25}K_0$, 3-$N_0P_0K_{60}$, 4-$N_0P_{25}K_{60}$, 5-$N_{25}P_{25}K_{60}$.

high phosphorus and potassium levels were in proper balance with nitrogen, the plants grew very well. A closeup of one of the lower leaves from the plant which showed the unbalanced condition is presented in Fig. 13. The margins of the most severly affected leaflets were yellow and necrotic, symptoms which are similar to potassium

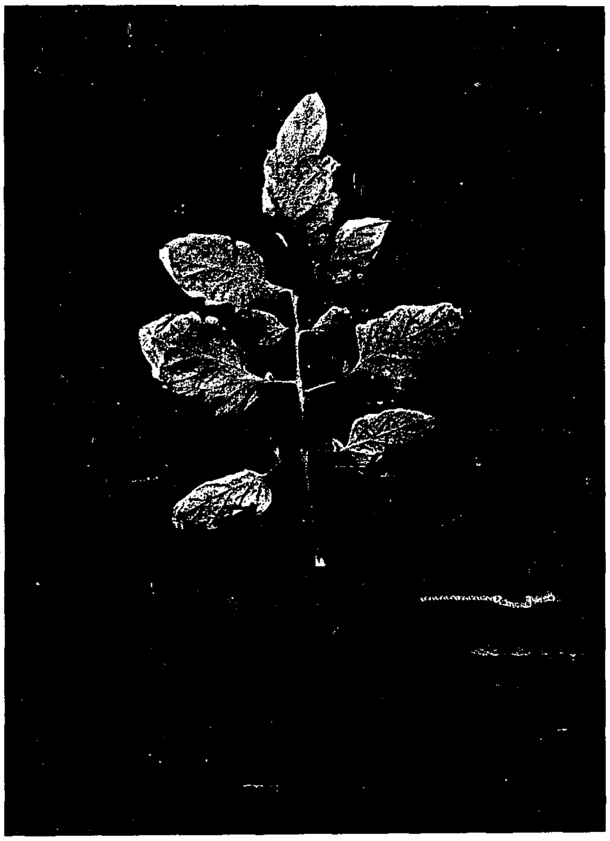

FIG. 13.—A tomato leaf, from the plant which received $N_0P_{25}K_{60}$, showing symptoms of nutritional unbalance.

deficiency. Tissue tests verified the fact that the plant was extremely high in potassium. This suggests that foliar toxicity symptoms of an element can easily be mistaken for deficiency symptoms of that or of some other element unless tissue tests are used in diagnosing nutritional disorders.

The results of this experiment indicate that for greenhouse tomatoes, grown as a spring crop, the nitrogen level should be maintained between 25 and 50 ppm in the soil extract, phosphorus between 5 and 10 ppm, and potassium between 15 and 30 ppm. In the presence of a continuous supply of nitrogen the phosphorus and potassium levels can exceed these limits considerably without injury to the plants. However, levels above those suggested result in luxury consumption and have no particular advantage.

Nitrogen, Phosphorus, and Potassium
Levels on Brookston Silt Loam

Experimental: In order to get further information pertaining to the nutrition of the tomato a 4x4x4 factorial experiment was conducted using Brookston silt loam soil. The treatments were duplicated. The general procedures followed were the same as in the previous experiment, although the nutrient levels were different. Nutrient levels in the soil extract were maintained at 0, 50, 100, and 200 ppm of NO_3, 0, 10, 20, and 40 ppm of phosphorus, and 0, 25, 50, and 100 ppm of potassium. The zero level represented the untreated soil. However, the untreated Brookston soil, tested at the time of setting up the experiment, had 75 ppm of NO_3, 3/4 ppm of phosphorus, and 5 ppm of potassium.

A general treatment was applied to all soils. This included manganese sulphate equivalent to 100 pounds per acre, magnesium sulphate equivalent to 500 pounds per acre, and sodium tetraborate ($Na_2B_4O_7$) equivalent to 10 pounds per acre. A summary of all nitrogen, phosphorus, and potassium applications is shown in Table 13. Treatments were mixed evenly throughout the soil before the distilled water was added.

Tomato plants of the Improved Bay State variety were started in flats four weeks before the beginning of the experiment. A sandy loam soil of medium to low fertility was used in the flats. The transplanting was done on

August 10, 1948. At that time the plants were of uniform size and showed no visual deficiency symptoms. The roots were washed free of all soil before they were transplanted.

TABLE 13.—A summary of the nitrogen, phosphorus, and potassium treatments applied to Brookston silt loam.

Nutrient level	C.P. reagent used	Gm. added per jar	Pounds per acre equivalent
N_0	$NaNO_3$	0.00	0.0
N_{50}	"	0.00	0.0
N_{100}	"	1.14	285.0
N_{200}	"	5.05	1262.5
P_0	$Ca(H_2PO_4)_2 \cdot H_2O$	0.00	0.0
P_{10}	"	10.67	2667.5
P_{20}	"	20.27	5067.5
P_{40}	"	37.33	9332.5
K_0	K_2SO_4	0.00	0.0
K_{25}	"	11.94	2985.0
K_{50}	"	19.99	4997.5
K_{100}	"	38.37	9592.5

The soils were tested frequently and nutrients were added as needed to maintain the original levels of nitrogen, phosphorus, and potassium.

When the entire crop was harvested on November 7, 1948 the first fruits were just beginning to ripen. Fruit yields recorded included all fruit on the plants at harvest time. At this time the seventh to sixteenth leaves, inclusive, from the base of the plants were collected to represent the leaf samples. These samples were later analyzed in the laboratory for nitrogen, phosphorus, and potassium.

<u>Results</u> <u>and</u> <u>Discussion</u>: The average results, by treatment, for dry weight, yield of fruit, and per cent composition of nitrogen, phosphorus, and potassium in the leaf samples is presented in Table 14.

Dry Weight: Nitrogen, phosphorus, and potassium each exerted a highly significant influence on the dry weight of the plants as the summary of analysis of variance in Table 15 shows. Fig. 14 as well as Table 15 indicates that the N_{200} level resulted in the greatest growth under the conditions of this experiment.

It is of interest to compare the effect of the heavy nitrogen treatment on this soil with its effect on the Oshtemo loamy sand. On the Brookston silt loam, plants which received the N_{200} treatment showed toxicity symptoms soon after its application. During the early stages of development growth was inhibited to some extent and the plants possessed the soft, succulent, slightly wilted appearance which was described as nitrogen toxicity in the previous experiment. The condition was less severe on the Brookston soil, however, and the plants soon overcame the toxicity, while the plants on the Oshtemo soil never fully

TABLE 14.—The average result by treatment for dry weight, yield of fruit, and per cent composition of nitrogen, phosphorus, and potassium in the leaf samples.

Treatment	Yield of fruit per plant(gm.)	Dry weight per plant (gm.)	Chemical composition of leaf samples*		
			% N	% P	% K
$N_0P_0K_0$	231.0	22.5	0.99	0.15	2.15
$N_0P_0K_{25}$	180.0	25.5	0.97	0.15	3.70
$N_0P_0K_{50}$	207.5	24.0	1.01	0.16	3.98
$N_0P_0K_{100}$	314.5	24.0	1.06	0.14	5.05
$N_0P_{10}K_0$	288.0	28.5	1.18	0.51	2.33
$N_0P_{10}K_{25}$	291.5	32.5	0.95	0.27	3.68
$N_0P_{10}K_{50}$	261.0	29.5	1.02	0.32	3.98
$N_0P_{10}K_{100}$	329.5	35.0	1.11	0.25	4.78
$N_0P_{20}K_0$	247.0	31.5	0.98	0.52	1.55
$N_0P_{20}K_{25}$	170.5	25.5	0.78	0.41	2.93
$N_0P_{20}K_{50}$	277.5	35.5	1.00	0.29	3.65
$N_0P_{20}K_{100}$	221.0	25.5	1.06	0.34	4.65
$N_0P_{40}K_0$	279.0	30.0	1.08	0.53	2.00
$N_0P_{40}K_{25}$	324.0	26.0	1.01	0.37	3.58
$N_0P_{40}K_{50}$	285.0	28.0	0.94	0.38	3.65
$N_0P_{40}K_{100}$	280.0	26.0	1.18	0.39	4.58

* Percentage is based on oven dry weight.

TABLE 14.—(continued) The average result by treatment for dry weight, yield of fruit, and per cent composition of nitrogen, phosphorus, and potassium in the leaf samples.

Treatment	Yield of fruit per plant(gm.)	Dry weight per plant (gm.)	Chemical composition of leaf samples*		
			% N	% P	% K
$N_{50}P_0K_0$	446.5	60.0	1.97	0.16	0.83
$N_{50}P_0K_{25}$	575.0	54.5	1.89	0.15	2.85
$N_{50}P_0K_{50}$	488.5	53.5	2.43	0.15	3.90
$N_{50}P_0K_{100}$	483.0	63.0	2.41	0.16	4.15
$N_{50}P_{10}K_0$	662.0	52.5	2.11	0.53	0.65
$N_{50}P_{10}K_{25}$	560.0	70.0	1.75	0.26	3.50
$N_{50}P_{10}K_{50}$	616.5	54.0	1.96	0.26	3.00
$N_{50}P_{10}K_{100}$	646.5	53.0	1.82	0.23	3.80
$N_{50}P_{20}K_0$	556.0	51.0	2.10	0.88	0.65
$N_{50}P_{20}K_{25}$	691.5	66.0	1.82	0.36	3.00
$N_{50}P_{20}K_{50}$	517.0	66.0	1.80	0.29	3.40
$N_{50}P_{20}K_{100}$	644.0	49.0	1.75	0.29	3.83
$N_{50}P_{40}K_0$	603.0	55.5	2.06	0.82	0.45
$N_{50}P_{40}K_{25}$	655.5	60.0	1.89	0.38	3.15
$N_{50}P_{40}K_{50}$	676.5	58.5	2.01	0.42	3.15
$N_{50}P_{40}K_{100}$	584.5	65.0	2.39	0.32	3.93

* Percentage is based on oven dry weight.

TABLE 14.—(continued) The average result by treatment for dry weight, yield of fruit, and per cent composition of nitrogen, phosphorus, and potassium in the leaf samples.

Treatment	Yield of fruit per plant(gm.)	Dry weight per plant (gm.)	Chemical composition of leaf samples*		
			% N	% P	% K
$N_{100}P_0K_0$	498.0	41.0	2.63	0.16	1.13
$N_{100}P_0K_{25}$	536.0	54.5	2.44	0.15	2.23
$N_{100}P_0K_{50}$	618.5	50.0	2.42	0.14	2.53
$N_{100}P_0K_{100}$	593.0	52.0	2.38	0.15	3.28
$N_{100}P_{10}K_0$	527.0	56.0	2.53	0.53	0.48
$N_{100}P_{10}K_{25}$	553.0	63.0	2.31	0.31	2.78
$N_{100}P_{10}K_{50}$	611.5	66.0	2.36	0.29	3.40
$N_{100}P_{10}K_{100}$	615.5	60.5	2.37	0.29	3.43
$N_{100}P_{20}K_0$	639.0	53.0	2.44	0.73	0.45
$N_{100}P_{20}K_{25}$	653.0	53.0	2.38	0.34	2.98
$N_{100}P_{20}K_{50}$	620.0	62.0	2.31	0.32	2.80
$N_{100}P_{20}K_{100}$	520.5	67.5	2.56	0.30	3.85
$N_{100}P_{40}K_0$	613.0	51.5	2.50	0.76	0.55
$N_{100}P_{40}K_{25}$	650.0	63.0	2.35	0.40	2.35
$N_{100}P_{40}K_{50}$	659.0	58.0	2.29	0.38	2.85
$N_{100}P_{40}K_{100}$	749.5	58.5	2.34	0.33	3.35

* Percentage is based on oven dry weight.

TABLE 14.—(continued) The average result by treatment for dry weight, yield of fruit, and per cent composition of nitrogen, phosphorus, and potassium in the leaf samples.

Treatment	Yield of fruit per plant(gm.)	Dry weight per plant (gm.)	Chemical composition of leaf samples*		
			% N	% P	% K
$N_{200}P_0K_0$	383.0	53.0	3.00	0.17	1.30
$N_{200}P_0K_{25}$	450.0	54.0	2.90	0.17	2.25
$N_{200}P_0K_{50}$	447.0	53.0	2.75	0.15	2.80
$N_{200}P_0K_{100}$	475.0	54.0	2.85	0.15	3.70
$N_{200}P_{10}K_0$	614.5	58.0	2.74	0.60	0.65
$N_{200}P_{10}K_{25}$	490.0	71.0	2.62	0.29	2.65
$N_{200}P_{10}K_{50}$	539.5	72.5	2.62	0.27	3.08
$N_{200}P_{10}K_{100}$	657.0	66.0	2.66	0.25	3.80
$N_{200}P_{20}K_0$	593.0	56.5	2.81	0.65	0.85
$N_{200}P_{20}K_{25}$	581.0	76.0	2.58	0.34	3.00
$N_{200}P_{20}K_{50}$	543.5	70.5	3.11	0.35	3.00
$N_{200}P_{20}K_{100}$	554.0	72.0	2.65	0.32	3.85
$N_{200}P_{40}K_0$	604.0	53.0	2.63	0.64	0.60
$N_{200}P_{40}K_{25}$	707.0	69.0	2.61	0.35	2.60
$N_{200}P_{40}K_{50}$	597.5	69.0	2.71	0.37	3.03
$N_{200}P_{40}K_{100}$	550.5	69.0	2.85	0.40	3.73

* Percentage is based on oven dry weight.

TABLE 15.—Analysis of variance of the dry weight data of tomato plants grown on Brookston silt loam.

Source	D.F.	S.S.	Mean square
Total	127	32,450.2	
Treatment	63	29,781.2	472.7**
N levels	3	24,518.8	8,172.9**
3 N_0 vs. $N_{50}+N_{100}+N_{200}$	1	23,719.6	23,719.6**
2 N_{50} vs. $N_{100}+N_{200}$	1	82.7	82.7
N_{100} vs. N_{200}	1	715.6	715.6**
P levels	3	1,350.5	450.2**
3 P_0 vs. $P_{10}+P_{20}+P_{40}$	1	1,298.0	1,298.0**
2 P_{10} vs. $P_{20}+P_{40}$	1	26.3	26.3
P_{20} vs. P_{40}	1	26.3	26.3
K levels	3	929.0	309.7**
3 K_0 vs. $K_{25}+K_{50}+K_{100}$	1	894.3	894.3**
2 K_{25} vs. $K_{50}+K_{100}$	1	28.5	28.5
K_{50} vs. K_{100}	1	6.3	6.3
NP	9	693.7	77.1
NK	9	569.4	63.3
PK	9	337.7	37.5
NPK	27	1,382.1	51.2
Between replicates	1	16.5	16.5
Within replicates (error)	63	2,652.5	42.1

* Significant at 5% point.
** Significant at 1% point.

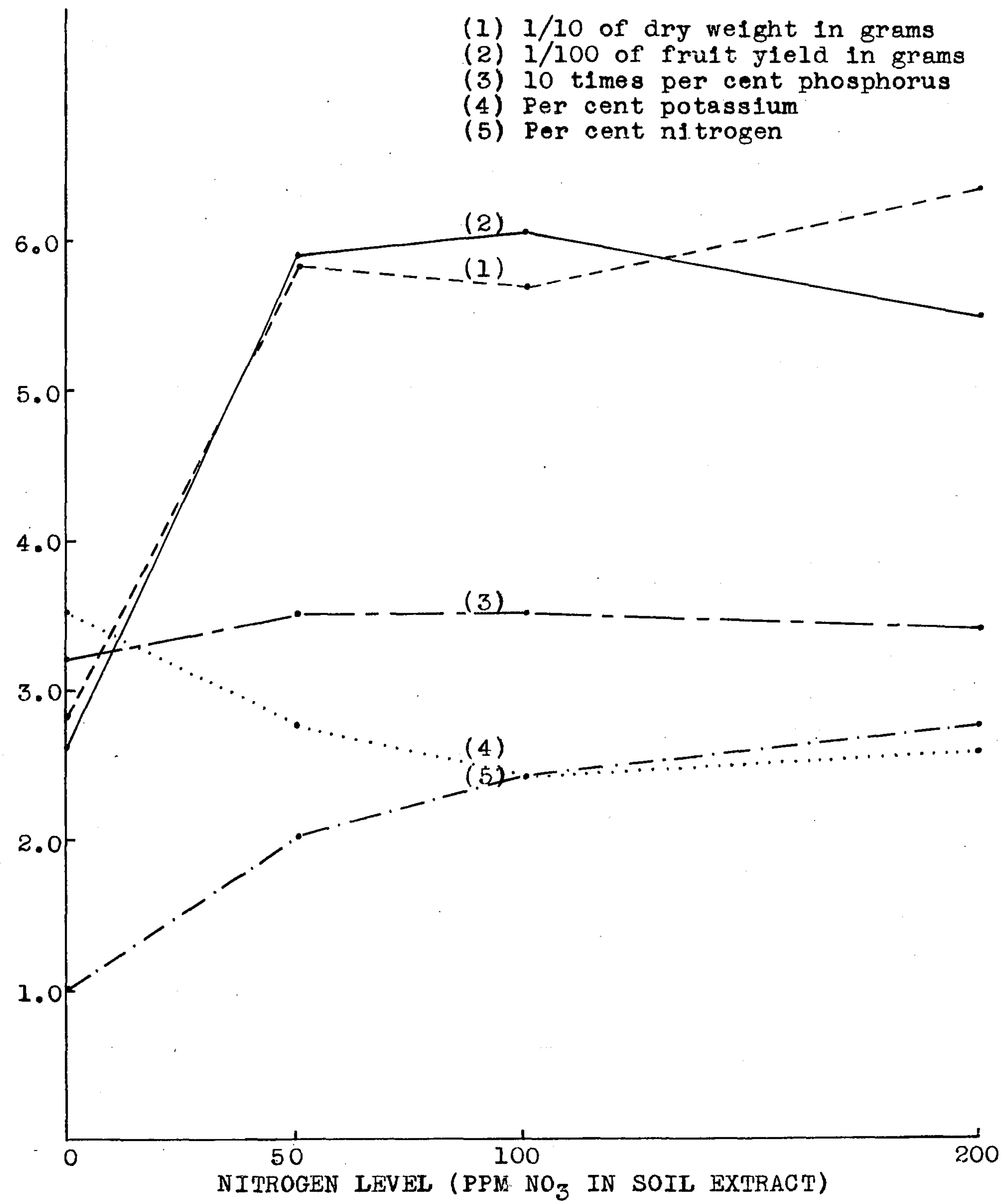

FIG. 14.—Effect of nitrogen levels on the average dry weight, fruit yield, and per cent nitrogen, phosphorus, and potassium in the leaf samples.

recovered. Eventually, those grown on Brookston soil at this high level of nitrogen made more growth than did those that received less nitrogen. The Brookston silt loam used in this experiment was higher in organic matter and had a much higher base exchange capacity than the Oshtemo loamy sand. These properties gave the Brookston soil a much greater buffering capacity which apparently accounted for the inconsistent results between the two experiments.

Symptoms of nitrogen starvation appeared seven weeks after transplanting on all plants which did not receive nitrogen. These symptoms were the same as those described in the previous experiment. No phosphorus or potassium deficiency symptoms occurred during the experiment.

Growth response to phosphorus treatments is shown in Table 15 and Fig. 15. They show that the only significant difference between levels was between none and some phosphorus. The second level, P_{10}, was fully as effective as the heavier applications. There was no indication that the highest phosphorus level, which was equivalent to over 9300 pounds per acre of C.P. primary monocalcium phosphate, was detrimental to the growth of the plants.

Potassium treatments caused results similar to those obtained for phosphorus as is apparent in Table 15 and Fig. 16. It is shown that K_{25} resulted in a significant response in growth over no potassium and that there was neither positive nor negative growth response to additional applications

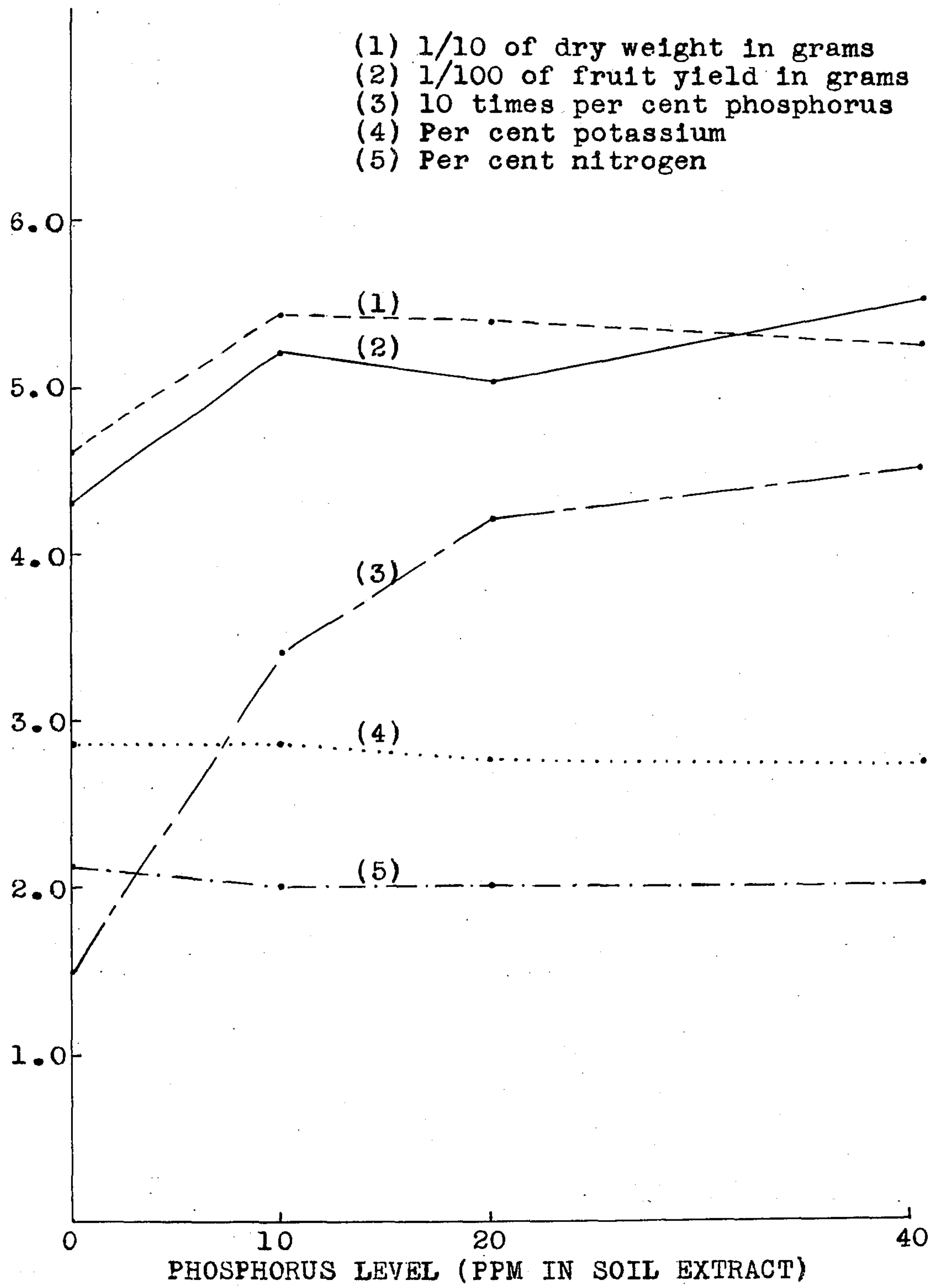

FIG. 15.—Effect of phosphorus levels on the average dry weight, fruit yield, and per cent nitrogen, phosphorus, and potassium in the leaf samples.

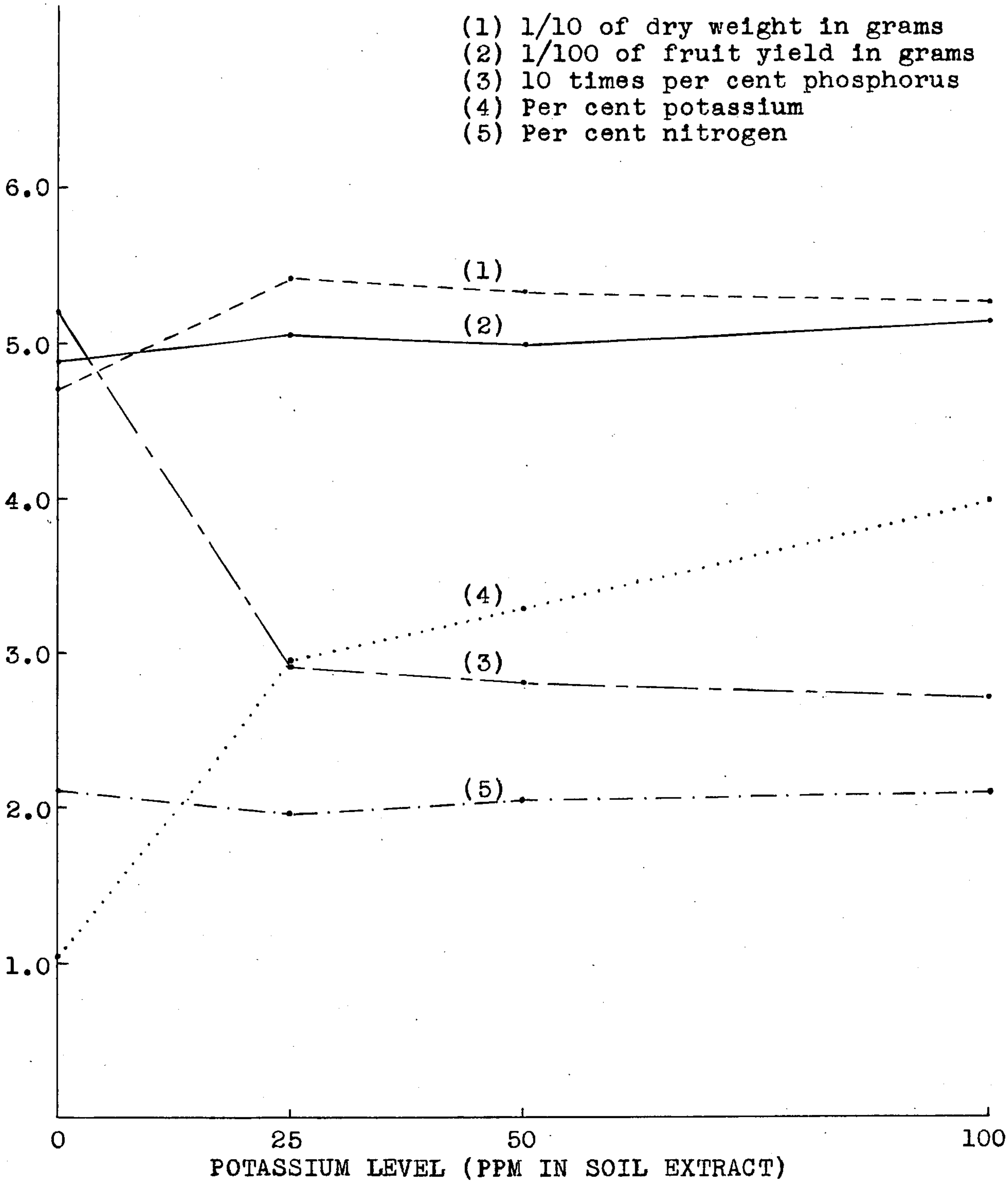

FIG. 16.—Effect of potassium levels on the average dry weight, fruit yield, and per cent nitrogen, phosphorus, and potassium in the leaf samples.

of this element.

Fruit Yield: High fruit yields were obtained only from large, healthy plants. It is apparent from the data in Table 16 and Fig. 14 that N_{50} and N_{100} resulted in significantly higher fruit yields than did N_0 or N_{200} even though N_{200} resulted in the largest plants. The decreased fruit yield at N_{200} was evidently due to an unbalanced ratio of carbohydrate to available nitrogen. Since this crop was grown in the fall, during a period of low light intensity and short days, the explanation is applicable. According to Kraus and Kraybill (19) excessive nitrogen in the presence of low carbohydrates results in low fruit production of the tomato.

The importance of an adequate supply of available phosphorus is indicated in Table 16 and Fig. 15. A response in fruit yield which was significant at the 1% point was obtained by the addition of phosphorus fertilizer. The P_{10} and P_{20} levels were equally effective in promoting fruit production. Even though the yields between P_{20} and P_{40} were sufficiently different to be significant at the 5% point, it is doubtful whether the higher level was of further value.

There was no response in fruit yield to applications of potassium fertilizers as Table 16 and Fig. 16 show. This can be accounted for by the fact that the supply of exchangeable potassium in the untreated soil was equivalent to 80 pounds per acre. In addition to the original supply a small

TABLE 16.—Analysis of variance of fruit yield of tomato plants grown on Brookston silt loam.

Source	D.F.	S.S.	Mean square
Total	127	3,523,327.5	
Treatment	63	3,059,639.5	48,565.7**
N levels	3	2,484,756.9	828,252.3**
3 N_0 vs. $N_{50}+N_{100}+N_{200}$	1	2,434,614.0	2,434,614.0**
2 N_{50} vs. $N_{100}+N_{200}$	1	2,836.7	2,836.7
N_{100} vs. N_{200}	1	47,306.3	47,306.3*
P levels	3	236,397.9	78,799.3**
3 P_0 vs. $P_{10}+P_{20}+P_{40}$	1	195,301.0	195,301.0**
2 P_{10} vs. $P_{20}+P_{40}$	1	2,140.0	2,140.0
P_{20} vs. P_{40}	1	38,956.9	38,956.9*
K levels	3	12,454.5	4,151.5
NP	9	75,905.9	8,434.0
NK	9	29,124.3	3,236.0
PK	9	67,369.8	7,485.5
NPK	27	153,630.2	5,690.0
Between replicates	1	5,913.2	5,913.2
Within replicates (error)	63	457,774.8	7,266.3

* Significant at 5% point.
** Significant at 1% point.

amount of potassium was released from the clay minerals during the growth of the crop.

In order to determine the amount of non-exchangeable potassium released from this soil an incubation experiment was conducted in the laboratory. A sample of the untreated Brookston soil was hydrogen saturated by thoroughly leaching with 0.1 N HCl to remove all exchangeable potassium. The HCl treatment was followed by successive washings of distilled water until the leachate was free from chlorides. After the hydrogen saturated soil had become air dry, ten-gram samples were allowed to incubate in the laboratory for five weeks with the moisture maintained at 40 per cent. Following this period of incubation, exchangeable potassium was again determined. It was found that the soil released the equivalent of 5 pounds per acre of potassium during the five weeks. This small release of non-exchangeable potassium was sufficient, in addition to the original 80 pounds per acre of exchangeable potassium to prevent the occurrence of potassium deficiency symptoms in the plants.

Nitrogen Content of Leaf Samples: A significant increase in the nitrogen content of the leaves was obtained with each increase of nitrogen in the soil as is shown in Table 17 and Fig. 14. The average percentage of nitrogen increased from 1.02 at the N_0 level to 2.75 at the N_{200} level.

The nitrogen content of the leaves was not affected by the phosphorus levels in the soil.

TABLE 17.—Analysis of variance of per cent nitrogen of leaves from tomato plants grown on Brookston silt loam.

Source	D.F.	S.S.	Mean square
Total	127	59.7165	
Treatment	63	57.0278	0.9052**
N levels	3	54.1816	18.0605**
3 N_0 vs. $N_{50}+N_{100}+N_{200}$	1	45.2445	45.2445**
2 N_{50} vs. $N_{100}+N_{200}$	1	7.0533	7.0533**
N_{100} vs. N_{200}	1	1.8838	1.8838**
P levels	3	0.3254	0.1085
K levels	3	0.4541	0.1514*
3 K_0 vs. $K_{25}+K_{50}+K_{100}$	1	0.1453	0.1453
2 K_{25} vs. $K_{50}+K_{100}$	1	0.2790	0.2790*
K_{50} vs. K_{100}	1	0.0298	0.0298
NP	9	0.5048	0.0561
NK	9	0.2272	0.0252
PK	9	0.2596	0.0288
NPK	27	1.0751	0.0398
Between replicates	1	0.0746	0.0746
Within replicates (error)	63	2.6142	0.0415

* Significant at 5% point.
** Significant at 1% point.

There is some indication that the nitrogen content of the leaves was increased by the higher levels of potassium, although this evidence is not conclusive.

Phosphorus Content of Leaf Samples: The phosphorus content of the leaves increased with each increase of the element in the soil as is indicated in Table 18 and Fig. 15. The concentration of phosphorus in the leaves increased from 0.15 per cent at the P_0 level to 0.45 per cent at the P_{40} level.

The phosphorus content of the leaves did not vary as nitrogen levels increased.

In the absence of adequate potassium, represented by K_0, as indicated in Table 18 and Fig. 16, there was a considerable accumulation of phosphorus in the leaves. However, the average phosphorus content of the leaf samples from plants which received K_{25}, K_{50}, and K_{100} was essentially the same.

The phosphorus content of the leaves was influenced by the NK and PK interactions. This indicates that the content of phosphorus in the leaves of plants at various soil nitrogen levels was affected by the quantity of potassium present. Similarly, it indicates that the content of phosphorus in the leaves of plants at various soil phosphorus levels was affected by the quantity of potassium present.

Potassium Content of Leaf Samples: As with the other two elements, potassium in the leaves continued to increase

TABLE 18.—Analysis of variance of per cent phosphorus of leaves from tomato plants grown on Brookston silt loam.

Source	D.F.	S.S.	Mean square
Total	127	4.0091	
Treatment	63	3.8440	0.0610**
N levels	3	0.0177	0.0059
P levels	3	1.7211	0.5737**
3 P_0 vs. $P_{10}+P_{20}+P_{40}$	1	1.5088	1.5088**
2 P_{10} vs. $P_{20}+P_{40}$	1	0.1957	0.1957**
P_{20} vs. P_{40}	1	0.0166	0.0166*
K levels	3	1.3743	0.4581**
3 K_0 vs. $K_{25}+K_{50}+K_{100}$	1	1.3645	1.3645**
2 K_{25} vs. $K_{50}+K_{100}$	1	0.0064	0.0064
K_{50} vs. K_{100}	1	0.0035	0.0035
NP	9	0.0295	0.0033
NK	9	0.1121	0.0125**
PK	9	0.4616	0.0513**
NPK	27	0.1277	0.0047
Between replicates	1	0.0001	0.0001
Within replicates (error)	63	0.1650	0.0026

* Significant at 5% point.
** Significant at 1% point.

with higher applications of potassium fertilizers as Table 19 and Fig. 16 show. The leaf samples averaged 1.04 per cent potassium at the K_0 level while the average at the K_{100} level was 3.98 per cent.

The levels of nitrogen had a marked influence on the content of potassium in the leaves. In Fig. 14 it can be seen that an inverse relationship was found between nitrogen levels in the soil and the potassium content of the leaves. As the nitrogen level increased, the nitrogen content of the leaves and the growth increased while potassium in the leaves decreased. This trend continued to the N_{100} treatment, above which there was no further decrease in per cent of leaf potassium.

The potassium content of the leaves did not vary as soil phosphorus levels were increased.

TABLE 19.—Analysis of variance of per cent potassium of leaves from tomato plants grown on Brookston silt loam.

Source	D.F.	S.S.	Mean square
Total	127	194.6172	
Treatment	63	185.2997	2.9413**
N levels	3	23.3242	7.7747**
3 N_0 vs. $N_{50}+N_{100}+N_{200}$	1	21.1876	21.1876**
2 N_{50} vs. $N_{100}+N_{200}$	1	1.7538	1.7538**
N_{100} vs. N_{200}	1	0.3829	0.3829
P levels	3	0.5033	0.1678
K levels	3	151.6855	50.5618**
3 K_0 vs. $K_{25}+K_{50}+K_{100}$	1	133.7176	133.7176**
2 K_{25} vs. $K_{50}+K_{100}$	1	9.6302	9.6302**
K_{50} vs. K_{100}	1	8.3377	8.3377**
NP	9	1.8635	0.2071
NK	9	2.8056	0.3117*
PK	9	1.5878	0.1764
NPK	27	3.5298	0.1307
Between replicates	1	0.3507	0.3507
Within replicates (error)	63	8.9668	0.1423

* Significant at 5% point.
** Significant at 1% point.

DIFFERENTIAL VARIETAL RESPONSE OF TOMATOES TO POTASSIUM FERTILIZER

In the past there have been several investigations into differential varietal response of various field crops to fertilization. Lyness (18), investigating 21 varieties of corn, observed large differences in susceptibility to phosphorus deficiency among varieties. Stringfield and Salter (34) reported a highly significant variance in yield between varieties of corn due both to season and soil fertility levels. Similarly, working with pure line varieties of barley, Gregory and Crowther (11,12) found a differential response to fertilization. Lamb and Salter (15) established differential varietal response of wheat by statistical analysis of the yields from 17 varieties grown at different fertility levels. Investigating the nutrition of apple trees, Blake, Nightingale, and Davidson (3) found that the calcium requirement of the Delicious and Stayman varieties is higher than that of the McIntosh and Baldwin. Likewise, Batjer and Magness (2) obtained higher percentages of potassium in leaves from Delicious apple trees than from those of the Rome Beauty and York varieties grown under the same conditions.

In March, 1948 an observation which indicated differential varietal response to soil treatment was made by the writer in a commercial tomato grower's greenhouse located at Grand Rapids, Michigan. Improved Bay State and Spartan

Hybrid tomato varieties were growing side by side in ground beds. The plants of both varieties were from six to eight feet tall and were heavily set with fruit. The first pickings were being made at the time of these observations. Leaves of the first mentioned variety showed a yellow mottling with the interveinous tissue more yellow than that adjacent to the veins. Mottling was more complete near the edges, but in severe cases it nearly covered the leaves as the leaflet in Fig. 17 shows. The leaves of the Spartan Hybrid plants were healthy green in color.

FIG. 17.—A mature tomato leaflet showing potassium starvation.

Cook and Millar (8) have described symptoms very similar to these as characteristic of potassium deficiency of mature tomato plants. Soil and tissue tests indicated that these symptoms were due to potassium starvation.

Experimental

A greenhouse experiment was conducted in an attempt to repeat and study the results mentioned above, under controlled growing conditions. The same varieties were grown at varying potassium levels. Eighteen kilograms of screened, air dry Oshtemo loamy sand was placed in 4-gallon, glazed, earthenware jars. The general treatment applied to all jars is given below:

$CaCO_3$	18.00 gm. per jar	2000 pounds per acre
$Ca(H_2PO_4)_2 \cdot H_2O$	19.85 "	2205 "
NH_4NO_3	6.48 "	720 "
$MnSO_4 \cdot 4H_2O$	0.90 "	100 "
$MgSO_4 \cdot 7H_2O$	4.50 "	500 "
$Na_2B_4O_7$	0.09 "	10 "

The experiment was designed with five replications of each variety at six potassium levels. These levels were established at 0, 5, 10, 25, 50, and 100 ppm of potassium in the soil extract, by the addition of K_2SO_4. The potassium treatments are presented in Table 20.

Three seeds were planted in each jar on July 16, 1948. On July 31 the plants were thinned to one per jar. In each

TABLE 20.—Potassium treatments applied to Oshtemo loamy sand.

Potassium level	K_2SO_4 added per jar (gm.)	Pounds per acre equivalent
K_0	0.00	0
K_5	1.93	214
K_{10}	3.83	425
K_{25}	9.59	1065
K_{50}	31.68	3520
K_{100}	49.19	5465

case this plant was reset to the center of the jar.

Nitrogen was added as needed during the experiment. No potassium or phosphorus was added after the initial application.

The seventh to eleventh leaves, inclusive, from the base of the plants were collected on October 13, 1948, to represent leaf samples for analysis. The entire crop was harvested on October 26.

Results and Discussion

Nine weeks after the seeds were planted four of the five Improved Bay State plants which did not receive potassium showed marginal leaf yellowing, a symptom of potassium starvation. The Spartan Hybrid plants did not show the leaf discolorations. However, both varieties were stunted by the lack of potassium and the plants were characterized by short internodes and small leaves. These conditions remained throughout the experiment with the leaf yellowing of the Improved Bay State plants increasing in severity, while the Spartan Hybrid plants never developed this symptom. Potassium deficiency symptoms occurred only at the K_0 level.

In this experiment, the Improved Bay State variety made less vegetative growth but produced more fruit than did the Spartan Hybrid variety. This is shown by the data presented in Table 21.

The mineral composition of the leaves and fruit, also shown in Table 21, varied considerably between varieties. The data for per cent potassium, calcium, magnesium, and phosphorus in the leaves, and the per cent potassium in the fruit were analyzed statistically as a split plot design as outlined by Snedecor (31). Considering the experiment as a whole, there was essentially no difference in the percentage of potassium in the leaves of the two varieties but the Improved Bay State variety produced fruit significantly higher in percentage of potassium than did the Spartan Hybrid variety. The Improved Bay State was found to contain more calcium in both leaves and fruit. No varietal difference was found in the per cent magnesium in the leaves or fruit. Leaves of the Spartan Hybrid plants contained significantly more phosphorus than did those of the other variety while the fruit showed very little varietal difference in this respect.

TABLE 21.—Response of two varieties of tomatoes to increased potassium levels as indicated by fruit yield, dry weight of plant, and chemical composition of leaf samples.

Treatment	Variety	Yield of fruit (gm.)(3)	Dry weight of plant (gm.)(3)	Average chemical composition of leaf samples(4)				Average chemical composition of the fruit(4)			
				% K	% Ca	% Mg	% P	% K	% Ca	% Mg	% P
K_0	I.B.S.(1)	220	33	0.43	3.04	0.58	0.48	2.04	0.27	0.14	0.64
	S.H. (2)	108	39	0.39	3.00	0.63	0.57	1.97	0.19	0.14	0.74
K_5	I.B .S.	596	69	0.59	3.45	0.71	0.39	2.27	0.20	0.14	0.56
	S.H.	409	73	0.72	3.28	0.64	0.45	2.18	0.14	0.11	0.57
K_{10}	I.B.S.	754	75	1.36	3.26	0.66	0.38	2.80	0.18	0.15	0.55
	S.H.	523	85	1.43	2.90	0.61	0.55	2.57	0.16	0.12	0.56
K_{25}	I.B.S.	653	92	3.54	2.90	0.57	0.34	3.35	0.17	0.15	0.51
	S.H.	564	89	3.80	2.64	0.54	0.54	3.47	0.15	0.16	0.57
K_{50}	I.B.S.	582	97	6.42	1.78	0.55	0.36	4.62	0.12	0.23	0.55
	S.H.	511	103	6.44	1.63	0.51	0.53	4.02	0.08	0.16	0.55
K_{100}	I.B.S.	744	92	7.18	1.45	0.45	0.38	4.74	0.08	0.22	0.55
	S.H.	468	105	7.70	1.24	0.47	0.55	4.22	0.07	0.19	0.55
Significance between varieties				n.s.	*	n.s.	**	**			

(1) Improved Bay State.
(2) Spartan Hybrid.
(3) Average of five replicates.
(4) Percentage is based on oven dry weight.
* Significant at 5% point.
** Significant at 1% point.

Varying the potassium levels had a marked effect on the chemical composition of the leaves. Fig. 18 shows the average per cent phosphorus, potassium, calcium, and magnesium in the leaf samples collected from each plant within the potassium levels. The potassium content of the leaves continued to increase with each additional increment added as a fertilizer, although, as shown in Fig. 18, the curve levels off somewhat with the last increment. Some individual leaf samples from plants which received the K_{100} treatment contained as much as 8.00 per cent potassium. The average content ranged from 0.41 per cent at the K_0 level to 7.44 per cent at the K_{100} level.

The phosphorus content of the leaves was reduced by the first increment of potassium fertilizer but was not further reduced by additional applications. This is clearly shown by the phosphorus curve in Fig. 18.

The concentrations of calcium and magnesium in the leaves were affected similarly by the treatments. As shown in Fig. 18 the first increment of potassium caused a marked increase in growth and favored the accumulation of calcium and magnesium. The concentration of both calcium and magnesium, however, was appreciably decreased by the heavier applications of potassium. These results are in agreement with Carolus (7), McCalla and Woodford (22), and other investigators.

It can be seen in Fig. 19 that the composition of the

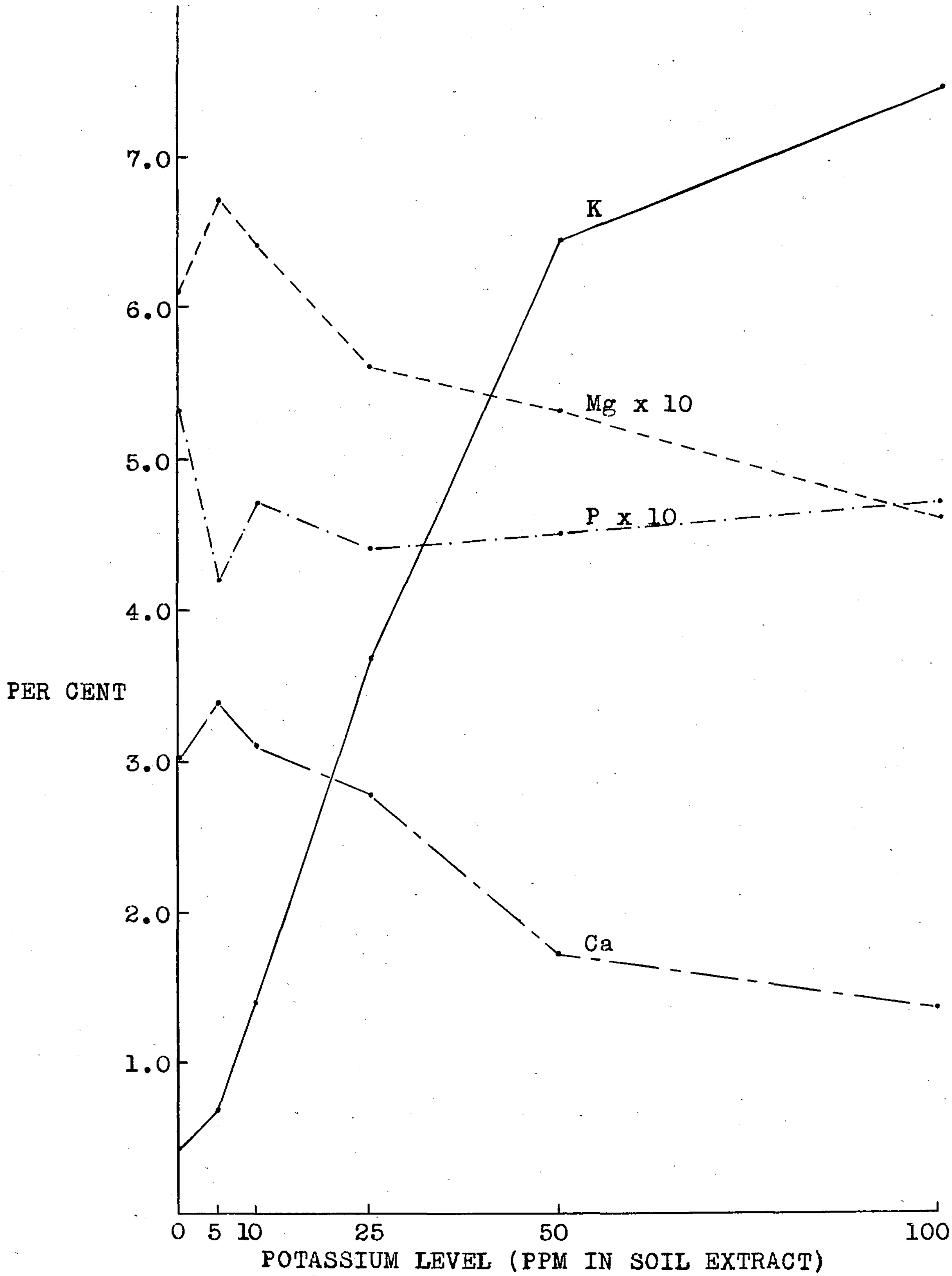

FIG. 18.—Effect of increased potassium levels in the soil on the chemical composition of the leaf samples of tomato plants.

fruit was more resistant to change due to treatment than was that of the leaves. As the potassium application was increased the content of potassium in the fruit increased but not to the extent that it did in the leaves. The range was from an average of 2.01 per cent at the K_0 level to an average of 4.48 per cent at the K_{100} level. This increase in potassium is to the extent of 2.2 times as compared with an increase of over 18 times in the leaves of plants which received the same treatments. As with the leaves there was a tendency for phosphorus to accumulate in the fruit where the soil potassium level was inadequate. The calcium and magnesium content of the fruit was extremely low, approximately 0.17 per cent and 0.15 per cent respectively. Increased potassium treatments tended to decrease the calcium and increase the magnesium in the fruit.

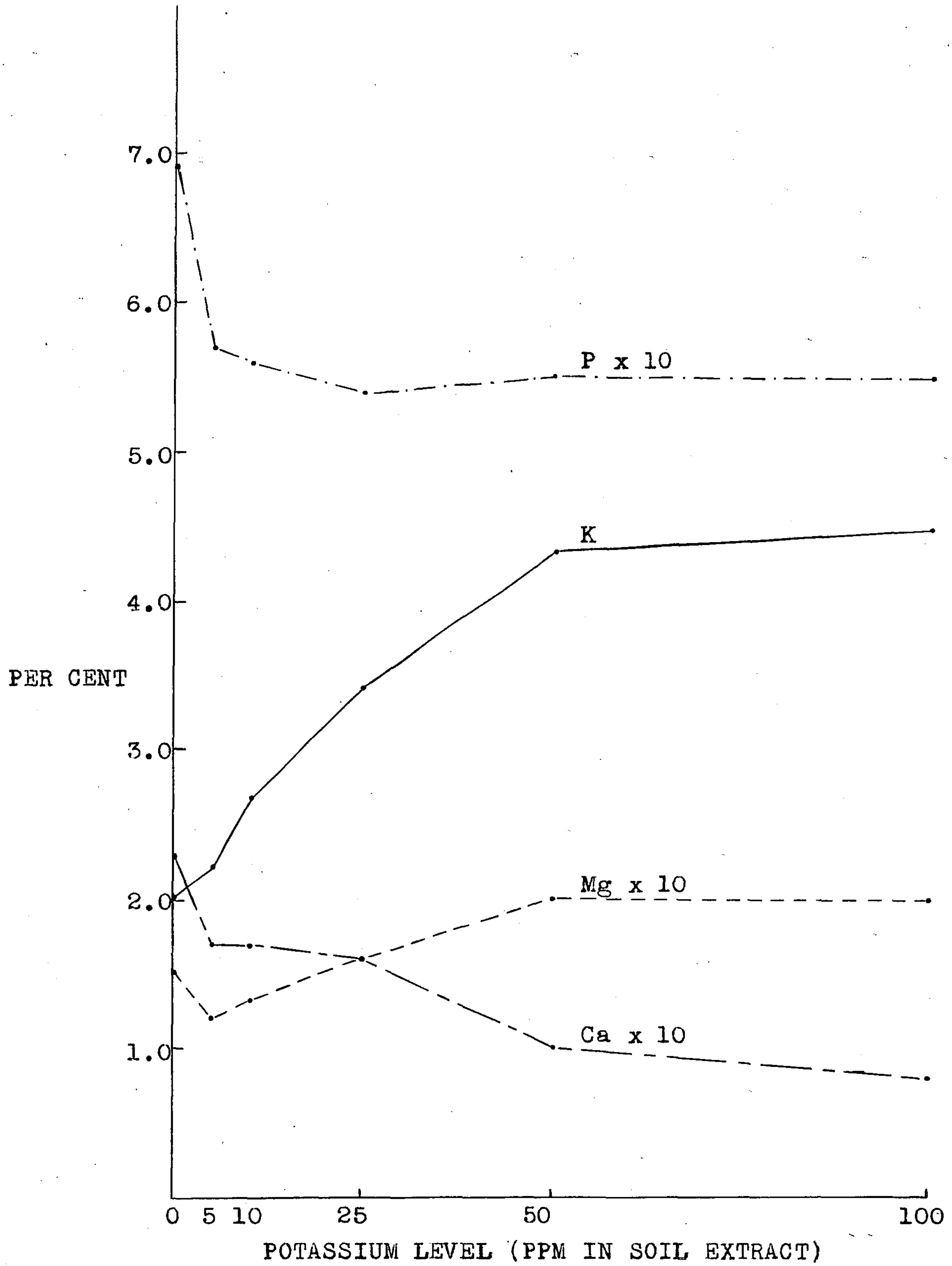

FIG. 19.—Effect of increased potassium levels in the soil on the chemical composition of tomato fruit.

EFFECT OF BORON LEVELS ON THE YIELD AND CHEMICAL COMPOSITION OF TOMATOES

It is an established fact that boron is essential for normal growth and development of plants. Johnston and Dore (13) and Johnston and Fisher (14) have demonstrated that appreciable quantities of this element are needed for the normal development of tomato plants. These investigators observed that tomato plants growing in water cultures required a concentration of approximately 0.5 ppm of boron for normal growth and that a concentration of 5.5 ppm was toxic to the plants. They indicated that boron deficiency symptoms of the tomato included death of the terminal growing point of the stem, breakdown of the conducting tissue in the stem, brittleness of stem and petiole, and poor root development. Boron toxicity symptoms of the tomato were described by these workers as a browning and dying of the leaf margins of the older leaves.

Raliegh (28) has observed that the fruit of tomato plants grown in a boron deficient media tend to be small with characteristic brown areas that later take on a rough appearance.

The effect of boron on the absorption of other elements has been undergoing rigorous research during recent years. In a thorough review of the subject, Parks, Lyon, and Hood (24) have pointed out that considerable disagreement exists among the results of various workers. Investigations in their laboratory showed that as the boron concentration of the media is increased, the absorption of certain elements increases to a maximum and then decreases. They suggest that the disagreement between results of independent workers is due to differences in the initial supply of boron.

Plants vary greatly in their requirement and tolerance for boron. Purvis and Hanna (27) have studied the boron tolerance of several plants. They found that the tomato is one of the more tolerant plants. It was not injured by the application of as much as 50 pounds of borax per acre. Their results indicate that the degree of boron toxicity, as shown by using the snap bean as an indicator crop, varies with soil type. Plant tolerance was correlated with the exchange capacity of the soil and with the amount of available boron present.

Investigations were undertaken to obtain further information regarding the requirement and tolerance range of tomato plants for boron. It was anticipated that some insight might be gained concerning the relationship of boron to the absorption of other mineral nutrients by making chemical analyses of the treated soils and the plants grown on them. Two experiments were conducted with these objectives in mind. The first was carried out during the spring of 1948, the second during the fall of the same year. They will be discussed in order.

Response to Boron Treatments on Overlimed Oshtemo Loamy Sand

<u>Experimental</u>: Seeds of the Master Marglobe (Stokes) variety were planted on March 27, 1948 in flats which contained Oshtemo loamy sand. Four weeks later the plants were transplanted, one per jar, into 1-gallon glazed jars which contained 4½ kilograms of screened, air dry Oshtemo loamy sand. The roots of each plant were washed free of soil before setting into the jars. At the time of transplanting, soil samples to be analyzed for boron were collected from each jar.

All treatments were applied and thoroughly mixed into the soil at the time of transplanting. The general treatment included:

Reagent	Pounds per acre equivalent
$CaCO_3$	4000
KNO_3	2000
K_2SO_4	760
$Ca(HPO_4)_2 \cdot H_2O$	2500
$MnSO_4 \cdot 4H_2O$	100
$MgSO_4 \cdot 7H_2O$	100

The lime application increased the pH of the soil from 4.4 to 7.8.

Boron was applied at the rate of 0, 10, 25, 50, and 200 pounds per acre of C.P. $Na_2B_4O_7$. All treatments were in triplicate. The experiment was terminated on August 9. At this time the upper half of each plant was saved for tissue analysis.

Hot water soluble boron in the soil and total boron in the plant tissue were determined by the quinalizarine procedure according to Berger and Truog (4).

Statistical analyses were made of the data from fruit yields, green weights, and composition of the leaf samples.

Results and Discussion: The tomato plants grown on this soil showed a marked response to boron as is indicated by the dry weight and fruit yield data in Table 22. The fruit yield was more than doubled by the addition of 10 pounds of $Na_2B_4O_7$ per acre and the statistical analysis showed the increase to be significant. As the rate of application of sodium tetraborate was increased over the initial 10 pounds the increase in yield of fruit became less until with the 50 pound per acre application the yield was significantly less than it was with the 10 pound application. The 50 pound per acre application, however, resulted in a yield which was significantly greater than was that obtained from pots which did not receive boron.

Green weight of the plants was affected similarly by the boron treatments. Applications equivalent to 10, 25, and 50 pounds per acre were equally effective in promoting plant growth. Each of these amounts caused the plants to become significantly heavier than were those which did not receive boron. The increase in yield where the application

TABLE 22.— Effect of boron treatments on the yield and chemical composition of tomato plants grown on Oshtemo loamy sand.

$Na_2B_4O_7$ added (lbs./acre)	Ave. fruit yield(gm.)	Ave. green wt.(gm.)	Ave. boron content(ppm)		Ca/B in plant	Average composition of plant (1)				
			soil	plant		% N	% P	% K	% Ca	% Mg
0	235.0	261.0	0.14	8.0	2175	2.05	0.38	2.19	1.70	0.20
10	565.7	329.3	0.53	25.1	645	1.38	0.27	1.26	1.62	0.16
25	440.3	350.0	1.36	45.7	335	1.43	0.28	1.53	1.53	0.15
50	379.3	319.3	2.86	61.6	242	1.60	0.32	1.93	1.49	0.19
200	333.3	283.7	9.46	249.9	77	1.83	0.38	2.19	1.85	0.16
L.S.D.(2)	133.5	42.0				0.63	0.06	0.35	n.s.	n.s.

(1) Percentage is based on oven dry weight.
(2) Least difference between treatment means required for significance at the 5% point.

of $Na_2B_4O_7$ was at the rate of 200 pounds per acre was not significant. Judging from green weight yields, applications of $Na_2B_4O_7$ could be as great as 50 pounds per acre, but from fruit yields it is evident that the limit should be placed at 10 pounds per acre.

Foliar symptoms indicating nutritional disorders appeared on plants which did not receive boron but the deficiency was not severe enough to cause death of the terminal growing points as described by Johnston and Dore (13). Boron starved plants in this experiment showed a yellowing of the leaflet tips with the affected area later dying. In advanced stages of the deficiency the entire area of the lower leaflets became yellow and, as the marginal tissue became necrotic, the edges of the leaflets curled upward. The disorder appeared on the older leaflets first and progressed to the younger ones.

Toxicity symptoms occurred on all plants which received 50 pounds per acre or more of $Na_2B_4O_7$. The symptoms were slight on the plants which received 50 pounds per acre, but were severe where 200 pounds was applied.

Boron toxicity symptoms appeared as yellowish-brown areas at the tips and along the margins of the older leaflets. The tissue in these areas later died resulting in brown necrotic regions. These symptoms were similar to those described by Johnston and Dore (13) and Johnston and Fisher (14). They were also similar to boron toxicity symptoms of soybeans, as described by Muhr (23).

Chemical analyses of the soil and plant tissue samples revealed that in both the boron concentration increased with applications of boron. As shown in Table 22 the water soluble boron in the soil increased from 0.14 ppm where boron was not applied to 9.46 ppm where 200 pounds per acre of $Na_2B_4O_7$ was applied. Likewise, the concentration of total boron in the tissue samples increased from 8.0 ppm to 249.9 ppm as a result of the 200 pounds per acre treatment.

The concentrations of nitrogen, phosphorus, and potassium in the tissue samples were each significantly affected by the boron treatments. The percentage of each element varied inversely with growth and fruit yield. There was a tendency for them to accumulate where boron was either deficient or present in toxic concentrations. Where growth and fruit yields were highest the concentration of each of the three elements was at a minimum.

The percentages of calcium and magnesium in the tissue samples were not affected by the boron treatments.

As is shown in Table 22, the calcium-boron ratio of the samples decreased from 2175 where boron was not applied to 77 where 200 pounds per acre of $Na_2B_4O_7$ was added. Normal plants, which received the 10 and 25 pound per acre applications, had a calcium-boron ratio of 645 and 335 respectively. Those plants grown with the 50 pound treatment showed slight toxicity symptoms and had a calcium-boron ratio of 242. These values are in fair agreement with those obtained by Brennan and Shive (6). They investigated the calcium-boron relationship in tomato plants and found that the ratio of these elements in the leaves of normal plants ranged from 201 to 593. They also observed that any great deviation from this range resulted in an unbalanced condition which caused physiological abnormalities in the plants. Values much above 593 were associated with boron deficiency symptoms while those much below 201 were associated with boron toxicity symptoms.

Response to Boron Treatments on Thomas Loamy Sand, Miami Loam, and Wisner Sandy Loam

Experimental: This experiment was similar to the preceding one but was expanded to include three soil types, Thomas loamy sand, Miami loam, and Wisner sandy loam. These soil types were selected because they ranged from neutral to alkaline in reaction and because such crops as sugar beets had shown favorable responses to applications of borax on them.

For this experiment Improved Bay State tomatoes were grown. The seeds were planted in flats on July 22, 1948. When the plants were about four inches high they were transplanted following the same procedure as was used in the preceding boron experiment.

The general treatment in this experiment was different from that used in the preceding experiment. The reagents applied to these soils included:

Reagent	Pounds per acre equivalent
NH_4NO_3	1325
K_2SO_4	1325
$Ca(HPO_4)_2 \cdot H_2O$	2500
$MnSO_4 \cdot 4H_2O$	100
$MgSO_4 \cdot 7H_2O$	500

Nitrogen was added as needed during the course of the experiment.

The boron treatments consisted of $Na_2B_4O_7$ at rates equivalent to 0, 10, 25, 50, and 100 pounds per acre. The treatments were in triplicate.

Soil samples to be analyzed for boron were taken from each jar four weeks after transplanting.

The experiment was terminated on November 7 at which time separate leaf samples were collected from each plant. The seventh to sixteenth leaves, inclusive, from the base of the plants made up the leaf samples. At the time of harvest the fruit were well formed but none were ripe.

Individual measurements and determinations were made on each plant and analysis of variance was run on fruit yield, dry weight of plants, and composition of the leaf samples.

Results and Discussion: The average result by treatment for fruit yields, dry weight of plants, chemical composition of leaf samples, and boron content of the soil samples for each of the soils, Thomas loamy sand, Miami loam, and Wisner sandy loam, is shown in Tables 23, 24, and 25 respectively. It can be seen from these data that fruit yields were not affected by treatment on any of the soils. Likewise, the dry weight of the plants on the Thomas and Wisner soils was not affected by treatment. However, the plants on Miami soil were significantly inhibited in growth where 100 pounds per acre of $Na_2B_4O_7$ was applied. As with the other two soils there was no appreciable increase in growth due to boron applications on the Miami soil.

Symptoms of boron starvation did not occur on any of the plants in this study. Toxicity symptoms occurred on all plants which received either of the two higher rates of $Na_2B_4O_7$. These symptoms were the same as those described for boron toxicity in the preceding experiment. As can be seen in Fig. 20, these symptoms were slight where 50 pounds per acre was applied but were severe where the application was 100 pounds per acre. It is of interest that even though severe toxicities occurred at the highest rate of application, fruit yields were not reduced and growth was inhibited only on the Miami loam.

The water soluble boron in the soil and the total boron in the leaf samples increased with increased boron applications, as was true in the preceding experiment. The boron content of the fruit changed only slightly with treatment. Fruit of normal plants contained between 11 and 15

TABLE 23.—Effect of boron treatments on the yield and chemical composition of tomato plants grown on Thomas loamy sand.

$Na_2B_4O_7$ added (lbs./acre)	Ave. fruit yield(gm.)	Ave. dry wt.(gm.)	Ave. boron content(ppm)			Ca/B in leaves	Ave. composition of leaf samples (1)				
			soil	leaves	fruit		% N	% P	% K	% Ca	% Mg
0	548.7	49.3	2.06	69.2	11.5	497	2.34	0.57	1.03	3.44	0.90
10	629.3	46.7	2.65	72.8	12.7	488	2.25	0.56	0.90	3.55	0.90
25	565.3	46.0	3.01	89.2	13.2	381	2.51	0.53	0.97	3.40	0.98
50	559.3	46.3	3.74	150.9	14.5	209	2.54	0.59	0.95	3.15	0.90
100	494.7	44.3	9.22	377.3	12.3	103	2.73	0.64	1.10	3.88	1.03
L.S.D.(2)	n.s.	n.s.					0.28	n.s.	n.s.	n.s.	m.s.

(1) Percentage is based on oven dry weight.
(2) Least difference between treatment means required for significance at the 5% point.

TABLE 24.—Effect of boron treatments on the yield and chemical composition of tomato plants grown on Miami loam.

$Na_2B_4O_7$ added (lbs./acre)	Ave. fruit yield(gm.)	Ave. dry wt.(gm.)	Ave. boron content(ppm)			Ca/B in leaves	Ave. composition of leaf samples(1)				
			soil	leaves	fruit		% N	% P	% K	% Ca	% Mg
0	358.3	42.0	1.32	33.0	11.5	1167	2.88	0.59	1.23	3.85	0.99
10	355.3	42.0	1.73	59.1	10.9	733	2.74	0.68	1.33	4.33	1.10
25	267.0	49.3	2.27	62.4	14.2	615	2.60	0.63	1.52	3.84	0.93
50	375.0	38.3	3.47	124.5	21.0	356	2.76	0.76	1.40	4.43	1.05
100	370.7	34.7	5.76	257.9	19.4	185	2.94	0.71	1.83	4.77	1.08
L.S.D.(2)	n.s.	7.6					0.15	n.s.	0.27	0.59	n.s.

(1) Percentage is based on oven dry weight.
(2) Least difference between treatment means required for significance at the 5% point.

TABLE 25.—Effect of boron treatments on the yield and chemical composition of tomato plants grown on Wisner sandy loam.

$Na_2B_4O_7$ added (lbs./acre)	Ave. fruit yield(gm.)	Ave. dry wt.(gm.)	Ave. boron content(ppm)			Ca/B in leaves	Ave. composition of leaf samples(1)				
			soil	leaves	fruit		% N	% P	% K	% Ca	% Mg
0	517.7	50.0	1.30	50.1	14.3	866	2.27	0.43	0.97	4.34	1.22
10	532.0	53.0	1.62	76.0	14.5	571	2.25	o.46	1.07	4.34	1.18
25	530.7	47.0	2.53	80.7	17.9	496	2.44	0.51	0.98	4.00	1.27
50	517.3	46.7	4.12	121.5	14.7	337	2.36	0.51	1.02	4.09	1.37
100	564.3	46.3	4.80	290.9	18.9	157	2.38	0.55	0.98	4.57	1.42
L.S.D.(2)	n.s.	n.s.					n.s.	0.07	n.s.	n.s.	n.s.

(1) Percentage is based on oven dry weight.
(2) Least difference between treatment means required for significance at the 5% point.

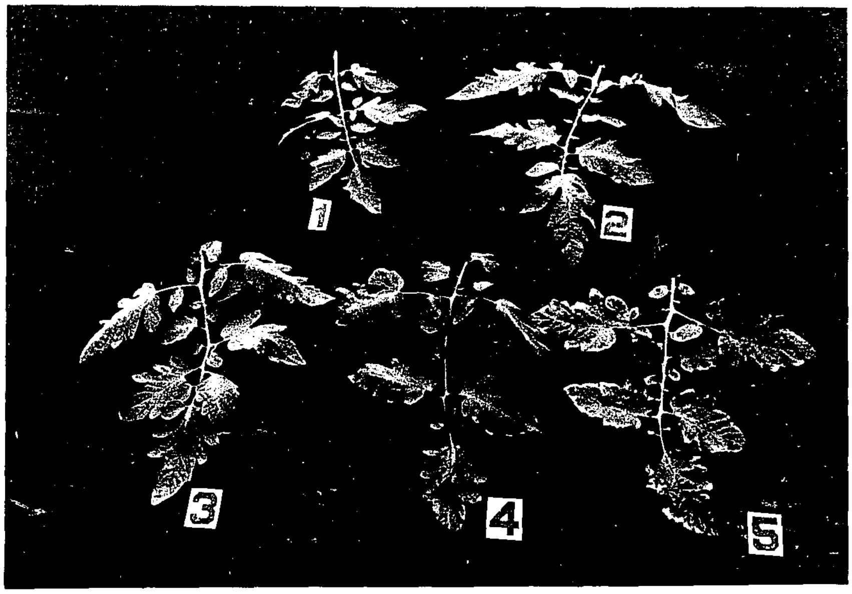

FIG. 20.—Leaves from tomato plants grown on Thomas loamy sand which received increased rates of $Na_2B_4O_7$. The applications in pounds per acre were: 1-0, 2-10, 3-25, 4-50, 5-100.

ppm of boron on a dry weight basis.

The mineral composition of the leaf samples in this experiment was not influenced by treatment as much as it was where the plants were grown on Oshtemo loamy sand. The composition of plants grown on the Thomas loamy sand was not affected by the sodium tetraborate applications so far as phosphorus, potassium, calcium, and magnesium in the leaves was concerned but there was a slight nitrogen accumulation where the boron application was the highest. This is shown in Table 23.

Similar results were obtained with the plants grown on Wisner sandy loam. As Table 25 shows, boron treatments did not affect the concentrations of nitrogen, potassium, calcium, or magnesium in the leaf samples, but did cause a slight accumulation of phosphorus where the highest boron treatment was made.

A greater variation in the composition of the leaf samples occurred in plants grown on the Miami loam than in those grown on the other two soils. In these samples the greatest boron application caused significant increases in per cent nitrogen, potassium, and calcium while the phosphorus and magnesium concentrations were not affected. This result is indicated in Table 24.

Considering the data from both boron experiments, the percentage of nitrogen, phosphorus, and potassium in the leaf samples was markedly changed only where growth was inhibited, due either to a starvation for boron or to an excess of boron. Leaf samples from plants which developed normally were essentially the same in their composition of nitrogen, phosphorus, potassium, calcium, and magnesium regardless of boron treatment. At the extreme levels of boron, where growth was inhibited, there was a tendency for nitrogen, phosphorus, and potassium to accumulate in the leaves. Within the limits of the boron applications used in these experiments the calcium concentration in the leaves of the boron deficient plants was not increased. Its concentration was increased by toxic amounts of boron only on the Miami loam. The percentage of magnesium in the leaves was not affected by any of the boron treatments.

During the course of the experiment it was observed that toxicity symptoms were more severe on the Thomas loamy sand than on either the Miami loam or the Wisner sandy loam. Chemical analyses later showed that the plants grown on the Thomas soil contained less calcium and more boron than did those grown with the same boron treatments on the other two soils. The water soluble boron, also, was generally higher in the Thomas soil. These conditions resulted in lower calcium-boron ratios in the leaves of the plants grown on this soil. As a result more severe toxicity symptoms occurred at the high boron levels on the Thomas loamy sand than on the other two types.

These data show that the calcium-boron ratio in the leaves of boron deficient tomato plants was greater than 1167 and the ratio in the leaves which showed toxicity symptoms was approximately 375 and below.

The soils studied were relatively high in calcium and tomato plants grown on them developed normally when the concentration of water soluble boron in the soil ranged from 0.50 to 2.75 ppm. When the concentration varied greatly in either direction from this range deficiency or toxicity symptoms were noted.

SUMMARY AND CONCLUSIONS

The results of a study of the effects of nitrogen, phosphorus, potassium, and boron levels in the soil on the yield and chemical composition of greenhouse tomatoes are presented.

Plants were grown in the greenhouse in pot culture. Levels of nitrogen, phosphorus, and potassium were based on parts per million in the soil extract according to the Spurway soil testing procedure.

Two factorial experiments involving nitrogen, phosphorus, and potassium were conducted. In the first, the soil was Oshtemo loamy sand with nitrate levels maintained at 0, 25, 50, 100, and 200 ppm, with phosphorus at 0, 2½, 5, 10, and 25 ppm, and with potassium at 0, 15, 30, 45, and 60 ppm. In the second, the soil used was Brookston silt loam and nitrate levels were maintained at 0, 50, 100, and 200 ppm, phosphorus at 0, 10, 20, and 40 ppm, and potassium at 0, 25, 50, and 100 ppm. In both experiments fruit yield and dry weight were obtained from each plant. Leaf samples were collected in the second experiment and were analyzed for total nitrogen, phosphorus, and potassium. Statistical analyses of these data were made.

Differential varietal response to potassium fertilizer was studied. Plants of the Improved Bay State and Spartan Hybrid varieties were grown at potassium levels of 0, 5, 10, 25, 50, and 100 ppm. Leaf and fruit samples were collected and analyzed for phosphorus, potassium, calcium, and magnesium.

Tomatoes were grown on Oshtemo loamy sand, Thomas loamy sand, Miami loam, and Wisner sandy loam with boron treatments ranging from 0 to 200 pounds per acre of $Na_2B_4O_7$. Minimum requirements as well as the tolerance range for the element were studied. The relationship of boron to the mineral composition of the leaves was investigated.

The results of these experiments may be briefly summarized as follows:

1. A method devised for determining the fertilizer "fixing power" of soil proved useful in establishing and maintaining nutrient levels.

2. Highest yields of fruit resulted where the nitrogen level was maintained between 25 and 50 ppm, phosphorus between 5 and 10 ppm, and potassium between 15 and 30 ppm.

3. Nitrogen levels above 50 ppm in Oshtemo loamy sand resulted in a decrease in both fruit yield and dry weight.

4. Phosphorus and potassium levels as high as 25 and 60 ppm, respectively, on Oshtemo loamy sand and as high as 40 and 100 ppm, respectively, on Brookston silt loam were not toxic to the plants where the nitrogen supply was adequate.

5. Deficiency symptoms of nitrogen, phosphorus, and potassium were observed. With nitrogen deficiency the older leaflets were uniformly yellow. In advanced stages the leaflet veins were distinctly purple while the interveinous

tissue remained a faded yellow. Phosphorus deficiency symptoms appeared as uniform purpling of the under side of the leaflets while the upper side became very dark green. Plants which were starved for potassium showed marginal yellowing of the younger leaflets and yellow mottling of the older ones. In the presence of soluble nitrogen characteristic white spots accompanied the yellowing where the plants were starved for potassium.

6. In the presence of a low supply of available potassium, symptoms of potassium starvation appeared earlier and with greater severity as either or both nitrogen and phosphorus levels were increased.

7. In the presence of a low available phosphorus supply, symptoms of phosphorus starvation were progressively more severe with increased nitrogen levels.

8. High phosphorus levels tended to counteract the harmful effects of excessive nitrogen.

9. The percentage of nitrogen, phosphorus, and potassium in the dry leaf samples increased with each addition of their respective salts.

10. Low nitrogen levels favored the accumulation of potassium in the leaves, but had no effect on the phosphorus content.

11. Phosphorus levels were unrelated to the concentration of nitrogen and potassium in the leaves.

12. Low potassium levels favored the accumulation of

phosphorus in the leaves,but had no effect on the nitrogen content.

13. High potassium levels caused a reduction in the percentage of calcium and magnesium in the leaves.

14. Improved Bay State tomatoes required a higher concentration of potassium in the leaves than did the Spartan Hybrid plants in order to prevent the occurrence of leaf yellowing due to potassium starvation.

15. Tomatoes showed a favorable response to boron when grown on overlimed Oshtemo loamy sand.

16. The concentration of boron in the plant tissues was directly related to the amount in the soil.

17. Boron treatment had a significant effect on the percentage of nitrogen, phosphorus, and potassium in the tissue samples only when it was low or high enough to cause restricted growth. In these cases the three elements accumulated. No relationship was found between boron treatment and magnesium concentration. The percentage of calcium in the leaves was increased by boron applications in only one of the four trials.

18. Tomato plants developed normally when the concentration of water soluble boron in the soils ranged from 0.50 to 2.75 ppm. When the concentration varied greatly from this range deficiency or toxicity symptoms were noted.

19. Applications equivalent to 50 pounds per acre or more of $Na_2B_4O_7$ resulted in boron toxicity symptoms on the plants.

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