THE EFFECTS OF VARIOUS LEVELS OF NITROGEN, PHOSPHORUS, AND POTASSIUM ON THE GROWTH OF SUGAR BEETS AND TABLE BEETS

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THESIS

THE EFFECTS OF VARIOUS LEVELS OF NITROGEN,
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OF SUGAR BEETS AND TABLE BEETS

by

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TABLE OF CONTENTS

INTRODUCTION

During the past century various methods of diagnosing the fertilizer requirements of plants have been developed. When pointing out some of the early investigators, one should give much credit to Theodore de Saussure who was among the first to apply quantitative methods to fertility investigations. This work, continued and enlarged upon by Boussingault and Liebig, blazed the trail for a great deal of the scientific research since that time. Liebig placed all emphasis upon the analyses of the ash of plants but it has been found that purely quantitative ash analyses are not sufficient, and therefore it has become common practice today to use the physiologically active mineral constituents in the soil and green plant tissue as a better guide to the nutrient needs of plants.

The culture of many crops has been intensively studied by these methods to determine the concentrations and ratios of nutrients which might result in greater yields. Beets are known to be extremely responsive to the application of nutrient elements. This study was therefore undertaken to determine the effect of different concentrations, and intensity ratios of nitrogen, phosphorus, and potassium on the growth and characteristics of sugar beets and table beets and to establish the optimum balance and levels of nutrient concentrations for these crops.

REVIEW OF LITERATURE

Ulrich (28) found that the concentration of nutrients in plants was a function of the time, plant, climate, and management practices. He also stated that the minimum growth possible within the limits of supply of a single element can result only when the concentration of all elements have been brought into balance at the level of intensity determined by that element. "At any level of nutritional intensity there exists a balance of nutrients at which optimum growth for that intensity level will result..." Further, at any level of nutritional intensity, provided that all nutrient elements are in proper balance, it is possible to obtain plants that appear normal in every respect and in which all metabolic processes are probably quantitatively normal. However, maximum growth and yield result only when the proper balance of nutrient elements occurs in combination with their optimum intensity. It is possible to have plants lacking in distinctive symptoms of malnutrition, but which fail to produce maximum yields.

Lundegardh (20) observed that leaf analysis gives the direction and extent of nutritional unbalance within the plant and provides the knowledge whereby the proper balance between fertilizer elements may be determined when fertilizer applications are made under various soil and cultural conditions.

Weidemann and Cook (33), after a greenhouse study of the deficiency symptoms of sugar beets grown in quartz sand, found the following: "Nitrogen deficient plants were very small, but had healthy appearing roots and spreading pale green leaves which developed a slight pinkish mottling with an increase in age. Plants deficient in phosphorus were very small with deep green, erect leaves, and red stems or crowns. The tap roots were small and covered with fine black roots..." Potassium deficient plants grew larger, but required more potassium to keep them alive. These plants became yellow and necrotic along the borders of their leaves.

Demidenko (11) concludes: "Nitrogen is required by sugar beets throughout the growth period. The time of the development of the four to seven pairs of leaves should be considered the most critical with respect to nitrogen..." The cutting off of nitrogen reduced both the yield of the roots and leaves. The excluding of nitrogen from the nutrient solution at the period of seven to ten leaf formation reduced the amount of soluble nitrogen; plant uptake of phosphorus as well as potassium was decreased, and the deficiency of one of the most important elements prevented the normal development of the organism as a whole.

By conducting other field experiments, Decoux and others (10) found that large applications of potash alone did not greatly change the expressed juice of sugar beet roots. Leaf growth, however, was found to have been influenced greatly by doses of nitrogen and potash. Potash in excess of the plants needs was found to be stored in the leaves. Heavy applications of nitrogen in the absence of potash produced marked injurious effects.

Demidenko (12) also found that a lack of potassium during early stages of the development of sugar beets resulted in reduced yield and increased quality of the crop. The critical period for potassium uptake was found to be that of maximum sugar accumulation during the period of the seventh to tenth leaf formation. Insufficient potassium during the second half of the growing season resulted in an increase of soluble nitrogen and the maximum uptake of nutrients was found to coincide with the critical period of potassium nutrition.

[illegible] (24) summarized results of the application of commercial fertilizers on sugar beets over a period of twenty years in the Arkansas Valley of Colorado and found a general need for phosphate bearing fertilizers. [illegible] (5) found that phosphorus was probably the limiting factor in the growth of sugar beets when preceded by other crops. Frank and others (15) concluded that at given phosphate values, the response to phosphorus increased with the clay content and acidity of the soil.

Atkinson, [illegible], and [illegible] (2) found that the amount of nitrogen and potassium was usually increased in the plant tissue when these materials were applied in a fertilizer. When nitrate concentrations were increased, phosphate diminished and when nitrogen decreased phosphorus increased.

[illegible] and [illegible] (13) state; "Fertilizers had a somewhat greater influence on the yield of roots than on the tops of sugar beets, but high yields of tops were generally associated with high root yields..." Phosphate and potash fertilizers had some influence on the dry matter of sugar beet tops, particularly on soils where there was a deficiency of these minerals. Treatments with carriers of [illegible] substantially raised the [illegible] in the beet foliage.

In experimental work on table beets, Blackmore, Newman, and others (3) found evidence that the yield of tops was less with low fertilizer treatments, and the size of the beets was larger on plots where complete and double treatments of fertilizers were added. Low temperature produced anthocyanin pigments, while high temperature and the abundant production of foliage caused this pigment to break down. Double applications of phosphorus produced the best normal color of the beets, while a deficiency of phosphorus resulted in the poorest color.

Rudzhavseva (18) studied the effects of fertilizer applications on various vegetables and found that table beets responded more to potash fertilizers than did any of the other vegetables studied. Smith and Schlenker (25) concluded from their experiments on the optimum soil nutrient levels for table beets that growth on plots with less than 10 p.p.m. nitrate was slow and took place at the expense of the nitrate reserve in the soil. At 25 p.p.m. there was greater response, especially where the number of plants was low, but maximum yield was not obtained until the 50 p.p.m. level was reached. The concentration of nitrogen in the expressed juice correlated with the growth rate of the beets. Less than 500 p.p.m. nitrate in the midrib correlated with the retarded growth rates. The nitrate concentrations in the midribs were greater where the best response was obtained.

EXPERIMENTAL METHODS

SOIL

Oshtemo loamy sand was selected as the soil in which to grow beets. Oshtemo, according to J. O. Veatch (30), includes light brown loamy sands and sandy loams, underlain by pervious sand with small admixtures of clay and gravel, and it is very low in fertility.

The nutrient levels in Oshtemo were determined by using the Spurway active test (26) and were found to be less than 1 p.p.m. nitrogen, 3 p.p.m. potassium, and 2 p.p.m. phosphorus. The pH was 5.0. All grass was scraped off, and only the first eight inches of top soil used. This was screened and air dried before it was potted.

Oshtemo was chosen because of its low fertility level. Since it is low in organic matter and clay content, interfering ions and colloids were mostly avoided and the problem of establishing an index of the nutrient requirements was greatly simplified.

FIXATION TESTS

Since the objective of this experiment was to measure the response of the beet crops to the available nutrients, the problem necessitated the establishing of the amount of minerals required to bring the soil to various levels of actively available nutrients so that the response could be studied at these different levels.

The soil was therefore calibrated by running tests to determine the fixing power of Oshtemo for nitrogen, phosphorus, and potassium when applied in the form of the mineral salts that were used in this experiment (Table 1). The fixation test for each element was run by weighing out twenty-four 150 gram samples of air dry soil to serve for twelve treatments in duplicate. The treatments included twelve levels each of nitrogen, phosphorus, and potassium. The soils were then brought to maximum water holding capacity which was kept constant at room temperature for two weeks. The Spurway test was then used to determine the active or available nutrients. The calibration curves shown in Figs. 1, 2 and 3 were drawn from the data obtained in these tests.

A look at these curves shows that the fixation of nitrate by Oshtemo resulted in a straight line relationship. In other words, the nitrate in the soil was directly proportional to the nitrate that was added. This is shown by the constant value of the slope of the curve throughout its entire length. Phosphorus was fixed to the greatest extent and the percentage of fixation decreased as larger quantities of phosphorus were added. Proportionally it was much less available when small increments of monocalcium phosphate were added than when larger applications were made. This is shown by the more rapid rise of the curve with increased increments of added phosphorus. The potassium fixation curve shows that there was also a slight decrease in percentage fixation as greater quantities of sulfate of potash were applied.

TREATMENTS

A 4 x 4 x 3 factorial design was chosen to carry out the

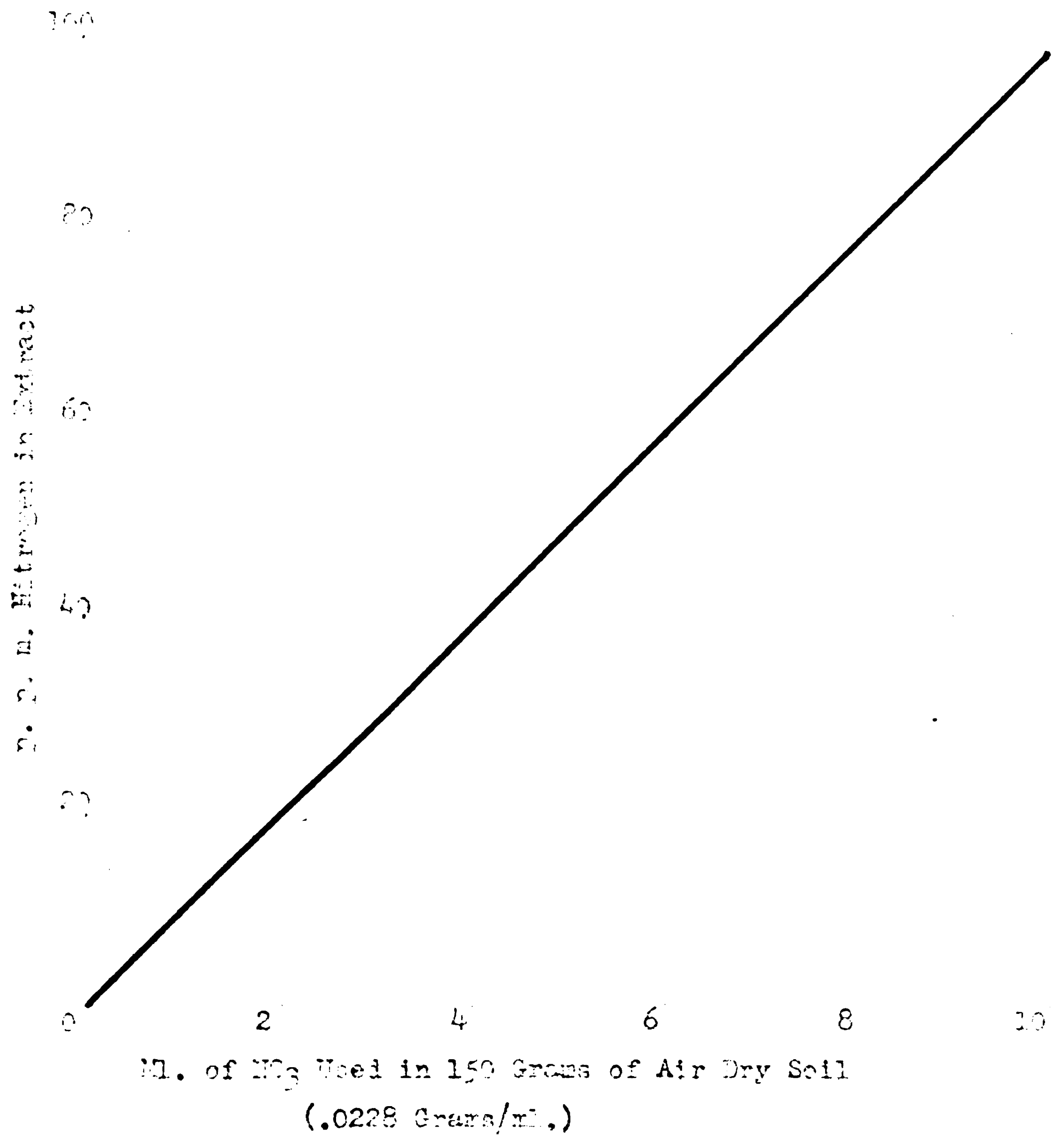

Fig. 1. -- Nitrogen fixation by Osthemo

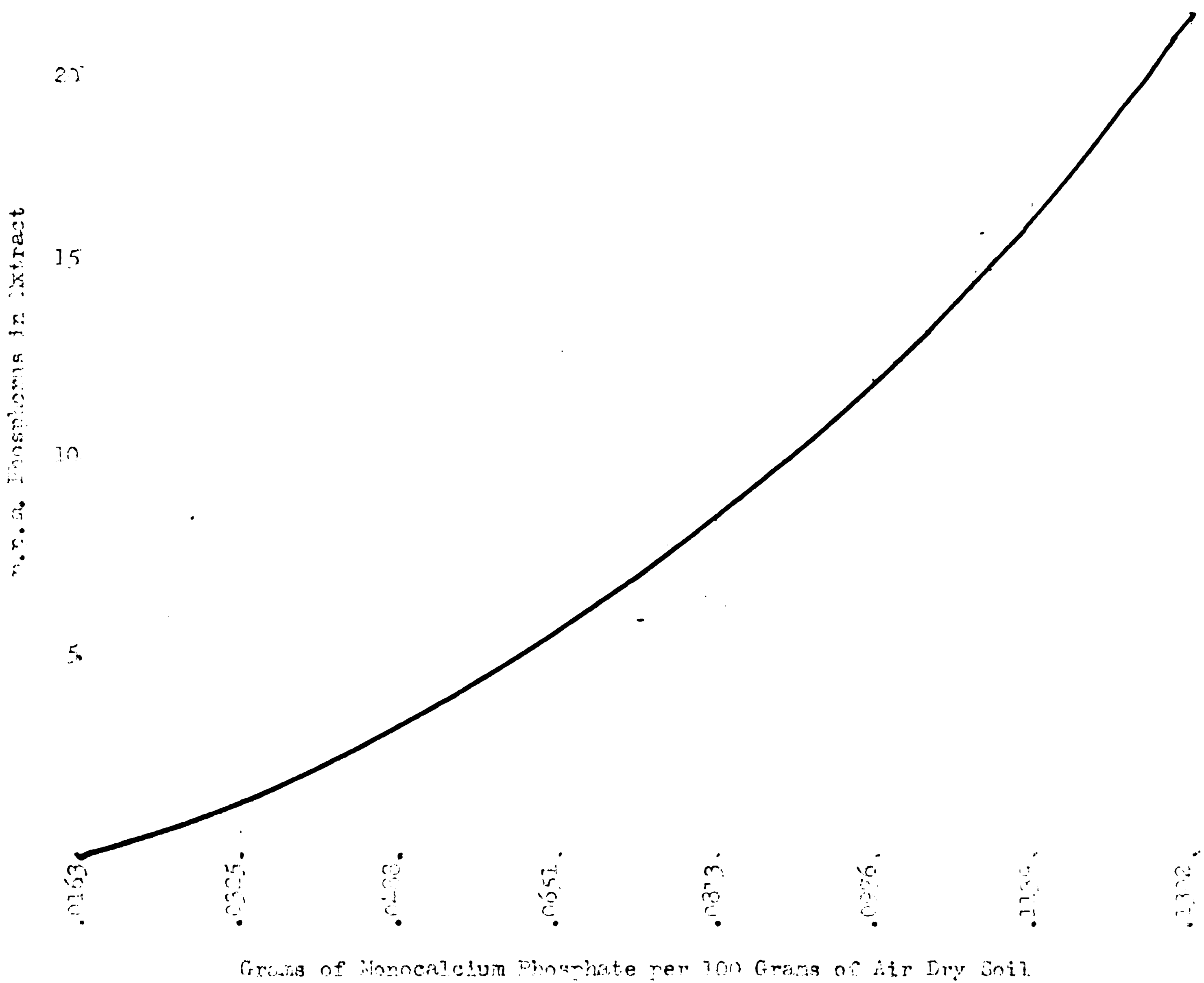

Fig. 2. -- Phosphorus fixation by [illegible] (3[illegible])

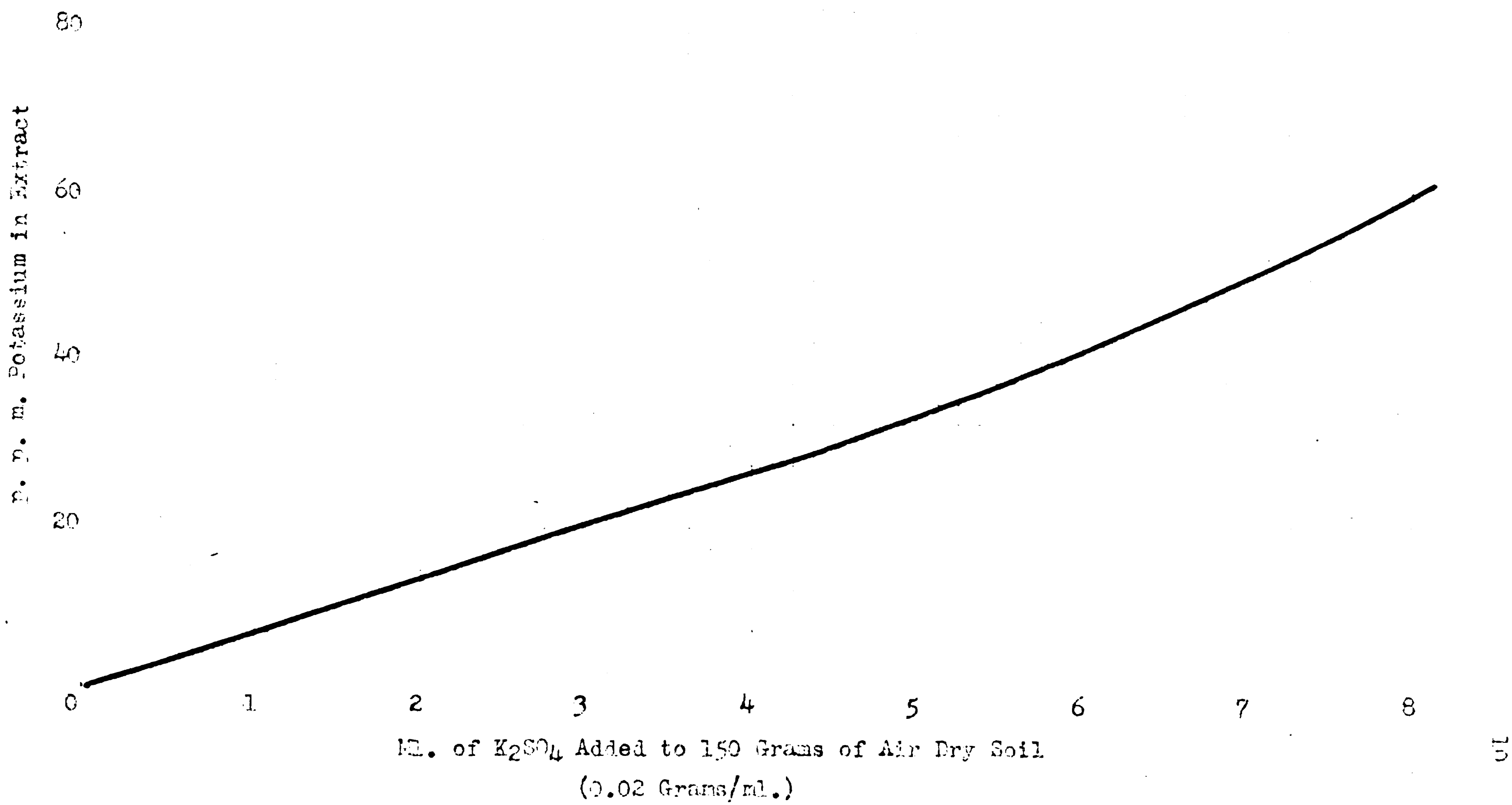

Fig. 3. -- Potassium fixation by Osthemo (32)

experiment. The four levels of nitrogen selected were 0, 25, 50, and 100 p.p.m.; potassium levels chosen were 0, 15, 30, and 60 p.p.m.; and the three levels of phosphorus selected were 0, 5, and 10 p.p.m. This gave a total of forty-eight treatments (Table 1) which were duplicated for both sugar beets and table beets, making a total of 192 pots. As in the fixation tests, monocalcium phosphate and sulphate of potash were used as carriers of phosphorus and potassium, respectively. There was a split application of the nitrate. One-half of the required nitrogen was furnished by ammonium nitrate with the other half being obtained from nitrate of soda. This was done to avoid the possibility of injury from too much sodium. Even though much evidence has been presented to show the beneficial effect of sodium for sugar beets and table beets (19), excessive concentrations might have seriously complicated this experiment. Complications resulting from high concentrations of sodium would be quite likely to develop in a sand such as Oshtemo where the buffer capacity of the soil is low. Also sodium nitrate would tend to offset the acid reaction promoted by large applications of ammonium nitrate (22). Beets are particularly sensitive to the deficiencies of manganese, magnesium, and boron (16). Therefore, to prevent any interferences by the malfunctioning of the physiological activities within the plants or the development of deficiency symptoms due to a lack of these elements, the following steps were taken: Manganese and magnesium sulphates were applied at the rate of 100 lbs. per acre and sodium tetraborate at the rate of five pounds per acre. Beets are lime loving crops and do best in a soil with plenty of calcium (17).

Therefore, four grams of calcium carbonate was added to each pot. The pH was raised from 5.0 to approximately 6.5.

Nine kilos of sand was placed in two-gallon pots that had been previously weighed. The soil was dumped into a mixing pan and thoroughly mixed after treatment. To apply nitrogen and potassium, the salts of these elements were dissolved in distilled water and the proper volume measured to raise the nutrients to the selected levels (Table 1). Volumes were adjusted to fit standard pipettes and then the nutrient concentrations per c. c. were calculated in order to facilitate the addition of the treatments. The quantities of fertilizer materials needed to raise the soil's active nutrients to the selected levels had already been determined by fixation tests (Figs. 1, 2, 3). Manganese, magnesium, and boron carriers were equally added to all pots at this time. The low solubility of monocalcium phosphate made it necessary that it be applied in the crystalline state. Calcium carbonate was also applied in a dry form.

GREENHOUSE AND LABORATORY PROCEDURE

Because this light textured soil had a tendency to wash badly, the moisture content of the soil was raised to 18 per cent of its dry weight with distilled water before the seeds were planted. The moisture equivalent of Oshtemo was not used as a basis for optimum moisture because it was found to be too low. The 18 per cent figure was arrived at by taking a tumbler of soil and measuring the amount of water necessary to moisten the soil without having any free water in the bottom of the tumbler.

Sugar beets were planted April 27 and the table beets on April 29. On May 6, the nutrients were checked and conductivity tests were run to determine the soluble salt content of the soil. Spurway's system (26) was used to determine the nutrient levels, and color comparisons to determine the phosphorus and potassium concentrations were made with a Lumetron Colorimeter (Figs. 4, 5). Proper growing space was provided by thinning the sugar beets to three plants per pot and the smaller table beets to five plants per pot. The benches were rolled out into the open on May 21 in order to avoid the excessive heat of the greenhouse and for better temperature control (3). The nitrogen levels were also checked at this time. On June 1 nitrate applications sufficient to restore the original levels were made. On June 18, pictures were taken to show the effect of the four nitrate levels, see Figs. 12 and 22. The levels were also restored on that date. Later, on June 25, the potassium concentrations were adjusted to their original levels (Table 5).

On July 11 the beets were harvested and the pictures shown as Figs. 13, 14, 23, and 24 were taken. The tops and roots were dried separately and weighed. Then the dried tissue was ground in a hammer mill, and total phosphorus determinations (28) were run on the composite replicates of roots and tops for both sugar beets and table beets. The procedure for the phosphorus determination was as follows: One-half-gram samples were weighed on an analytical balance and placed in porcelain crucibles. After this each sample was treated with 2 ml. of 1.0 molar ammonium nitrate and 0.2 molar magnesium nitrate solution. This was then ashed in a furnace at a temperature of 550°C for four hours and the ash was taken up in 200 ml. of 2 per cent acetic acid. From this 5 to 10 ml. were made up to 100cc and finally 10 ml. of the latter was used to determine phosphorus colorimetrically, using F and S reducing agent (14). The readings were made with a Lumetron colorimeter.

MAINTENANCE OF NUTRIENT LEVELS

The soil was tested by using the Simplex soil testing system (26). The levels were checked about every two weeks. A soil sampling tube was used to take the sample which made it possible to remove a column of soil that represented a true cross section of the growing medium extending from the top to the bottom of the container. The column of soil was dried and thoroughly mixed.

The nutrients in the soil were extracted by using 0.0[illegible] acetic acid with a soil-extract ratio of 1:4. Nitrate determinations in the extract were made with diphenylamine in concentrated sulphuric acid according to the specifications of the Michigan Agriculture Experiment Station Technical Bulletin, 132, 1949 (26). Phosphorus and potassium were also determined by the Simplex active test. Volumes of soil and extracting solution were of sufficient size to make possible the use of a colorimeter. Standard curves for determining the quantities of nutrients in the extract were drawn by developing known concentrations of these elements and plotting their per cent transmission against concentration (Figs. 4, 5). From the soil test results it was possible, by use of the curves shown in

Figs. 1, 2, and 3 in quantifying the amounts of nutrient [illegible] necessary to restore the soils to their original nutrient levels.

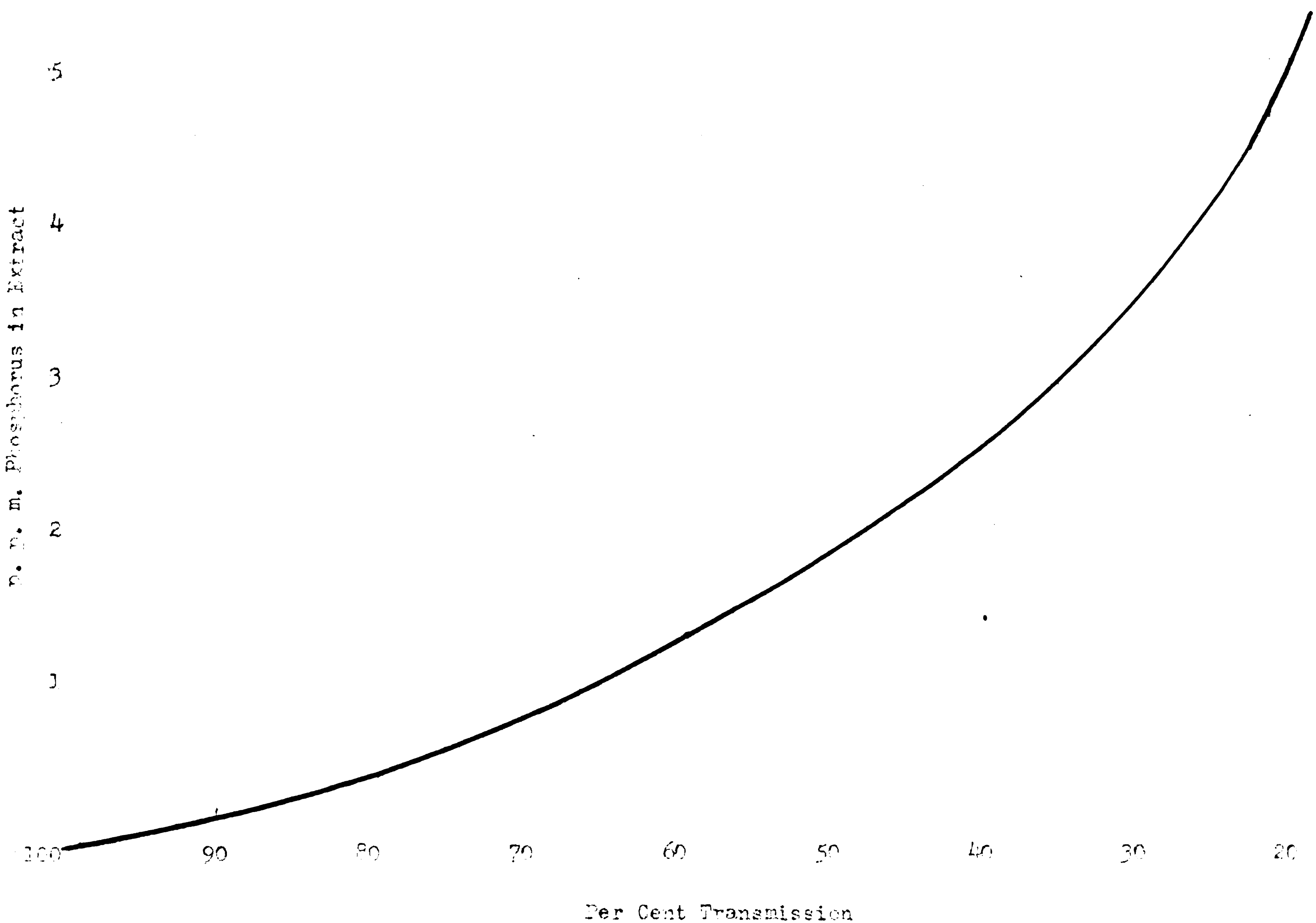

Fig. 4. -- Standard curve for phosphorus determination

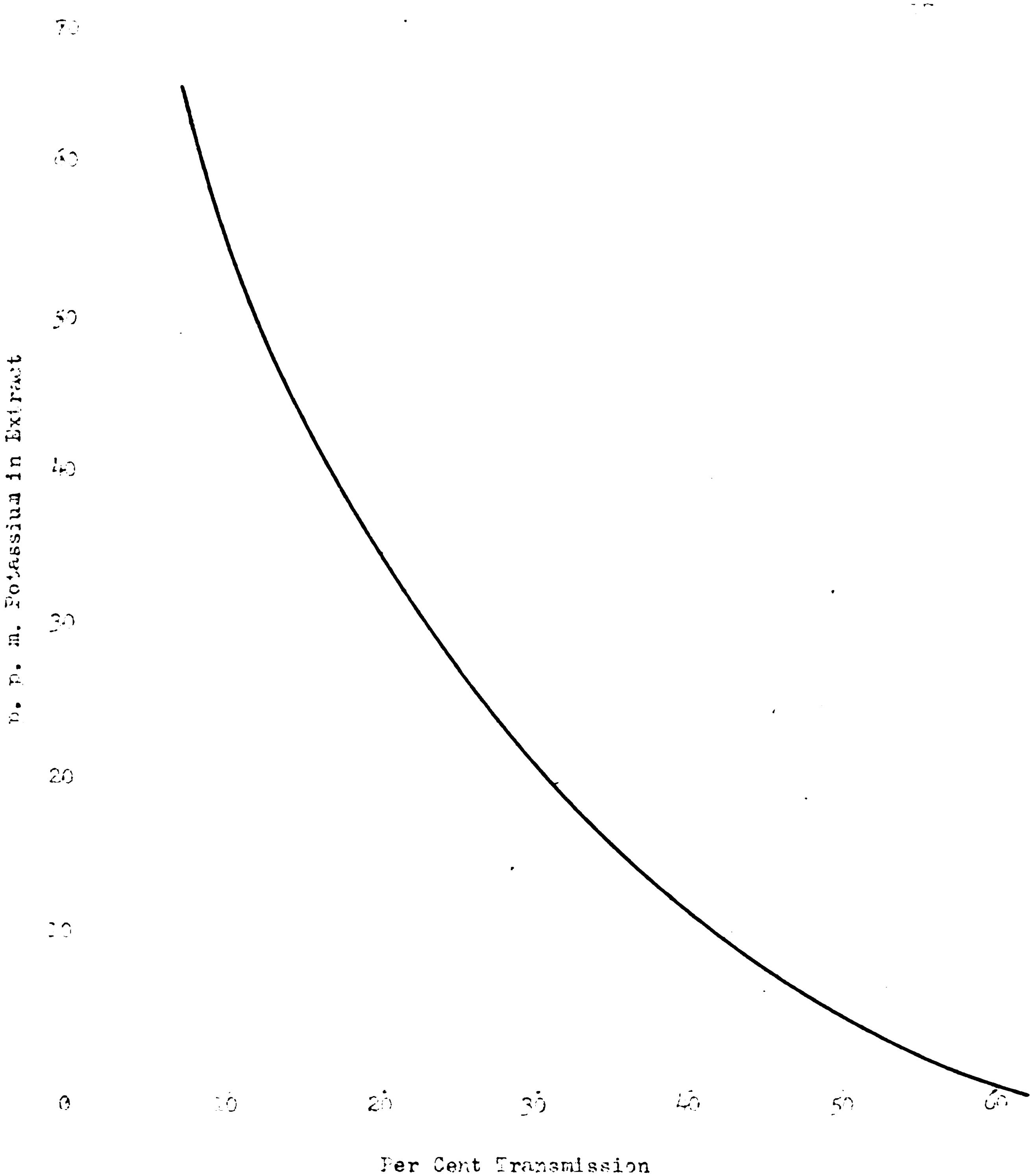

Fig. 5. -- Standard curve for potassium determination

DATA

Table 1.—Treatments

Treatments	Nutrient Levels (p.p.m. in extract)			Grams of Carrier per Pot			
	P	NO_3	K	$CaH_4(PO_4)_2$	NH_4NO_3	$NaNO_3$	K_2SO_4
1	0	0	0	0	0	0	0
2	0	0	15	0	0	0	2.79
3	0	0	30	0	0	0	5.40
4	0	0	60	0	0	0	9.99
5	0	25	0	0	0.81	1.71	0
6	0	25	15	0	0.81	1.71	2.79
7	0	25	30	0	0.81	1.71	5.40
8	0	25	60	0	0.81	1.71	9.99
9	0	50	0	0	1.62	3.42	0
10	0	50	15	0	1.62	3.42	2.79
11	0	50	30	0	1.62	3.42	5.40
12	0	50	60	0	1.62	3.42	9.99
13.	0	100	0	0	3.24	6.84	0
14	0	100	15	0	3.24	6.84	2.79
15	0	100	30	0	3.24	6.84	5.40
16	0	100	60	0	3.24	6.84	9.99
17	5	0	0	5	0	0	0
18	5	0	15	5	0	0	2.79
19	5	0	30	5	0	0	5.40
20	5	0	60	5	0	0	9.99
21	5	25	0	5	0.81	1.72	0
22	5	25	15	5	0.81	1.72	2.79
23	5	25	30	5	0.81	1.72	5.40
24	5	25	60	5	0.81	1.72	9.99
25	5	50	0	5	1.62	3.42	0
26	5	50	15	5	1.62	3.42	2.79
27	5	50	30	5	1.62	3.42	5.40
28	5	50	60	5	1.62	3.42	9.99
29	5	100	0	5	3.24	6.84	0
30	5	100	15	5	3.24	6.84	2.79
31	5	100	30	5	3.24	6.84	5.40
32	5	100	60	5	3.24	6.84	9.99

Table [illegible]. — Continued

Treatments	Nutrient Levels (p.p.m. in culture)			Grams of Chemical per pot			
	N	P_2O_5	K	$CaH_4(PO_4)_2$	[illegible]	[illegible]	[illegible]
33	10	0	0	10	0	0	0
34	10	0	15	10	0	0	2.7[illegible]
35	10	0	30	10	0	0	5.4[illegible]
36	10	0	60	10	0	0	[illegible]
37	10	25	0	10	0.91	1.77	0
38	10	25	15	10	0.91	1.7[illegible]	2.7[illegible]
39	10	25	30	10	0.91	1.7[illegible]	5.4[illegible]
40	10	25	60	10	0.91	1.7[illegible]	[illegible]
41	10	50	0	10	1.82	3.40	0
42	10	50	15	10	1.82	3.40	2.7[illegible]
43	10	50	30	10	1.82	3.40	5.4[illegible]
44	10	50	60	10	1.82	3.40	[illegible]
45	10	100	0	10	3.64	6.94	0
46	10	100	15	10	3.64	6.94	2.7[illegible]
47	10	100	30	10	3.64	6.94	5.4[illegible]
48	10	100	60	10	3.64	6.94	[illegible]

Table 2. -- First Addition of Nitrogen (p.p.m.)

Table Beets						Sugar Beets					
Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added
1	0	17	0	33	0	1	0	17	0	33	0
2	0	18	0	34	0	2	0	18	0	34	0
3	0	19	0	35	0	3	0	19	0	35	0
4	0	20	0	36	0	4	0	20	0	36	0
5	2.5	21	2.5	37	2.5	5	5	21	5	37	5
6	2.5	22	2.5	38	2.5	6	5	22	5	38	5
7	2.5	23	2.5	39	2.5	7	5	23	5	39	5
8	2.5	24	2.5	40	2.5	8	5	24	5	40	5
9	0	25	0	41	0	9	2.5	25	2.5	41	2.5
10	0	26	0	42	0	10	2.5	26	2.5	42	2.5
11	0	27	0	43	0	11	2.5	27	2.5	43	2.5
12	0	28	0	44	0	12	2.5	28	2.5	44	2.5
13	0	29	0	45	0	13	0	29	0	45	0
14	0	30	0	46	0	14	0	30	0	46	0
15	0	31	0	47	0	15	0	31	0	47	0
16	0	32	0	48	0	16	0	32	0	48	0

Table 3. -- Second Addition of Nitrogen (p.p.m.)

Table Beets						Sugar Beets					
Treatment	p.p.m. Added	Treatment	p.p.m. Added	Treatment	p.p.m. Added	Treatment	p.p.m. Added	Treatment	p.p.m. Added	Treatment	p.p.m. Added
1	0	17	0	33	0	1	0	17	0	33	0
2	0	18	0	34	0	2	0	18	0	34	0
3	0	19	0	35	0	3	0	19	0	35	0
4	0	20	0	36	0	4	0	20	0	36	0
5	20	21	22.5	37	17.5	5	25	21	22.5	37	22
6	22.5	22	25	38	22.5	6	22.5	22	22.5	38	25
7	22.5	23	25	39	22.5	7	22.5	23	22.5	39	22.5
8	22.5	24	25	40	22.5	8	22.5	24	22.5	40	22.5
9	25	25	30	41	20	9	37.5	25	37.5	41	27.5
10	35	26	40	42	30	10	37.5	26	37.5	42	32.5
11	30	27	40	43	35	11	37.5	27	42.5	43	32.5
12	30	28	40	44	40	12	30.5	28	42.5	44	32.5
13	25	29	25	45	25	13	30	29	30	45	30
14	30	30	30	46	35	14	35	30	40	46	35
15	25	31	40	47	35	15	35	31	35	47	30
16	30	32	30	48	30	16	30	32	35	48	25

Table 4. — Final Nitrate Test (p.p.m. in extract)

Table Beets						Sugar Beets					
Treat-ment	p.p.m. in Soil	Treat-ment	p.p.m. in Soil	Treat-ment	p.p.m. in Soil	Treat-ment	p.p.m. in Soil	Treat-ment	p.p.m. in Soil	Treat-ment	p.p.m. in Soil
1	0	17	0	33	0	1	0	17	0	33	0
2	0	18	0	34	0	2	0	18	0	34	0
3	0	19	0	35	0	3	0	19	0	35	0
4	0	20	0	36	0	4	0	20	0	36	0
5	15	21	12	37	18	5	10	21	12	37	10
6	10	22	10	38	10	6	8	22	10	38	10
7	10	23	10	39	10	7	8	23	8	39	8
8	10	24	10	40	10	8	10	24	10	40	10
9	45	25	40	41	40	9	35	25	30	41	40
10	30	26	30	42	35	10	25	26	25	42	30
11	35	27	30	43	35	11	30	27	25	43	25
12	40	28	35	44	40	12	30	28	35	44	35
13	90	29	85	45	90	13	80	29	80	45	55
14	80	30	80	46	85	14	70	30	80	46	70
15	80	31	80	47	80	15	70	31	85	47	80
16	[illegible]	32	80	48	80	16	85	32	85	48	[illegible]

Table 5. -- Potassium Added (p.p.m.)

Table Beets						Sugar Beets					
Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added	Treat-ment	p.p.m. Added
1	0	17	0	33	0	1	0	17	0	33	0
2	2	18	2	34	2	2	3	18	3	34	3
3	2	19	2	35	2	3	3	19	3	35	3
4	2	20	2	36	2	4	3	20	3	36	3
5	0	21	0	37	0	5	0	21	0	37	0
6	5	22	5	38	5	6	6	22	6	38	6
7	5	23	5	39	5	7	6	23	6	39	6
8	5	24	5	40	5	8	6	24	6	40	6
9	0	25	0	41	0	9	0	25	0	41	0
10	5	26	5	42	5	10	6	26	6	42	6
11	5	27	5	43	5	11	6	27	6	43	6
12	5	28	5	44	5	12	6	28	6	44	6
13	0	29	0	45	0	13	0	29	0	45	0
14	2	30	2	46	2	14	4	30	4	46	4
15	2	31	2	47	2	15	4	31	4	47	4
16	2	32	2	48	2	16	4	32	4	48	4

Table 6. -- Final Test for Potassium (p.p.m. in Extract)

Table Beets						Sugar Beets					
Treat-ment	p.p.m.	Treat-ment	p.p.m.	Treat-ment	p.p.m.	Treat-ment	p.p.m.	Treat-ment	p.p.m.	Treat-ment	p.p.m.
1	2	17	1	33	*--	1	--	17	--	33	--
2	13	18	12	34	14	2	12	18	8	34	13
3	27	19	25	35	26	3	25	19	20	35	28
4	58	20	50	36	54	4	50	20	12	36	54
5	--	21	--	37	--	5	--	21	--	37	--
6	11	22	10	38	13	6	11	22	10	38	15
7	30	23	28	39	30	7	26	23	25	39	25
8	43	24	45	40	50	8	40	24	40	40	45
9	--	25	--	41	--	9	--	25	--	41	--
10	12	26	14	42	14	10	12	26	11	42	13
11	25	27	28	43	28	11	26	27	25	43	24
12	54	28	50	44	56	12	50	28	45	44	52
13	--	29	--	45	--	13	--	29	--	45	--
14	13	30	15	46	14	14	14	30	13	46	14
15	28	31	27	47	[illegible]	15	[illegible]	31	[illegible]	47	[illegible]
16	55	32	[illegible]	48	58	16	54	32	50	48	56

* less than 1 p.p.m. in extract solution.

Table 7. -- Final Test for Phosphorus (p.p.m. in extract)

Table Beets						Sugar Beets					
Treatment	p.p.m.	Treatment	p.p.m.	Treatment	p.p.m.	Treatment	p.p.m.	Treatment	p.p.m.	Treatment	p.p.m.
1	.25	17	1.0	33	2.5	1	1.6	17	2.1	33	3.6
2	.25	18	.73	34	2.0	2	.25	18	1.3	34	2.4
3	.25	19	.70	35	1.2	3	.25	19	.5	35	2.4
4	.35	20	1.1	36	2.0	4	.25	20	.5	36	1.6
5	.45	21	1.2	37	2.5	5	1.1	21	1.8	37	2.8
6	.25	22	.40	38	2.3	6	.25	22	.5	38	1.6
7	.25	23	.70	39	1.5	7	.25	23	.5	39	1.2
8	.75	24	1.2	40	1.5	8	.25	24	.65	40	1.4
9	.45	25	1.3	41	2.0	9	.90	25	1.1	41	2.6
10	.25	26	.70	42	1.8	10	.40	26	.5	42	2.0
11	.25	27	1.0	43	1.6	11	.25	27	.5	43	1.1
12	.25	28	.70	44	2.0	12	.25	28	.7	44	1.6
13	1.1	29	2.3	45	2.3	13	1.2	29	1.4	45	3.0
14	.35	30	.5	46	1.6	14	.25	30	.75	46	1.8
15	.25	31	.40	47	2.1	15	.25	31	1.2	47	1.8
16	.25	32	1.4	48	2.0	16	.25	32	[illegible]	48	[illegible]

RESULTS AND DISCUSSION

SUGAR BEETS

__Nitrogen.__ Of the three elements which were applied in the various concentrations and combinations shown in Table I, nitrogen caused the most pronounced effects on growth. This is indicated by the data represented in Table 2. It is graphically shown by Figs. 6 and 7 that the yield of sugar beet foliage reached a maximum at the 50 p.p.m. level, while the yield of roots was greatest at the 25 p.p.m. level. This indicates that up to the time of harvesting, nitrogen stimulated sugar beet roots to maximum production at a lower level of intensity than it did for sugar beet tops. However, the reduction in the yield of roots between the 25 and 50 p.p.m. levels, a little over 2 grams per pot, was probably too small to be significant. It therefore seems that the optimum growth of sugar beets, as a whole, came at the 50 p.p.m. level.

Statistical analyses (Tables 9 and 10) show that the nitrogen fertilizers produced highly significant increases in the yield of sugar beets. The F values show that the tops responded more than did the roots. The increases [illegible] significantly different when nitrogen [illegible] was applied as compared to [illegible] increases when beets were also [illegible] with phosphorus and potassium salts. This is shown by an analysis of variance given in Table 9 and 10. There was not a significant interaction between

[illegible]

The fact that nitrate varies so rapidly in soil made it [illegible] difficult to analyze the different concentrations and hold them at or near their original levels. Tables 2 through 4 show the tests and consumption of nitrogen over the period in which the experiment was carried out. Some difficulty was experienced in making determinations for nitrogen, especially at the higher levels. Numerous dilutions had to be made to bring the readings within the range of the comparison charts (26). For that reason the accuracy of some of the determinations is probably questionable. As can be seen in Table 2 the highest levels of nitrogen concentrations had not diminished sufficiently at the time of the first addition of nutrients to register a loss in nitrogen.

Hunger symptoms due to shortages of nitrogen were the first deficiencies noticed on both crops. These grew progressively more evident with the growth and development of the plants. Sugar beets that did not obtain sufficient nitrogen were greatly reduced in size (Fig. 11), and the foliage generally possessed a pale green color. Beets that were grown in nitrate deficient soil were also restricted in size (Figs. 13 and 14). Where nitrogen was low, the plants lower leaves gradually turned from light green to deep shades of yellow, then finally died.

Phosphorus. Phosphorus produced highly significant increases in the yields of the tops and roots of sugar beets (Table 9 and 10). Previous investigations (27) and long time practices in the state of [illegible] have [illegible] a fertilizer [illegible] phosphorus [illegible] is needed for the most favorable production of this crop. The optimum concentration of phosphorus is graphically represented by Figs. 8 and 9. The 5 p.p.m. phosphorus level proved to be the most desirable. As shown by Fig. 9 there was a very slight further increase in yield at the 10-p.p.m. level. However, this small increase was not significant.

The data reported in Table 8 revealed a negative correlation between the yield of sugar beets and the concentration of total phosphorus in the dry tissue. Computation showed the correlation coefficient to be -0.[illegible], highly significant. The data (Table 8) show also that there is a direct relationship between the decrease in total phosphorus per gram of plant tissue and the quantity of nitrogen and potassium added as fertilizer. Thus it seems that the absorption of phosphorus very definitely tended to increase where there was a deficiency of nitrogen and potassium (9).

This, coupled with luxury consumption induced by excessive applications of phosphorus, probably accounts for the super abundance of this element in the beet tissue. According to Collings (6) sugar beets grown under field conditions contain approximately 1500 p.p.m. of phosphoric acid which is considerably below the figures given here. However, it should be pointed out that the age and maturity of the plants may also have contributed to the high proportion of phosphorus absorbed. It is a known fact that some plants can absorb enough phosphorus within the first few weeks of their growing season to insure a supply that is sufficient to take care of their needs during the remaining period of growth. It may be assumed, then, that if given sufficient time for growth and development the comparison of the concentration of phosphorus in the leaf tissue to the weight of the tissue would be greatly diminished.

There was significantly higher uptake of phosphorus by the plant foliage than by the roots. This may be expected since phosphorus makes up a part of the nuclear proteins and also probably functions in the formative processes that go on within the plants (21).

Up to the time of harvesting, except for a difference in the size of the plants, there were no visible differences resulting from the phosphorus treatments.

Tops were consistently heavier than the roots, the root-top ratio being 0.72 as an average for the 96 pots in the experiment. Perhaps the root-top ratio would have changed if the beets had been allowed to mature. In a report by Schreiner and Brown (23), the tops of sugar beets represented 22 per cent of the entire crop. It is logical to suppose that if the period of growth had been extended in this experiment, the root weight of sugar beets might have surpassed the weight of the foliage. The roots, being primarily storage organs, should develop at a more rapid rate after an adequate leaf surface had been formed.

This also leads to the belief that with an advance in the state of maturation of the sugar-beet plants, more response to the phosphate treatments might be expected. Brown and Irvine (4) have shown that beets build up a high concentration of phosphorus during the first half of the growing season in order to furnish the roots with phosphorus during later stages of development. It then appears likely that the developing leaves might have priority on the phosphorus supply during the early stages of growth. Were a shortage of this element [illegible], the deficiency symptoms might then readily appear in the leaf area at the time when the root requirement begins to demand translocation from the tops.

Generally, characteristic hunger signs for phosphorus show up early in the life of the plant. It is believed that this untreated soil contained enough phosphorus to prevent these symptoms from appearing.

<u>Potassium.</u> The analysis of variance (Tables 9 and 10) show that there was a highly significant response to potassium. Maximum production came in each case, for roots and tops, at the 30 p.p.m. level of potassium. Figures 10 and 11 show that the need for 30 p.p.m. of potassium, as compared to 15 p.p.m. was greater in the case of roots than for tops. The interaction between potassium and the other elements (nitrogen and phosphorus) was not significant (Tables 9 and 10).

Where no potassium was added the plants showed the characteristic visual symptoms of potassium deficiency. The older leaves turned brown around the margins and the interior of the leaf became crinkled and cupped. The most severely deficient leaves were almost entirely necrotic at the time of harvest. Many of the necrotic leaves became broken and frayed as they were moved about.

The more pronounced cases of potassium deficiency occurred at higher levels of phosphorus and nitrogen (Fig. 15). No doubt, the intensified unbalance resulting from greater intake of nitrogen and phosphorus, where these elements were high was responsible for these more strongly defined potassium deficiency symptoms. It has been shown (9, 2[illegible]) that deficiency symptoms due to the insufficient uptake of one element are more marked when a soil is well supplied with the other fertilizer elements than when there is a deficiency of all elements with a balanced ratio at the lower level.

Table 8. -- The Effect of Varying Levels of Nitrogen, Phosphorus, and Potassium on the Yield of Sugar Beets and the Phosphorus Content of the Beet Tissue

Treatment**	Yield in Grams of Dry Material Per Pot		Phosphorus in Dry Tissue (p.p.m.)	
	Tops	Beets	Tops	Roots
1	3.8	2.9	3,800	2,400
2	3.5	5.0	3,000	2,000
3	4.5	7.4	3,000	1,800
4	5.5	6.6	1,600	1,800
5	12.2	8.2	1,600	2,000
6	27.0	18.9	1,400	1,000
7	25.1	24.1	1,400	1,000
8	21.2	19.4	1,000	1,000
9	20.0	9.7	1,000	1,400
10	26.3	14.0	1,400	1,000
11	37.9	13.8	[illegible]	1,000
12	21.3	14.0	1,400	600
13	17.9	10.8	1,400	600
14	27.3	15.8	1,000	1,000
15	23.3	11.6	1,000	1,000
16*	23.1	11.3	1,400	600
17	6.7	3.7	10,000	3,000
18	6.8	11.0	10,400	2,600
19	7.6	10.3	10,800	3,800
20	10.4	13.0	6,000	2,800
21	15.5	12.4	4,800	3,800
22	24.7	33.0	3,000	3,000
23	32.8	30.6	3,000	2,800
24	24.5	22.6	2,000	2,600
25	31.1	14.3	5,600	3,200
26	43.3	22.3	3,400	2,400
27	33.3	17.8	3,000	4,000
28	40.2	24.5	2,000	3,000
29	26.8	11.1	4,400	4,400
30	36.5	23.4	3,200	2,800
31	38.5	28.6	2,800	2,900
32	26.3	15.6	2,800	3,200

*Plants damaged

** See Table I

Table 8. -- Continued

Treatment	Yield in Grams of Dry Material Per Pot		Phosphorus in Dry Tissue (p.p.m.)	
	Tops	Roots	Tops	Roots
33	4.9	3.6	20,000	5,200
34	7.5	6.3	10,400	3,400
35	9.9	10.3	14,000	3,000
36	8.5	8.8	15,000	3,400
37	20.5	12.4	10,000	4,000
38	27.6	31.7	10,400	3,800
39	33.8	28.8	6,000	3,000
40	29.4	27.2	6,800	3,200
41	26.1	15.3	8,800	4,000
42	47.0	23.5	8,000	2,900
43	38.5	33.6	6,400	2,800
44	29.5	27.8	6,000	3,600
45	23.1	9.5	8,400	6,400
46*	25.4	22.9	6,400	4,400
47*	27.3	12.7	4,400	3,400
48	37.0	24.5	5,200	4,000

*Plants damaged

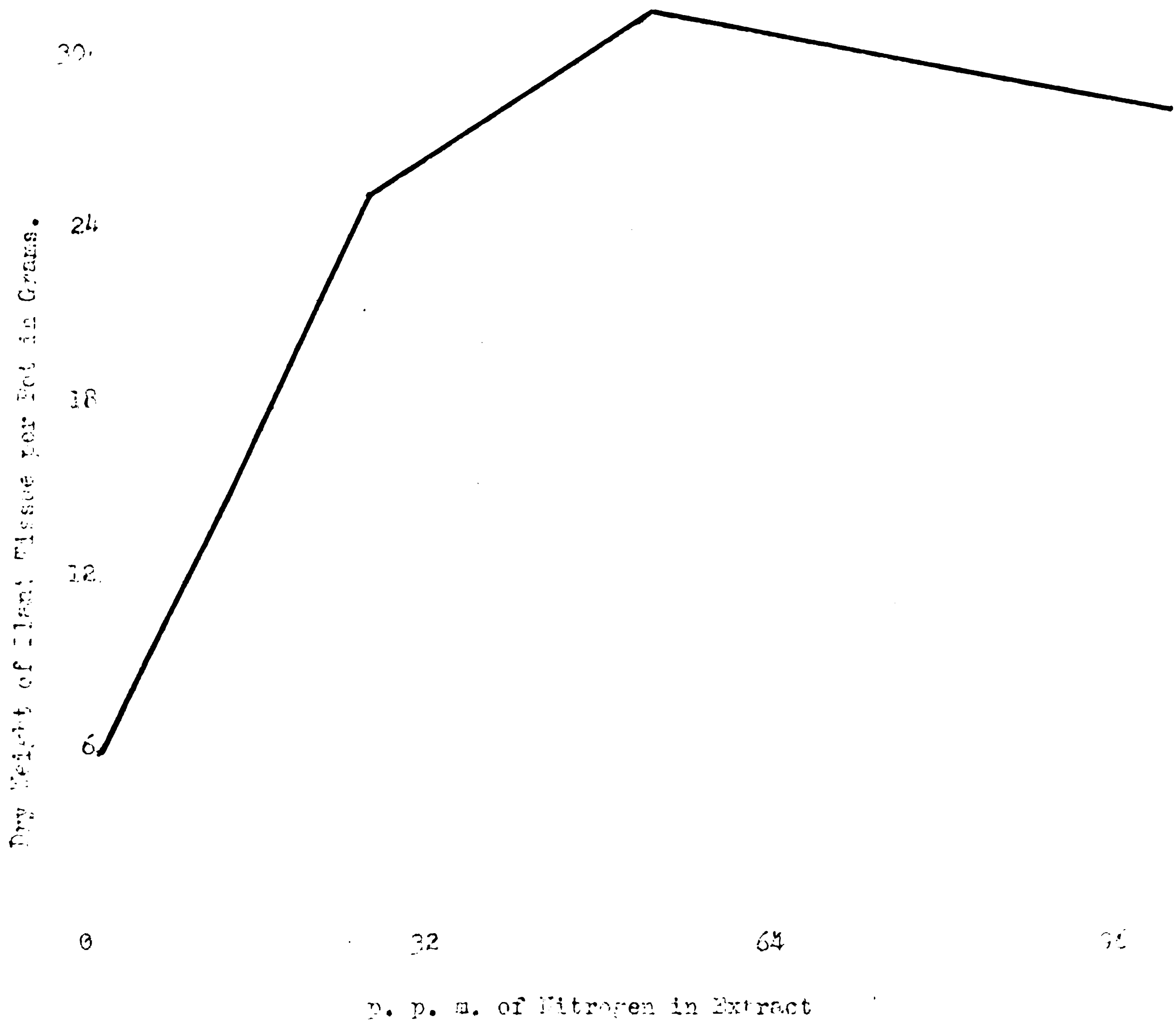

Fig. 6. -- Relation between different nitrogen levels and the production of sugar-beet foliage.

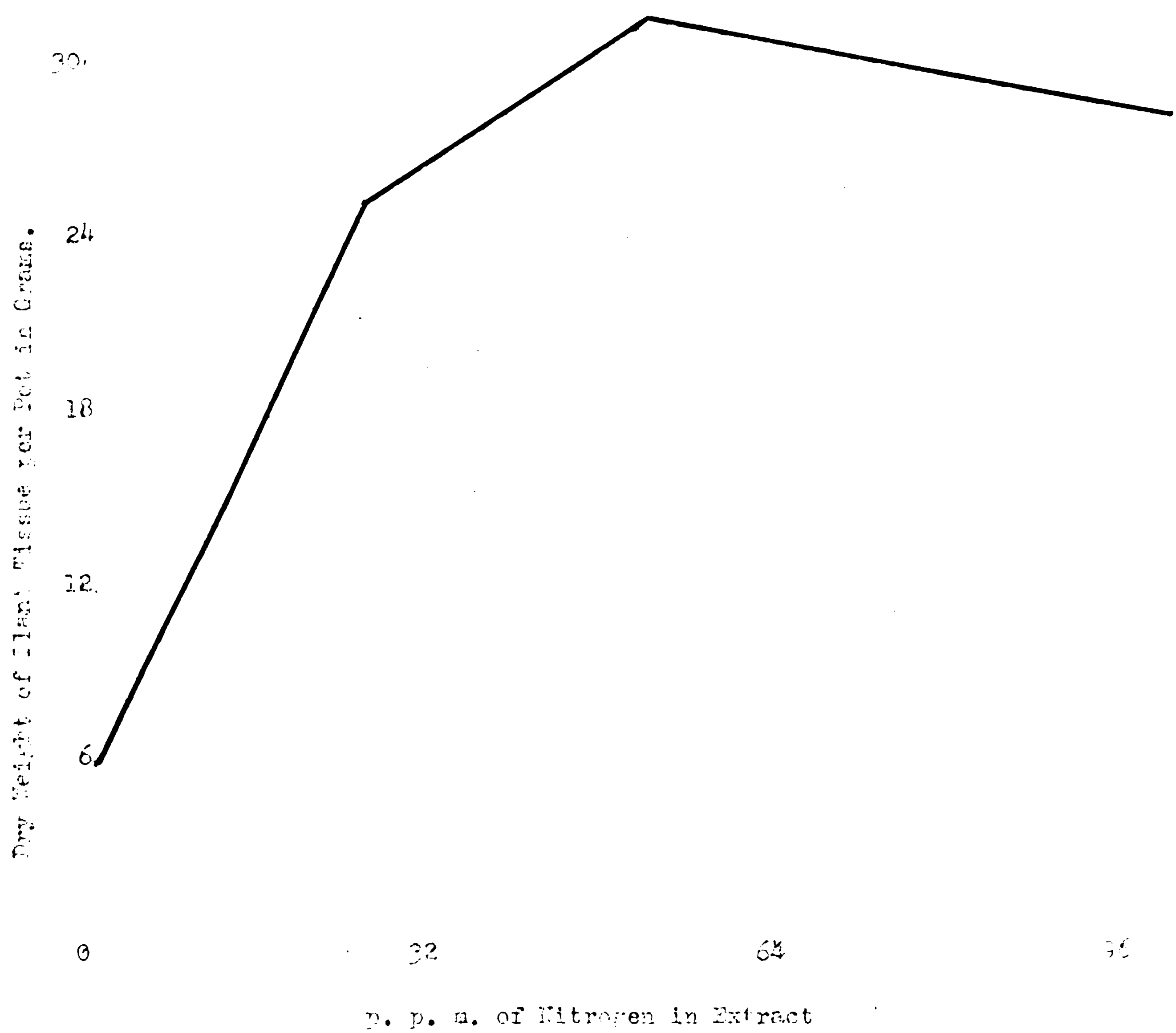

Fig. 6. -- Relation between different nitrogen levels and the production of sugar-beet foliage.

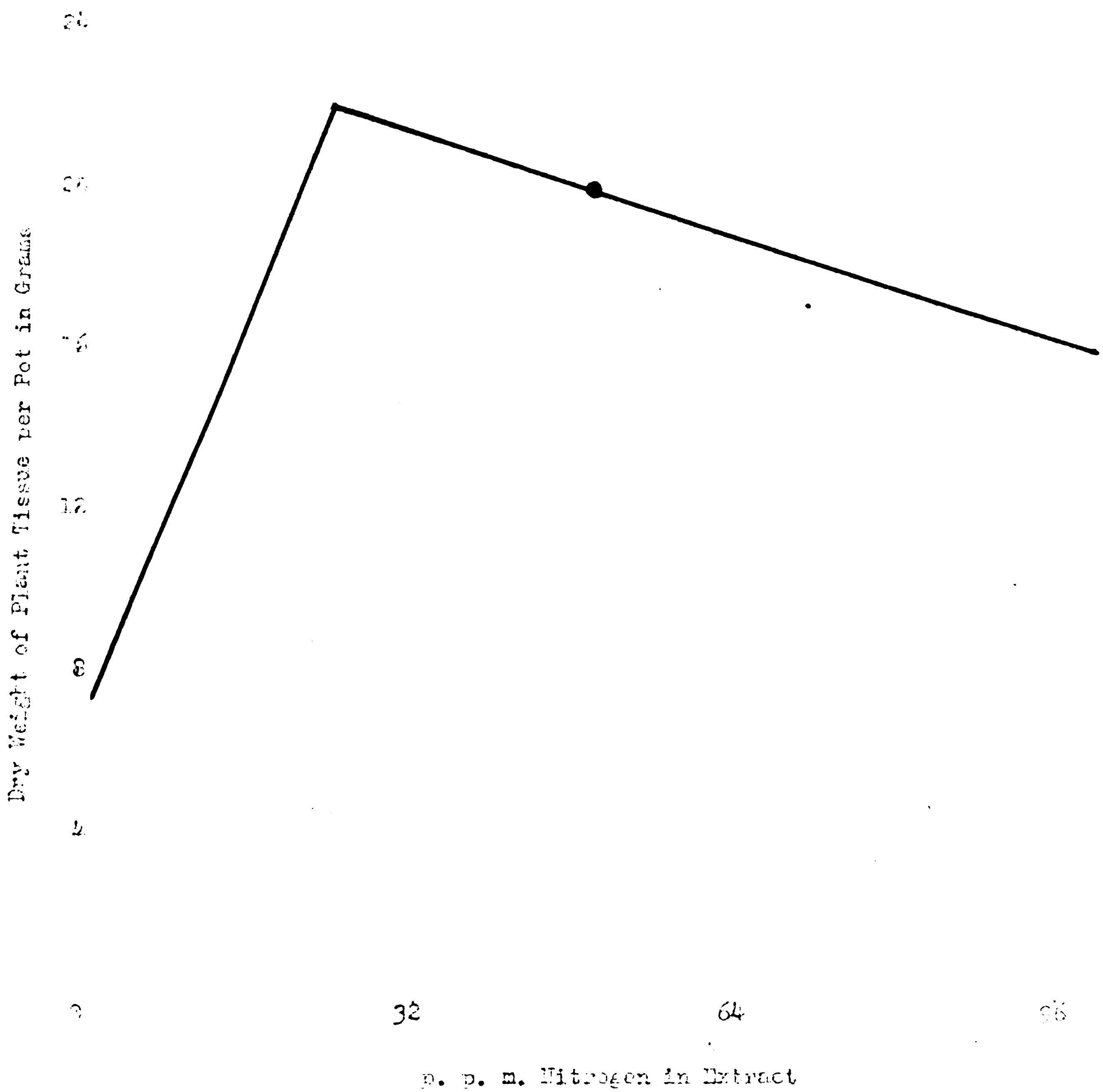

Fig. 7. -- Relation between different levels of nitrogen and the production of sugar beet roots.

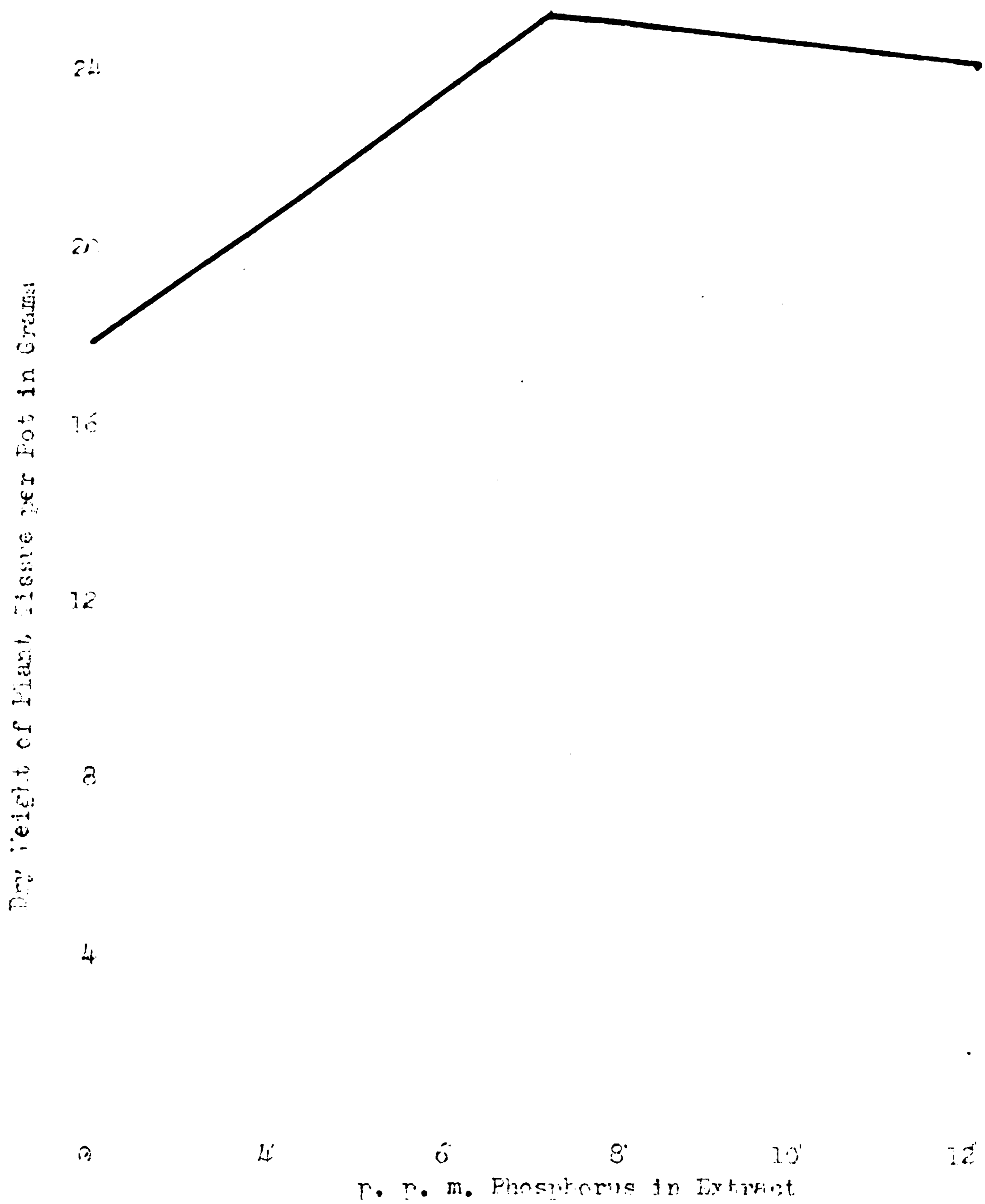

Fig. 8. — Relation between different phosphorus levels and the production of sugar beet tops.

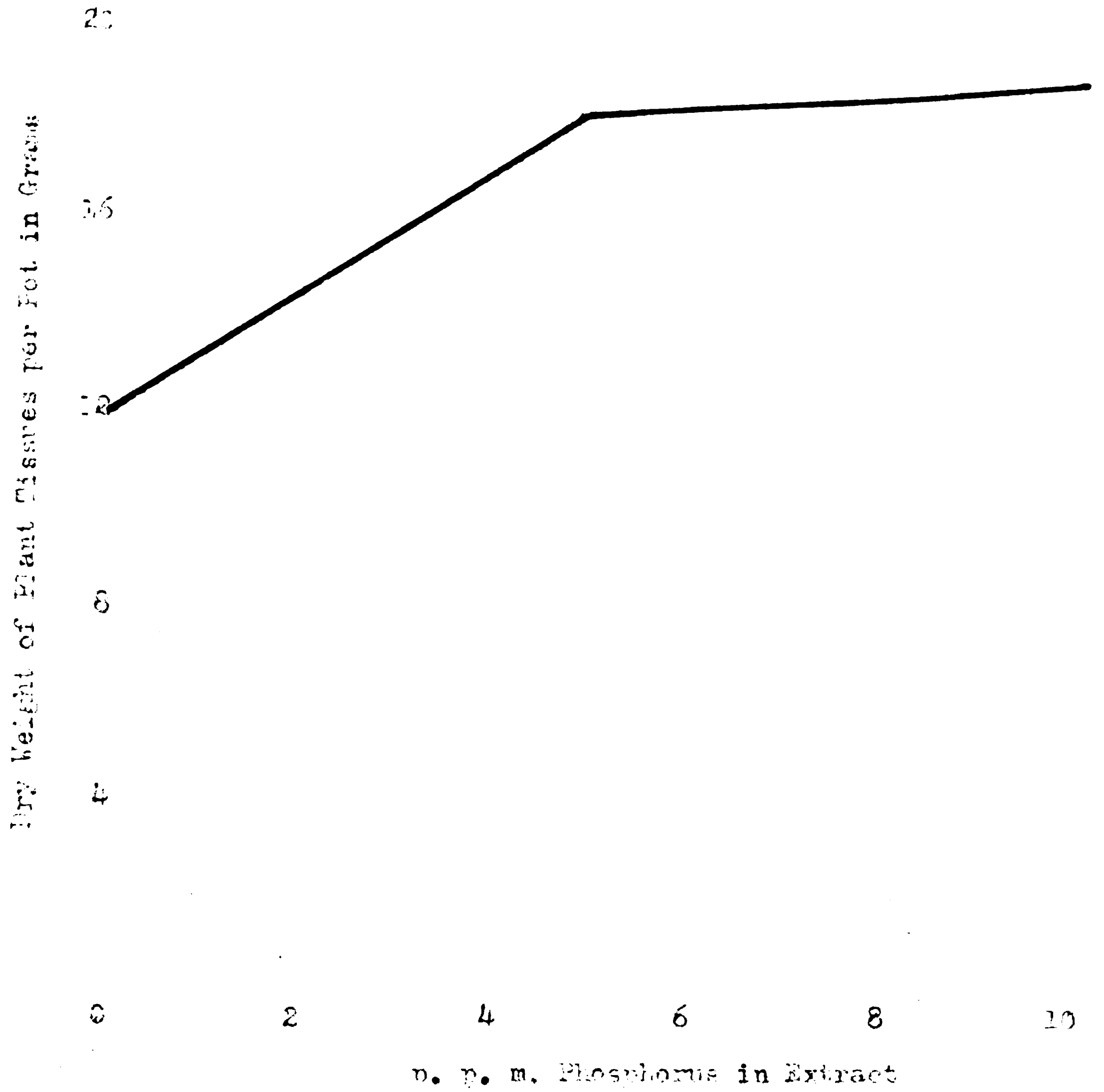

Fig. 9. -- Relation between different phosphorus levels and the production of sugar beet roots.

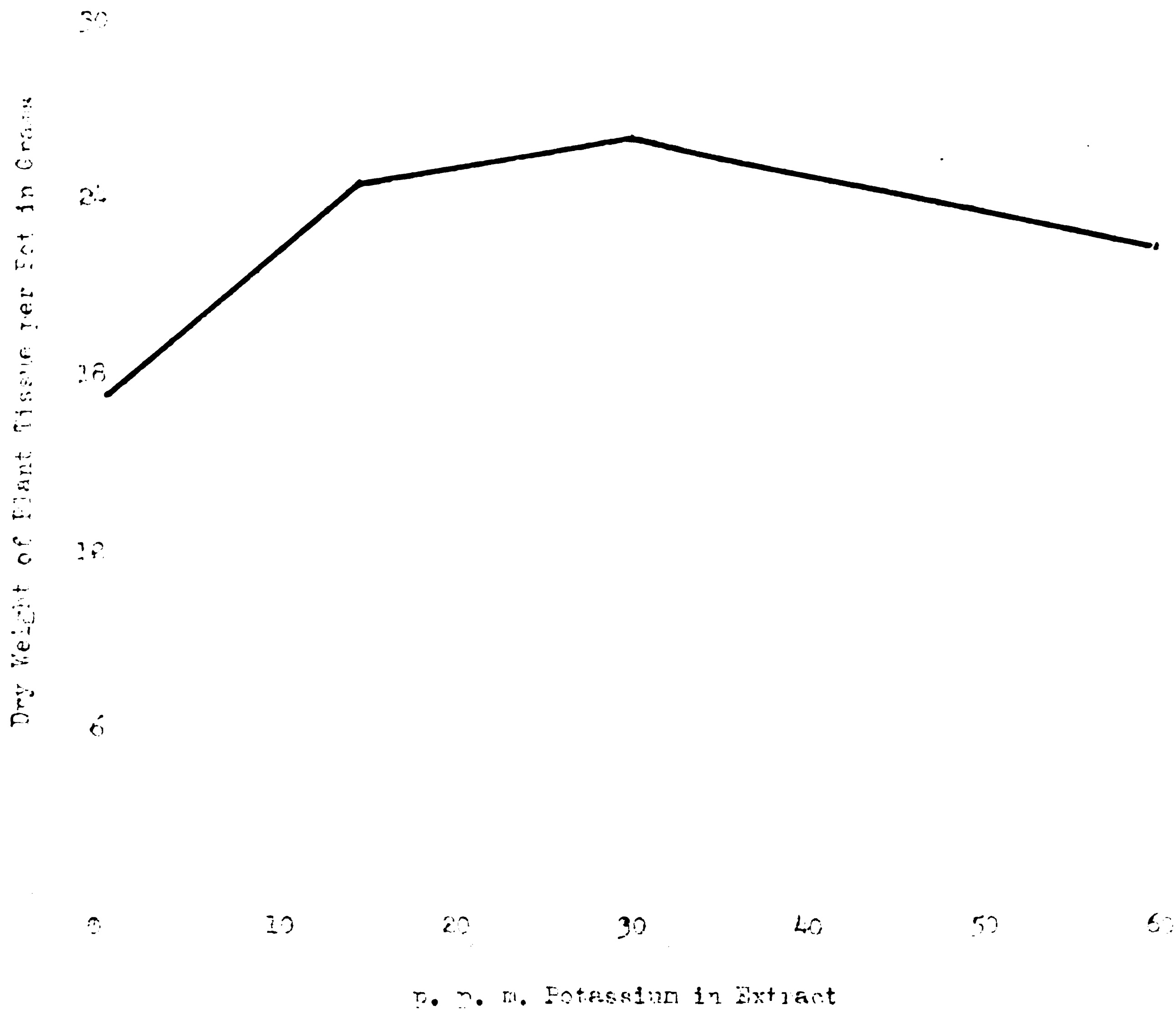

Fig. 10. -- Relation between different levels of potassium and the production of sugar beet foliage.

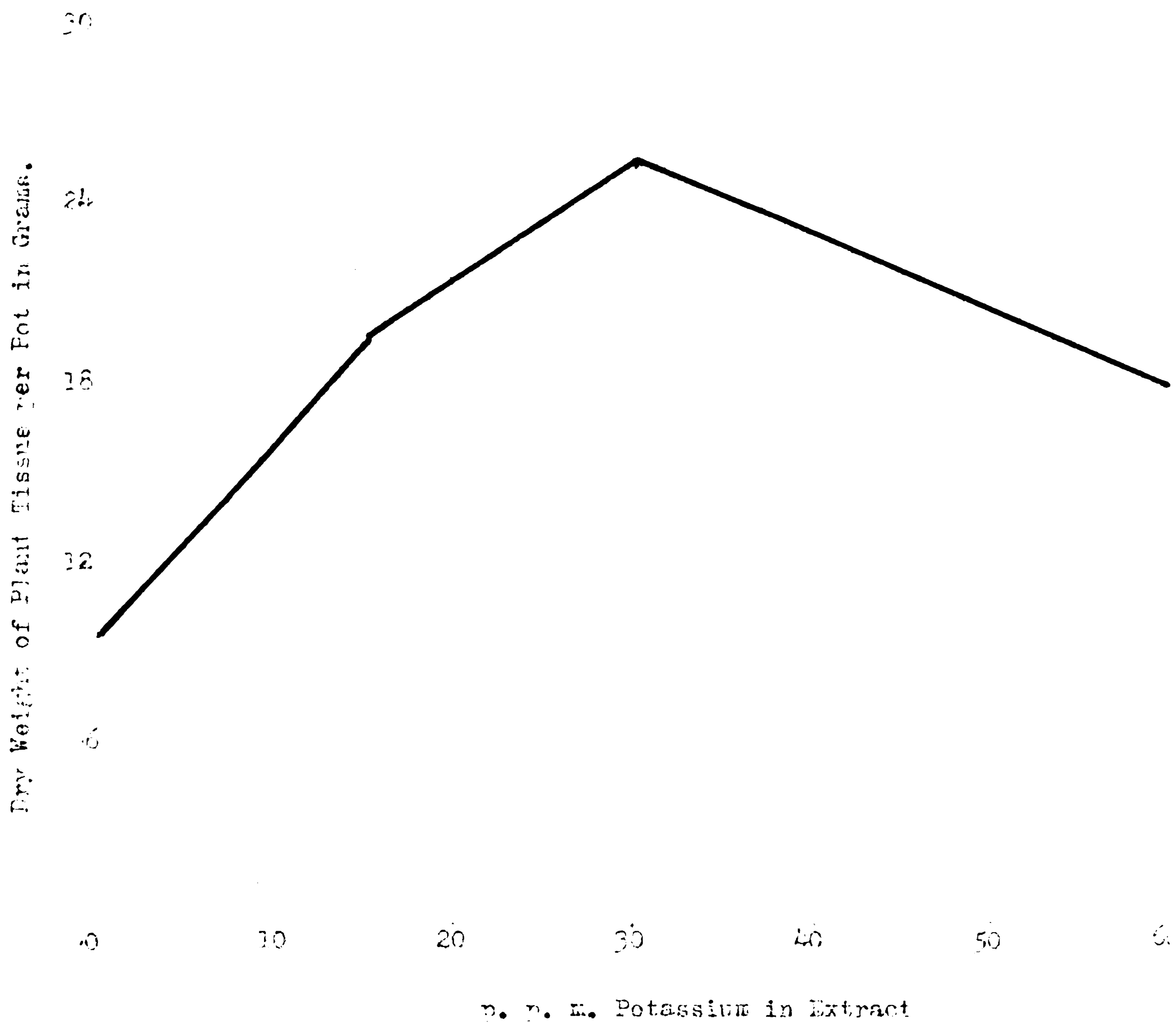

Fig. 11. -- Relation between different levels of potassium and the production of sugar beet roots.

Table 9. — Analysis of Variance of the Dry Weight of

Sugar Beet Tops

Source of Variation	D. F.	S. S.	M. S.	F.
Total	95	13,877.72	146.08	
Repl.	1	51.33	51.33	
P	2	978.59	489.30	**14.65
N	3	8,839.38	2,946.46	**88.01
K	3	927,67	309.22	**9.24
N-K	9	359.18	39.91	
P-K	6	151.66	25.28	
P-N	6	282.31	47.05	
P-K-N	18	709.19	39.40	
R-Tr				

** Highly Significant

Table 10. -- Analysis of Variance of the Dry Weight of Sugar Beet Roots

Source of Variation	D. F.	S. S.	M. S.	F.
Total	95	8,695.94		
Repl.	1	698.76	698.76	**22.96
P	2	758.42	379.21	**12.46
N	3	2,951.11	983.70	**32.32
K	3	1,545.91	515.30	**16.93
N-K	9	356.07	39.56	
P-K	6	156.01	26.00	
P-N	6	88.57	39.82	
P-K-N	18	710.72	39.48	
Error	47	1,430.37	30.43	

** Highly Significant

Fig. 12. -- Early growth response of sugar beets to four levels of nitrate on Oshtemo loamy sand. The treatments were: (1) zero, (2) twenty-five, (3) fifty, and (4) one hundred p.p.m. -- phosphorus and potassium were not applied. The nitrogen deficient plants were greatly reduced in size and were pale green in color. The greatest yield appeared at the fifty p.p.m. level.

Fig. 13. — The effect of the different nitrate levels on the growth of sugar beets. (1) zero, (2) twenty-five, (3) fifty, and (4) one hundred p.p.m. Phosphorus and potassium were not applied.

Fig. 14. -- Growth response to different levels of nitrate. Treatments shown: (1) zero, (2) twenty-five, (3) fifty, and (4) one hundred p.p.m. Phosphorus was maintained at five and potassium at thirty p.p.m.

Fig. 15. — Sugar beets showing potassium deficiency. Note marginal "firing" and necrosis of older leaves. The phosphorus level was ten and the nitrate level was twenty-five p.p.m.

TABLE BEETS

Nitrogen. As was found for sugar beets, nitrogen also stimulated greater growth response in table beets than did either phosphorus or potassium. As shown by the data presented in Table 11, the results of the application of nitrogen for table beets generally paralleled those of nitrogen for sugar beets.

Table beets, roots and tops, reached their maximum production at the 50 p.p.m. nitrate level. The production of table beet tops averaged approximately four times as much dry tissue at the 25 p.p.m. level as was obtained at the zero level of nitrate concentration (Fig. 16). An increase of an additional 25 p.p.m., to 50 p.p.m., at which maximum growth was obtained resulted in only a very small further increase in yield. At the 100 p.p.m. level the high concentration of nitrate salts was injurious. This was evident by a slight depression in top growth and a very serious depression in root growth, as shown by Fig. 17. As with the tops, the marked increase in yield of roots as a result of the first increment of nitrogen was followed by a very slight further increase, as the level of nitrate was raised to 50 p.p.m.

The high significance in the response of table beets to nitrogen fertilizers is shown in the analysis of variance tables (Tables 12 and 13). These tables further show that the interactions of nitrogen, phosphorus, and potassium were not significant. It is shown by these computations that nitrogen caused a notably higher stimulation to the top growth of the beets than to the growth of the roots. [illegible] the response was highly significant.

Visually, table beets grown in soil low in nitrogen varied from reddish to a purplish bronze color. This was also characteristic of phosphorus deficient plants. Since nitrogen is essential in the formation of the plants' protoplasm, it is intimately associated with phosphorus in the growth processes that go on within the plant. Both are indispensable in the synthesis of nuclear proteins which are found in the cells' interior and function in nuclear division and cell enlargement (21). Therefore, without nitrogen there could be little assimilation of carbohydrate. The carbohydrate, instead, was diverted to the formation of anthocyanin pigments which appeared in the form of the deep bronze to reddish color of the beets foliage. In this respect table beets differed from sugar beets which did not show evidence of the production of anthocyanin. Other visible nitrogen deficiency symptoms were not different from those of sugar beets, namely, stunting and death and shedding of the lower leaves.

<u>Phosphorus</u>. There was general response to phosphate fertilizer by table beets, though the degree of response was greater for tops than for the roots. The statistical analysis reported in Tables 12 and 13 show the effect of phosphorus on the tops to be highly significant while for the roots the response was not significant. The greatest increase in the yield of dry tissue came at the 5 p.p.m. level for both tops and roots (Figs. 18 and 19). The response shown here is similar to the results obtained for sugar beets, in that both crops made their best growth at 5 p.p.m. available phosphorus. This shows again the similarity between the two plants in their requirement for nutrients.

The phosphorus content of the plants is presented in Table 7. It is seen that the [illegible] of the leaf tissue was consistently higher when there was a decrease in the amount of added nitrogen and potassium (2). There was a slight tendency for the plants to absorb more phosphorus when there was either a surplus of this element or a diminished supply of nitrogen and potassium. On increasing nitrogen and potassium, it was found that the roots absorbed phosphorus at a rate 2 per cent and 13 per cent less, respectively, when nitrogen and potassium were added separately. The combination of [illegible] reduced by [illegible] per cent the amount of phosphorus that was absorbed when only [illegible] phosphate was applied. An even greater reduction in phosphorus was noted for [illegible]. Addition of potassium caused the absorption of [illegible] per cent less phosphorus than where the phosphate material was applied by itself. Nitrate fertilizer, in the highest concentration, reduced the phosphate content of the foliage by 25 per cent. A combination of nitrogen and potassium at their highest levels caused the uptake of phosphorus to be only 22 per cent of what it was where neither of these elements was added.

The highly significant correlation coefficient of -0.[illegible] was obtained when the relationship between the yield of dried tissue of the leaves and the quantity of phosphorus absorbed was studied. Thus, like sugar beets, an inverse relationship between dry weight and absorbed phosphorus is indicated, showing that excessive phosphorus uptake accompanied slow growth.

Typical plants (Fig. 21) taken from the three levels of phosphorus when no additional treatments were added give visual verification [illegible]

[illegible] of table beets. It may be pointed out that even though the [illegible] were larger as a result of greater applications of phosphorus, which is especially true for the tops, the plants which did not receive fertilizers were normally proportioned and the roots were like those grown under conditions of optimum concentration and balance of nutrients ([illegible]).

The off color of table beet tops, induced as a result of phosphorus shortage was very much the same as that described for plants grown on soil low in nitrogen. These off colors of purple and bronze appeared more intense where nitrate and phosphorus deficiencies were accompanied by high potassium. According to Hofler and Knight ([illegible]), these two elements (phosphorus and nitrogen) are so interrelated that there is no assimilation of nitrogen without phosphorus taking part in the reaction. It appears that these anthocyanin pigments are excessively produced in table beets and certain other plants wherever the photosynthetic processes in the plant are adversely affected by a deficiency of phosphorus.

Potassium. The general effect of potassium was to increase yields of both tops and roots. As was true for sugar beets, the roots of table beets were especially responsive to potassium treatments. The data given in Table [illegible] and illustrated in Figures 20 and 21 furnish evidence that the addition of potassium to the soil notably contributed to the quantitative development of the beet crop.

It is of interest to note that the pattern of response resulting from potassium applications was similar for roots and tops. However, [illegible] of foliage was reached at the 30 p.p.m. level of concentration and [illegible] was diminished by 8 per cent at the 60 p.p.m. level. Root yields also registered a maximum at the 30 p.p.m. level, but leveled off and maintained this same rate of production at the 60 p.p.m. level. Further examination of these data, as shown by the analysis of variance (Tables 12 and 13) indicates that beet top yields were significantly increased where potassium was applied and that the increase was highly significant in the case of the roots. At the harvest date the ratio of roots to tops had reached a value that averaged 1.1 for the [illegible] pots in the experiment. This higher proportion of roots to tops distinctly contrasts with the proportion of sugar beet roots to tops. In the latter case the root-top ratio was 0.72, a greater yield of tops than roots. The differences here evidently resulted because of differences in the length of time needed for the plants to mature. Tables beets are usually mature enough to harvest in 50 to 60 days after planting. On the other hand, sugar beets require more than twice this length of time to give the best yield of roots.

Visible hunger signs appeared in the form of restricted growth of the entire plant. Diminished growth was accompanied by drooping foliage that was especially noticeable in the lower leaf area where necrosis occurred along the leaf margins. Many of the lower leaves died which gave the plants the same frayed appearance that was shown by sugar beets.

Table [illegible]. -- The Effect of Varied Levels of Nitrogen, Phosphorus, and Potash on the Yield of Table Beets and the Phosphorus Content of the Beet Tissue

Treatment**	Yield in Grams of Dry Material Per Pot		Phosphorus in Dry Tissue (p.p.m.)	
	Tops	Roots	Tops	Roots
1	3.0	[illegible]	8,200	[illegible]
2	2.6	2.5	5,200	4,000
3	3.1	3.7	3,200	3,400
4	3.7	4.0	2,900	3,000
5	8.5	9.7	1,300	[illegible]
6	10.5	13.5	1,000	2,600
7	11.4	12.4	480	2,000
8	10.3	15.6	1,400	2,000
9	10.1	13.1	2,000	3,000
10	14.1	12.7	1,600	2,400
11	11.5	15.7	1,600	2,000
12	13.0	20.1	1,200	2,000
13	9.7	6.1	1,800	3,400
14	13.9	15.0	2,000	2,600
15	14.4	12.2	1,400	1,800
16	8.9	12.8	1,600	1,600
17	2.4	1.9	28,000	6,000
18	3.5	3.3	24,400	7,200
19	4.3	3.1	16,000	5,600
20	3.6	4.7	20,000	5,600
21	12.4	14.5	6,000	5,600
22	17.6	28.4	4,200	4,400
23	12.6	16.9	4,800	4,400
24	16.3	26.6	3,800	4,400
25	15.0	16.4	6,000	5,600
26	13.5	19.4	5,200	4,400
27	17.9	21.8	2,900	4,400
28	20.3	24.8	3,600	3,800
29	8.5	4.3	3,200	8,000
30	13.0	11.1	4,400	5,000
31	15.9	21.2	1,600	4,000
32*	13.2	11.0	3,000	3,800

* Plants damaged

** See Table 1

Table 11. -- Continued

Treat-ment	Yield in Grams of Dry Material Per Pot		Phosphorus in Dry Tissue (p.p.m.)	
	Tops	Roots	Tops	Roots
33	3.5	4.0	24,000	9,200
34	4.3	3.2	28,000	8,900
35	5.2	5.1	26,000	5,000
36	6.4	5.9	30,000	6,000
37	12.6	8.9	10,500	7,600
38	12.6	16.0	1,600	8,000
39	14.1	24.1	7,200	5,200
40	14.6	21.5	10,000	5,200
41	10.6	9.0	6,400	6,400
42*	14.2	10.9	9,200	6,000
43	16.0	22.6	7,600	5,600
44	13.7	20.3	5,600	4,800
45	11.6	5.5	5,600	7,200
46	16.9	13.2	8,400	5,600
47	13.1	10.4	5,600	4,800
48	14.6	8.5	6,400	5,000

* Plants damaged

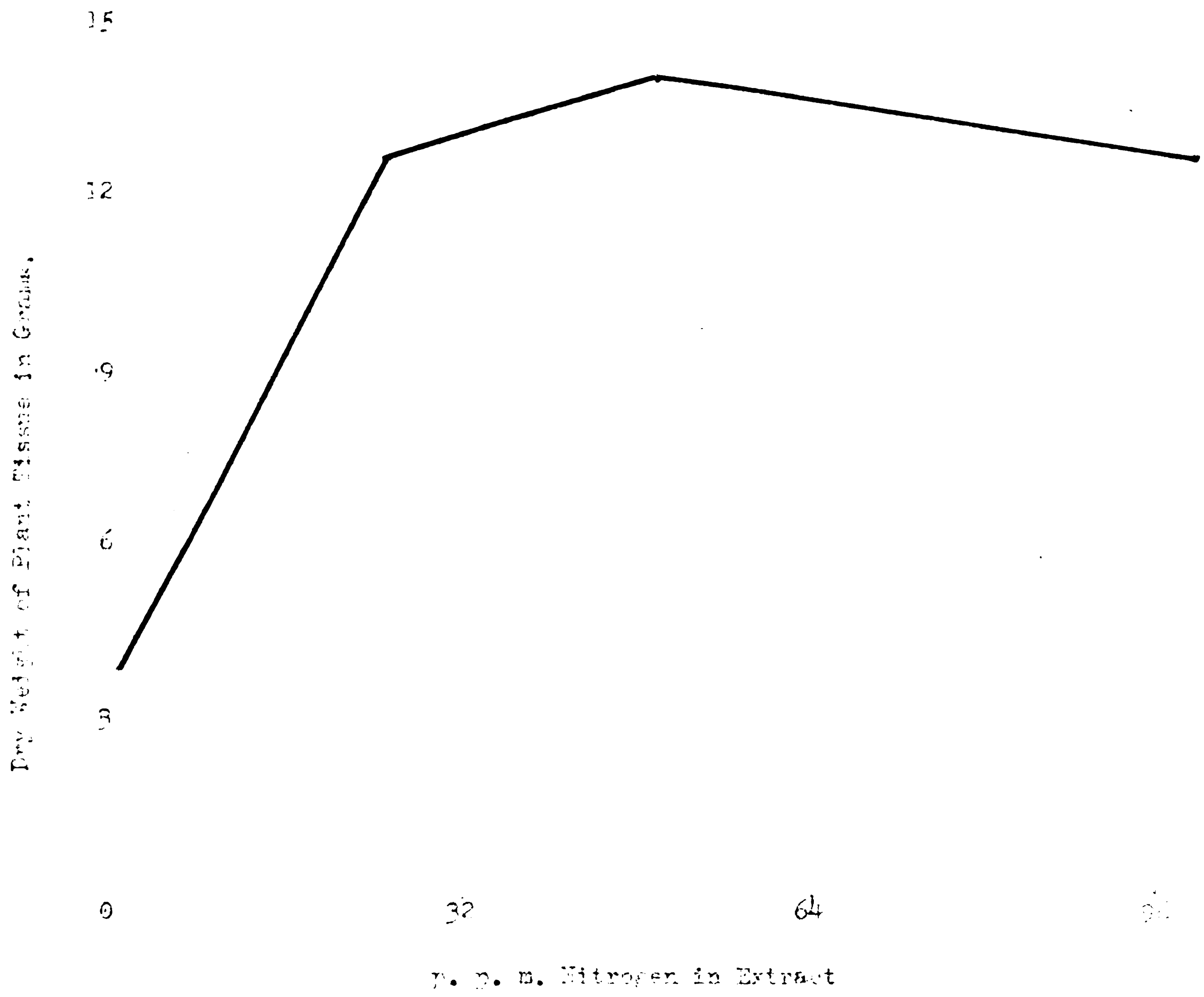

Fig. 16. -- Graphic representation of the effects of various nitrate levels on the production of table beet tops.

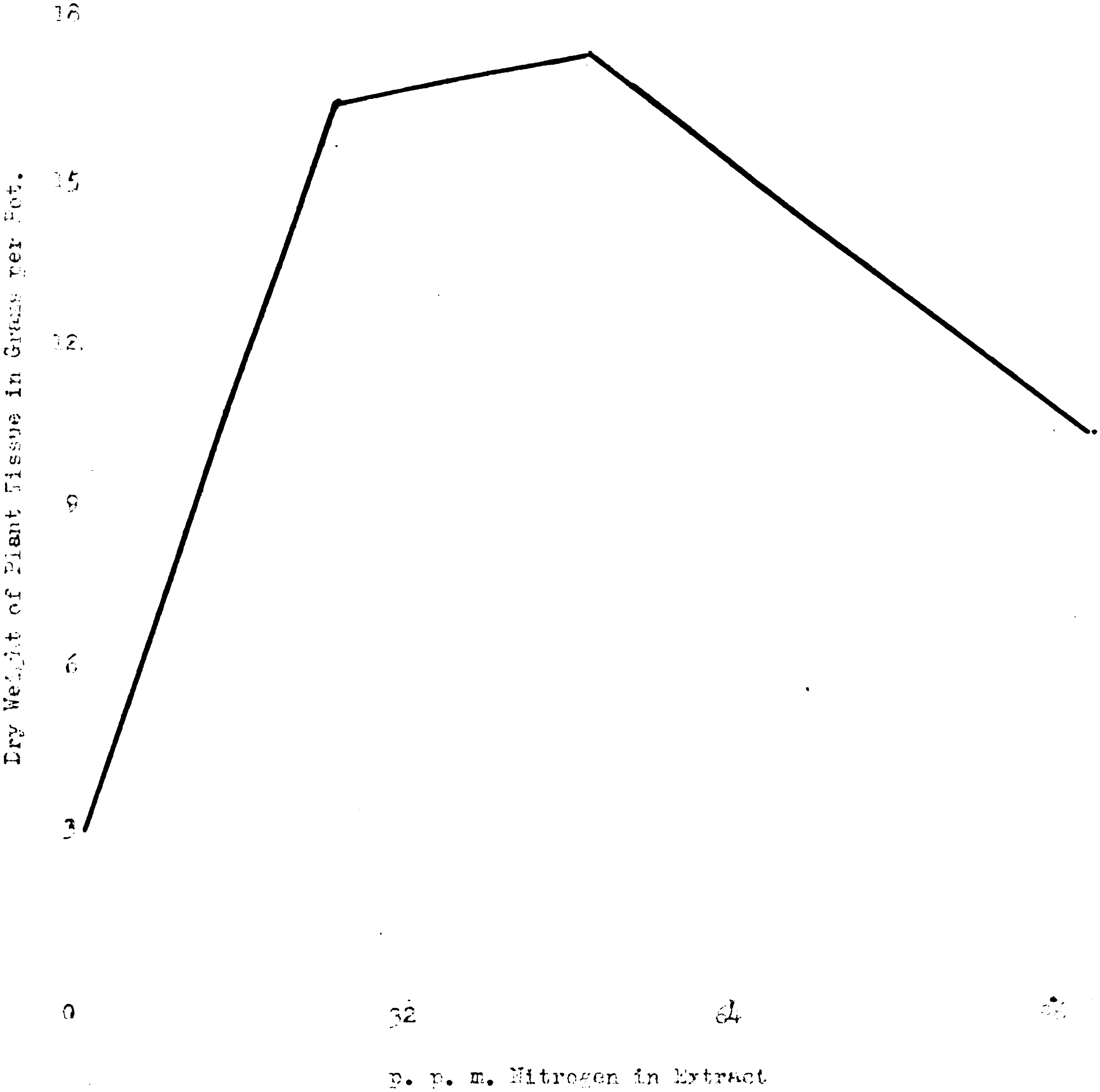

Fig. 17. -- A graphic representation of the effect of different levels of nitrogen on the production of table beet roots.

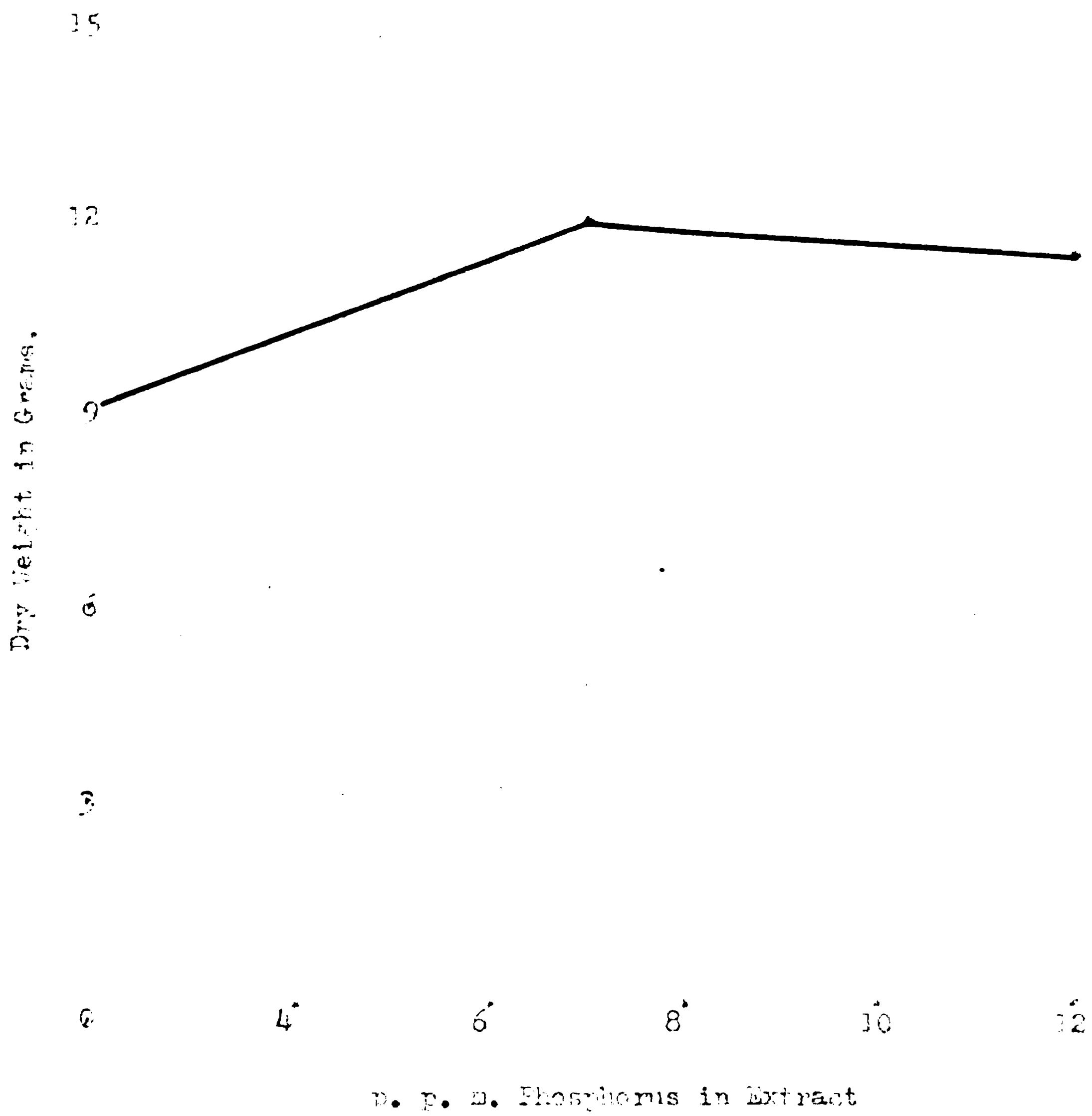

Fig. 18. — Relation between p. p. m. of available phosphorus and the dry weight of table beet tops.

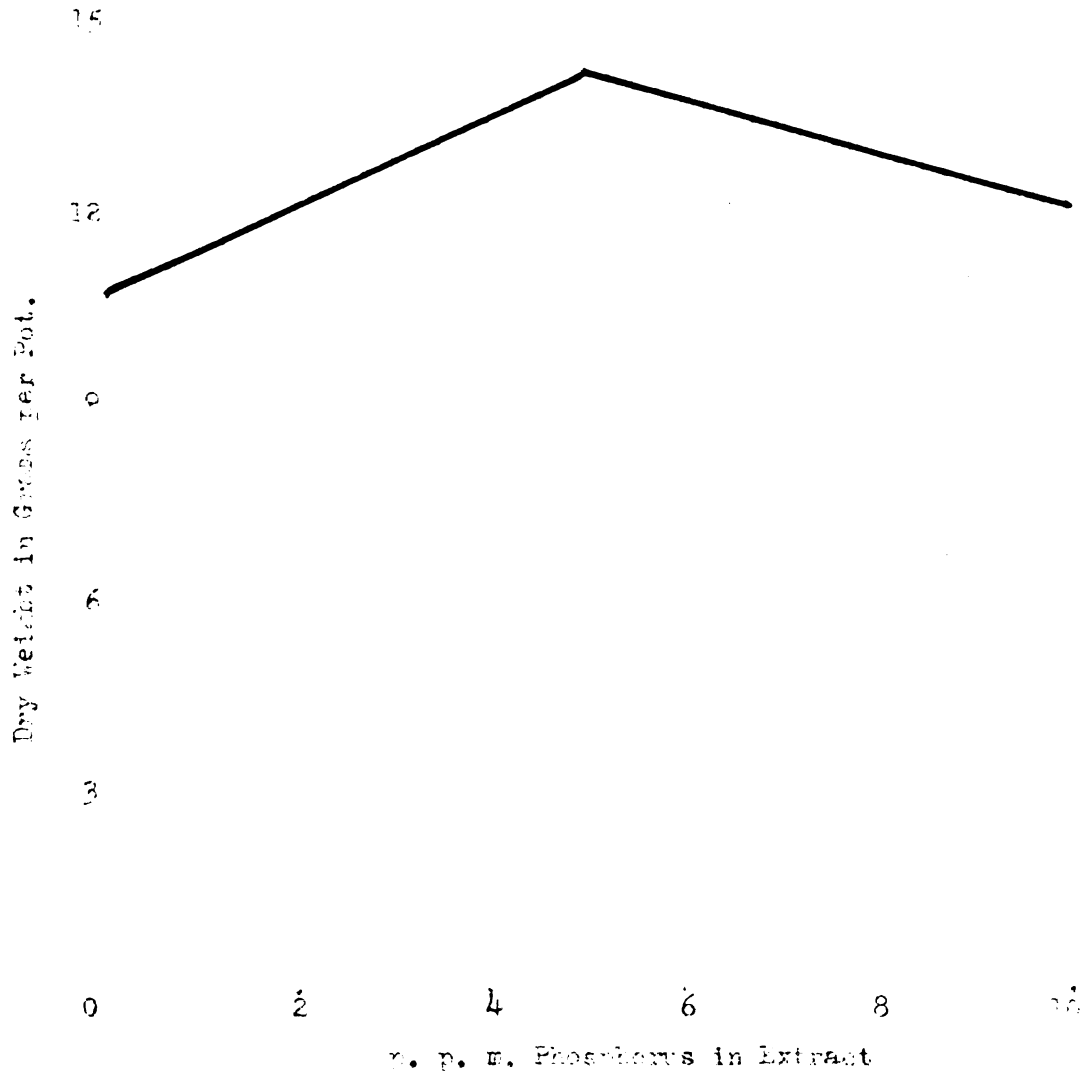

Fig. 12. — Graphic representation of the effect of three levels of monocalcium phosphate on the production of table beet roots.

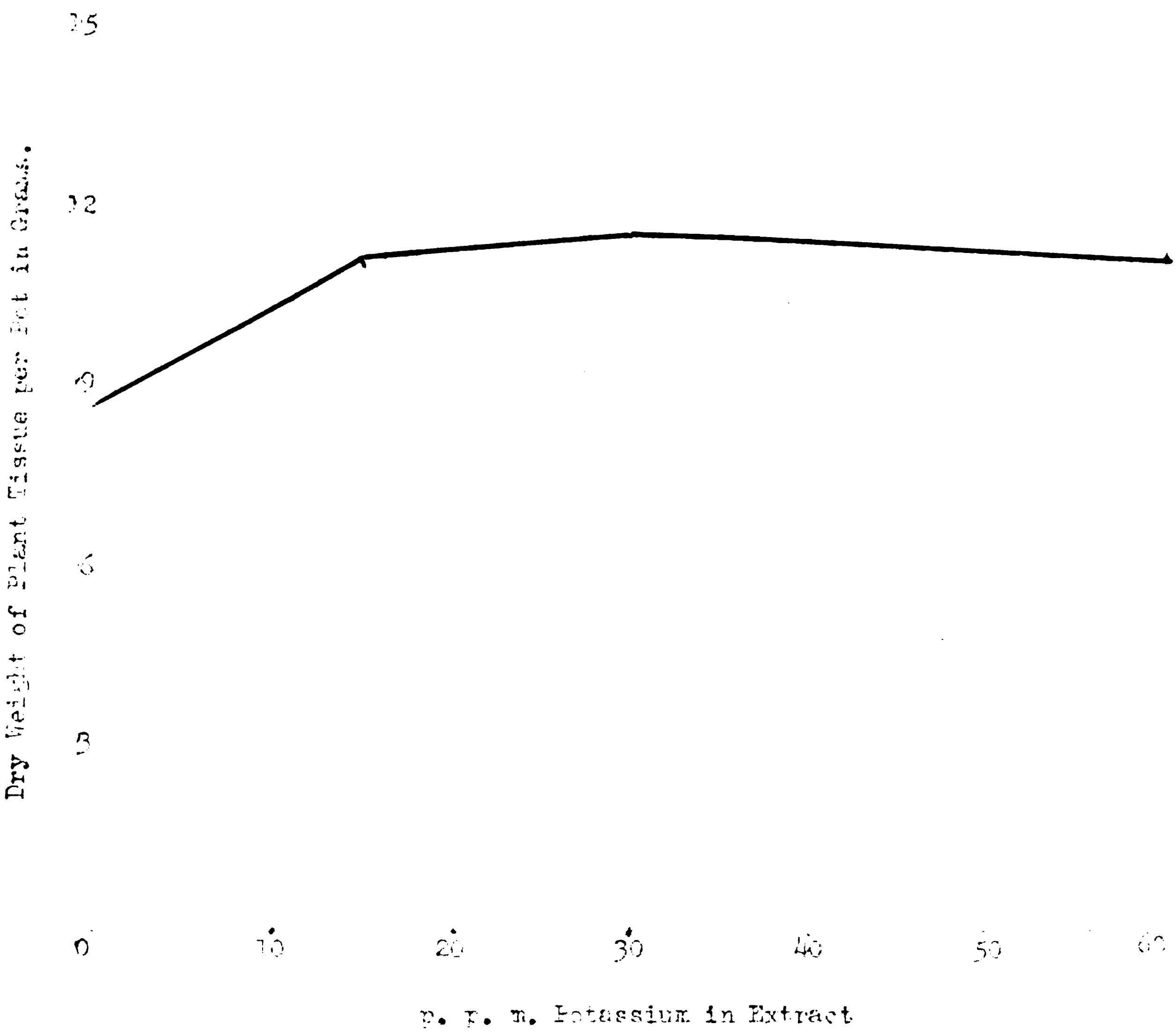

Fig. 20. -- Graphic representation of the effect of various levels of potassium on the production of table beet tops.

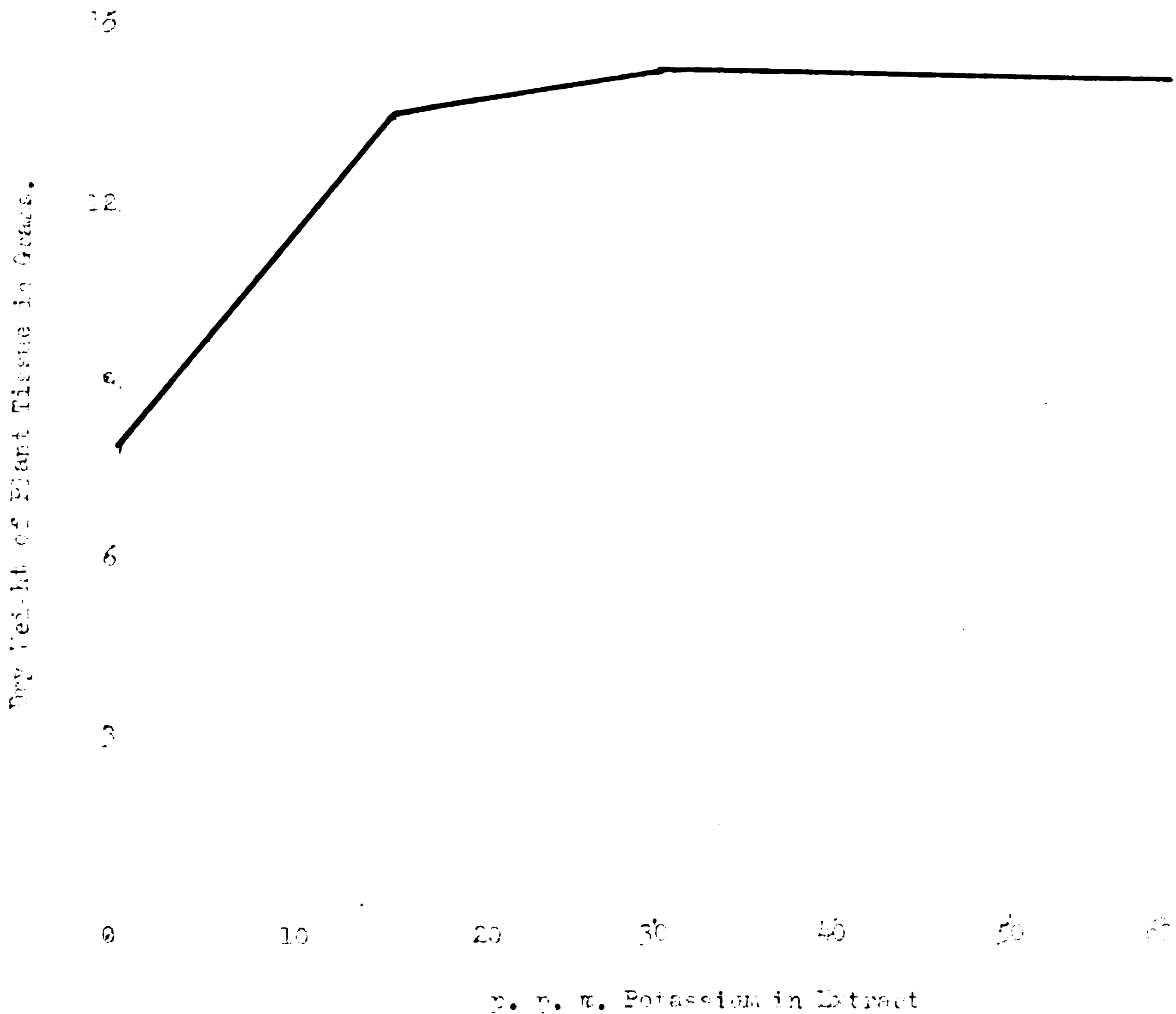

Fig. 21.-- Graphic representation of the effect of different potassium levels on the production of table-beet roots.

Table 12. -- Analysis of Variance of the Dry Weight of Table Beet Tops

Source of Variation	D. F.	S. S.	M. S.	F.
Total	95	2,870.62		
Repl.	1	31.97	31.97	
P	2	135.34	67.67	**6.12
N	3	1,623.07	541.02	**47.11
K	3	131.62	43.88	*3.97
N-K	9	65.10	7.23	
P-K	6	29.52	4.92	
P-K-N	18	303.46	16.86	
R-Tr	47	519.85	11.06	

* Significant
** Highly significant

Table 13. -- Analysis of Variance of the Dry Weight of Table Beet Roots

Source of Variation	D. F.	S. S.	M. Sq.	F.
Total	95	6,615.32		
Repl.	1	7.42	7.42	
P	2	164.83	82.42	
V	3	3,066.93		**33.13
F	3	684.59	228.19	**7.24
V-F	9	268.85	29.87	
P-F	6	87.13	14.52	
P-V	6	289.37	48.23	
P-V-F	18	545.94	30.22	
E-Tr	47	1,480.37	31.52	

**Highly significant

Fig. 22. -- Growth response of table beets to four levels of nitrate. The treatments were (1) zero, (2) twenty-five, (3) fifty, and (4) one hundred p.p.m. Phosphorus and potassium were not applied. The nitrogen deficient plants were greatly reduced in size, yellowish and slightly bronzed in color. Greatest growth occurred at the fifty p.p.m. level.

Fig. 22. -- Growth response of table beets to four levels of nitrate. The treatments were (1) zero, (2) twenty-five, (3) fifty, and (4) one hundred p.p.m. Phosphorus and potassium were not applied. The nitrogen deficient plants were greatly reduced in size, yellowish and slightly bronzed in color. Greatest growth occurred at the fifty p.p.m. level.

Fig. 23. -- The Effect of nitrate levels on the growth of table beets. (1) zero, (2) twenty-five, (3) fifty, and (4) one hundred p.p.m. Phosphorus and potassium were not added. Note the highly significant response at the twenty-five p.p.m. level as compared to level No. 1.

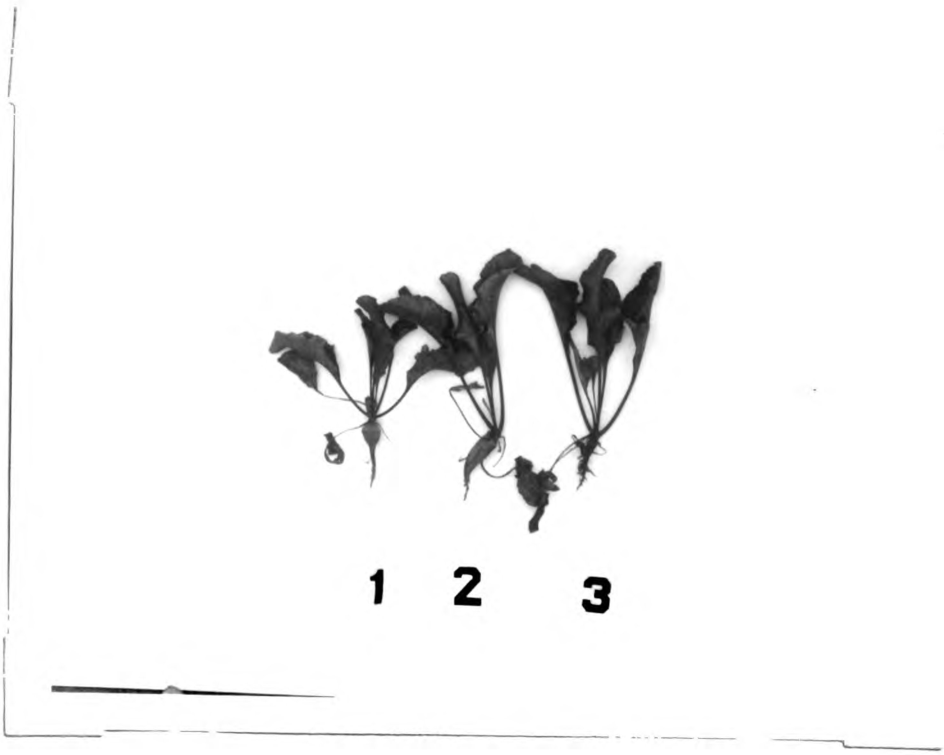

Fig. 24. — Table beets showing successive levels of zero, five, and ten p.p.m. phosphorus at zero levels of nitrogen and potassium. Limited response to phosphorus is shown. Five p.p.m. phosphorus gave the greatest yield.

SUMMARY AND CONCLUSION

Sugar beets and table beets were grown in pots of Oshtemo loamy sand. Levels of nitrogen, potassium, and phosphorus were arranged as a 4 x 4 x 3 factorial experiment. A study was made of the effect of the variable nutrient levels on the production and visible characteristics of these two crops and on their content of phosphorus.

Nutrient levels were maintained by testing for the active portion of fertilizer elements in the soil by using Spurway's Simplex system. Color comparisons were made with a colorimeter for greater accuracy in determining phosphorus and potassium. Determinations for total phosphorus absorbed by the plants were also run and its uptake correlated with plant yield and the rates of application of nitrogen and potassium.

There was a great deal of similarity in the response of table beets and sugar beets to the fertilizer treatments. The greatest stimulation of crop production by a single element was produced by nitrogen. This was probably due, in part, to the tendency for nitrogen to stimulate vegetative growth and to the very low level of nitrogen in the untreated soil. Maximum yield of tops resulted at the 50 p.p.m. for both crops, but for the roots the results from the two crops varied somewhat. For table beet roots, maximum yield occurred where the nitrate level was 50 p.p.m. but that level was too high for sugar beets.

A deficiency of nitrogen greatly diminished the yield of both beet crops and produced excessive accumulations of anthocyanin pigments in table beets which caused the foliage to have a deep reddish to bronze color. The tops of sugar beets appeared yellowish in varying degrees of intensity depending on the extent of nitrogen starvation. In the more extreme cases of nitrate deficiency, chlorosis was followed by drying and shedding of the lower leaves.

Phosphorus significantly increased the yield of table beets and sugar beets. The optimum level of this nutrient was found to be 5 p.p.m. Phosphorus in the tissue of beets when correlated with yield revealed that yield and phosphorus uptake were inversely related. The same relationship was found between total phosphorus in the plants and the quantity of nitrogen and potassium applied. Phosphorus absorption was greatly increased where there was a shortage of the other fertilizer nutrients and diminished as the supply of nitrogen and potassium increased.

Plant size constituted the only visible symptoms of phosphorus deficiency in sugar beets. Besides diminished yield, table beets showed a greater intensity of anthocyanin production where low phosphorus was coupled with a deficiency of nitrogen. These conditions appeared more conspicuous where the above conditions were accompanied by high potassium applications.

Thirty p.p.m. potassium was found to be the critical level in the production of each beet crop. Tops and roots responded readily to potassium. The increase in root yield as a result of added potassium proved to be more significant than did the increase in the foliage.

Beets grown in potassium deficient soil developed necrotic and frayed margins on the lower leaves. Slower growth of the leaf margins resulted in crinkled leaves. And where there was an extreme shortage of potassium the oldest leaves died.

In pointing out the differences and similarities between table beets and sugar beets, it was found that the two plants closely paralleled each other in response to the various fertilizer treatments. However, variations in the length of growing season for the crops probably account for the relatively wide differences in the rates at which the roots developed in relation to the tops. Since the table beets needed a much shorter period to mature, they had a larger root top ratio than did the sugar beets when the plants were harvested. Sugar beet root yields were 28 per cent lower than were the top yields. On the other hand, the average weight per pot of table beet roots was 10 per cent greater than that of the corresponding tops.

Except for the visible discolorations due to the accumulation of anthocyanin pigments in table beets where nitrogen and phosphorus was low, sugar beets and table beets reacted to the fertilizer treatments much in the same way, from the standpoint of symptoms. At lower levels of nutrient concentrations where fertilizer elements were not sufficient for maximum production but were more nearly balanced, the plants, though small were more nearly normal in appearance than those at higher levels where the relationship between the nutrients was greatly unbalanced.

1. [illegible]

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