NUTRIENT LEVELS FOR CORN AND BEANS

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This is to certify that the

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NUTRIENT LEVELS FOR CORN AND BEANS

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CONTENTS

INTRODUCTION

In recent years farmers have been using ever increasing amounts of commercial fertilizers in an effort to increase yields. In some instances, where very high applications have been made, yields have not held up to expectations. This has resulted in a question as to why one quantity of fertilizer should cause a great increase in yield while a larger quantity of the same fertilizer resulted in no increase or even a decrease. Numerous experiments have indicated that improperly balanced nutrition may result in depressed yields. This study was conducted with the view of determining the most desirable levels of the three main fertilizer constituents, N, P, K, in the soil for two common Michigan crops, field beans and corn. The crops were grown in Oshtemo sandy soil because of its very low nutrient content.

REVIEW OF LITERATURE

Liebig in 1840 introduced his "law of minimum" which stated that the absence of any one essential element causes a soil to be barren. This was followed in 1907 by Osterhout (5) who believed that protective salts could be used to prevent other salts from becoming toxic. Then came the recent period with the nutrient balance theories of Beeson (2), Shear and Crane (7), Pierre and Bower (6), and Shear, Crane and Myers (8). In the balance theories it was pointed out that maximum growth was achieved only when the fertilizer constituents were in a certain balanced ratio. A wide divergence from the ratio may cause a "luxury" intake of one element in an attempt on the part of the plant to compensate for insufficient quantities of other plant nutrients. Shear, Crane, and Myers (8) stated it as follows: "All other factors being constant, plant growth is a function of nutritional intensity and balance. At any given level of nutritional intensity a multiplicity of ratios may exist between these elements. Maximum growth and yield occur only upon the coincidence of optimum intensity and balance."

"As any element decreases or increases substantially from its concentration at optimum intensity, the maximum growth possible within the new limits of supply of that element can result only when the concentrations of all elements have been brought into balance at the new level of intensity determined by that element."

PROCEDURE

Oshtemo sandy soil was weighed to 8000 grams and placed in two gallon, glazed jars. Oshtemo was used because of its lack of bases which could interfere with nutrient relations in the soil or plant. The soil was taken from the Rose Lake Experimental station, sifted through a quarter inch mesh screen, and air dried. The amounts of each fertilizer element needed to establish certain levels in the soil were determined by Watson (11). He did this by allowing some soil to come to equilibrium after adding nutrients in varying amounts, after which he tested the samples by the Spurway method.

Calcium phosphate, due to its low solubility, was added dry and mixed into the soil. All nitrogen, potassium, and minor nutrients were added in solution and washed into the soil. The rates of application of each are given in Table 1 and the desired nutrient levels are indicated in Table 2. An examination of this table shows that all combinations of 4 nitrate levels, 3 phosphorus levels and 4 potassium levels are included. The design, then, is factorial in nature, 4x3x4, making a total of 48 treatments. Each treatment was duplicated.

The soils were thoroughly mixed after the fertilizer nutrients were added to them. Early hybrid no. 11

field corn and Michelite white field beans were planted on June 7 and were up by June 11. Due to poor seedling survival, however, beans were replanted July 6 and were up July 9. The corn was thinned to four plants per pot and the beans to eight. In tissue testing one entire bean plant was removed from each pot. Not all of the bean plants survived to the time they were harvested. The corn, because of its height, was grown entirely in the greenhouse on benches which were turned regularly to equalize locational variations. The beans were moved outside immediately after sprouting and remained there throughout the experiment. The plants were watered with distilled water in quantities sufficient to prevent wilting, although some wilting did occur during the very hot weather.

The corn was harvested at silking time and the beans as they started to bloom. They were harvested at the soil level, and ground to pass a 40 mesh screen. Phosphorus was determined by the method used by Ulrich (10) while potassium was determined by the flame photometer method described by Attoe(1). The tissue tests and soil tests were made with the Spurway soil testing kit by the method suggested by Cook et al (4).

METHODS OF ANALYSIS

Total phosphorus was determined as suggested by Ulrich (10) by treating a 0.5 gm sample of dry plant material with 5 cc of a 1.0 molar ammonium nitrate and 0.2 molar magnesium nitrate solution, dehydrating, followed by ashing in an electric furnace at 550°C for 3 hours. The ash was taken up in 200 cc of 2% acetic acid and 10 cc of this was diluted to 95 cc with distilled water. The phosphate concentration of the extract was determined by developing the phosphomolybdate blue color through the addition, in rapid succession, of 4 ml of molybdic acid (3) and 6 drops of stannous chloride reagent (9) then diluting to 100 cc. The amount of blue coloration formed after standing for exactly 8 minutes was read with a Lumetron photoelectric colorimeter using the green filter.

Potassium was determined in the plant material by the flame photometer method used by Attoe (1). In the procedure, a sample of .5 gm of dry plant material, ground to pass a 40 mesh screen in a Wiley mill, was placed in a flask and 100 ml of extracting solution was added. The flask was stoppered and shaken intermittently by hand for one hour. The suspension was filtered through a Whatman

No. 2 filter paper. The photometer was standardized with a series of standard solutions containing 0, 10, 20, 40, 70, 100, and 150 ppm of potassium and another series of 0, 100, 200, 300, and 400 ppm of potassium to take care of the higher concentrations.

The extracting solution was 2N with respect to ammonium acetate and 0.2N with respect to magnesium acetate. It was prepared by diluting a stock solution with equal parts of distilled water.

The stock solution was 4N with respect to ammonium acetate and 0.4N with respect to magnesium acetate. It was prepared by diluting 228 ml of glacial acetic acid with 300 ml of distilled water and then adding with agitation 270 ml of concentrated ammonium hydroxide. To this was added 42.8 gms of $Mg(C_2H_3O_2)_2 \cdot 4H_2O$. The solution was adjusted to pH6.9 with ammonium hydroxide or acetic acid.

Table 1. Application rates of the various fertilizer nutrients per pot (11) and the equivalent rates on an acre basis.

P - as mono-calcium phosphate

ppm in extract	gm applied per pot	pounds per acre
0	0	0
5	5.8	1450
10	8.8	2200

K as KCl

0	0	0
15	4.22	1055
30	8.34	2085
60	15.11	3777.5

NO_3 as NH_4NO_3

0	0	0
12.5	0.72	180
25	1.44	360
50	2.88	720

NO_3 as $NaNO_3$

0	0	0
12.5	1.52	380
25	3.04	760
50	6.08	1520

Ca as $CaCO_3$	4000
Mn as $MnSO_4$	25
Mg as $MgSO_4$	200
Cu as $CuSO_4$	25
B* as $Na_2B_4O_7$	2.5

*Borax applied on corn only

Table 2. Nutrient levels stated as parts per million in the soil extract using Spurway active test.

	P-0	P-5	P-10
	K	K	K
	0	0	0
NO_3-0	15	15	15
	30	30	30
	60	60	60
	0	0	0
	15	15	15
NO_3-25	30	30	30
	60	60	60
	0	0	0
	15	15	15
	30	30	30
NO_3-50	60	60	60
	0	0	0
	15	15	15
	30	30	30
NO_3-100	60	60	60

Table 3. Actual soil tests in parts per million at the time the green bean tissue tests were made which was after 20 days of bean growth at the nutrient levels indicated.

	P-0*			P-5			P-10		
	N	P	K	N	P	K	N	P	K
NO_3-0	0	tr	0	0	5	0	0	10	0
	0	tr	15	0	5	15	0	10	15
	0	tr	30	0	5	30	0	10	30
	0	tr	60	5	5	60	0	10	60
NO_3-25	tr	tr	0	0	5	0	0	10	0
	tr	tr	15	0	5	15	0	10	15
	15	tr	30	0	5	30	0	10	30
	20	tr	60	20	5	60	20	10	60
NO_3-50	25	tr	0	25	5	0	25	10	0
	25	tr	15	0	5	15	20	10	15
	20	tr	30	0	5	30	5	10	30
	10	tr	60	50	5	60	0	10	60
NO_3-100	85	tr	0	50	5	0	50	10	0
	75	tr	15	50	5	15	50	10	15
	65	tr	30	60	5	30	50	10	30
	75	tr	60	70	5	60	20	10	60

*Columns divided on basis of desired phosphorus levels. Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 4. Actual soil tests in parts per million after 30 days of bean growth and 52 days after the fertilizer applications for the nutrient levels indicated.

	P-0			P-5			P-10		
	N*	P	K**	N	P	K	N	P	K
NO_3-0	0	tr	0	0	5	0	0	10	0
	0	tr	15	0	5	15	0	10	15
	0	tr	30	2-0	5	30	0-2	10	30
	0	tr	60	5-0	5	60	0	10	60
NO_3-25	25	tr	0	10-20	5	0	20-40	10	0
	20	tr	15	20-15	5	15	20-2	10	15
	25-20	tr	30	25	5	30	15-10	10	30
	20-25	tr	60	15-25	5	60	25-10	10	60
NO_3-50	20-25	tr	0	15	5	0	25	10	0
	25-20	tr	15	25-10	5	15	20	10	15
	25-20	tr	30	30-25	5	30	20	10	30
	25-35	tr	60	50-25	5	60	25-15	10	60
NO_3-100	50	tr	0	75-50	5	0	25-35	10	0
	50	tr	15	40-15	5	15	35-25	10	15
	50-40	tr	30	50-30	5	30	40-20	10	30
	60-50	tr	60	60-40	5	60	40-25	10	60

*Two figures indicate a difference in duplicate treatments.

**Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 5. Green tissue tests on beans twenty days after planting as affected by the nutrient levels indicated (4).

	P-0			P-5			P-10		
	N	P	K**	N	P	K	N	P	K
NO_3-0									
	tr*	lo	tr	tr	med	lo	0	hi	tr
	hi	lo	lo	m hi	med	hi	tr	hi	v hi
	med	lo	hi	m hi	med	v hi	med	med	v hi
	hi	lo	v hi	m hi	hi	v hi	hi	med	v hi
NO_3-25									
	hi	lo	lo	hi	med	lo	hi	hi	lo
	hi	lo	hi	hi	med	hi	hi	hi	hi
	hi	lo	hi	hi	m lo	v hi	hi	hi	v hi
	hi	lo	v hi	hi	lo	v hi	hi	m hi	hi
NO_3-50									
	hi	lo	lo	hi	med	lo	v hi	med	lo
	hi	lo	hi	hi	med	hi	v hi	med	med
	hi	lo	v hi	hi	med	v hi	v hi	hi	v hi
	hi	lo	hi	hi	m lo	hi	v hi	hi	hi
NO_3-100									
	v hi	lo	lo	hi	med	lo	v hi	hi	lo
	v hi	lo	lo	hi	med	hi	v hi	med	hi
	v hi	lo	hi	hi	med	v hi	v hi	med	v hi
	v hi	lo	hi	hi	med	v hi	v hi	med	v hi

*tr - trace
m lo - medium low
m hi - medium high

v hi - very high
lo - low
hi - high
med - medium

**Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 6. Average dry weight per pot of beans harvested 30 days after planting when grown on the nutrient levels indicated.

	P-0	P-5	P-10
	4.35*	5.15	6.07
	2.23	3.15	3.70
NO_3-0	2.40	2.77	3.42
	1.65	.7**	2.72
	5.30	8.35	8.80
	4.10	8.52	10.80
NO_3-25	4.70	5.80	5.10
	2.95	2.95	5.20
	7.15	9.67	8.55
	5.37	12.57	10.05
NO_3-50	5.10	9.85	11.30
	3.60	5.50	7.65
	5.30	6.37	8.15
	5.67	11.20	7.05
NO_3-100	4.05	9.45	11.00
	2.50	8.55	8.57

*Columns divided on basis of desired phosphorus levels. Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

**Only two plants survived to harvest time in each pot.

Table 7. Average height of beans in cm. when harvested 30 days after planting as affected by the nutrient levels indicated.

	P-0	P-5	P-10
NO_3-0	18.5*	18.0	21.0
	18.0	17.0	22.5
	18.5	16.5	21.0
	14.5	13.0	16.5
NO_3-25	19.0	21.0	23.5
	19.5	25.0	28.0
	21.0	22.0	20.5
	17.5	14.0	16.0
NO_3-50	18.5	21.0	21.5
	19.0	27.0	26.5
	18.0	23.5	21.5
	17.5	14.0	20.0
NO_3-100	16.0	15.5	18.5
	19.0	21.0	14.5
	19.0	19.5	20.5
	15.5	19.0	17.5

*Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 8. Parts per million of Phosphorus in dry bean tissue as affected by the nutrient levels indicated.

	P-0	P-5	P-10
	P*	P	P
NO_3-0	2680	4680	5120
	3080	4920	4520
	2920	4920	4980
	2600	4240	4980
NO_3-25	2360	4300	5460
	2240	3760	3540
	2160	4300	4300
	2300	4240	4440
NO_3-50	2760	4360	5200
	2000	3920	4600
	2160	3840	4760
	2520	3680	4600
NO_3-100	2000	4080	5280
	2000	3680	4600
	1920	4000	4840
	2240	4000	4300

*Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 9. Parts per million of Potassium in dry bean tissue as affected by the nutrient levels indicated.

	P-0	P-5	P-10
	K*	K	K
	14600	19000	10200
	53200	61200	54000
NO_3-0	70200	66400	64800
	79600	80238	81500
	14000	9900	6800
	37200	40800	40400
NO_3-25	54000	59200	57600
	75200	75600	71000
	19000	9000	9500
	38400	42000	37200
NO_3-50	56400	53200	50800
	73400	81500	72600
	18800	12000	11600
	37600	38400	33600
NO_3-100	50400	55600	49200
	74400	69200	65600

*Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 10. Actual soil tests in parts per million for the nutrient levels indicated after 58 days of corn growth.

	P-0			P-5			P-10	
NO_3-0								
N*	P	K**	N	P	K	N	P	K
0	tr	0	0	5	0	0	10	0
0	tr	15	0	5	15	0	10	15
0	tr	30	0	5	30	0	10	30
0	tr	60	0	5	16	0	10	60
NO_3-25								
20-tr	tr	0	0	5	0	tr-5	10	0
10	tr	15	5-0	5	15	0-5	10	15
15-20	tr	30	5-0	5	30	0-5	10	30
20-25	tr	60	10-tr	5	60	10-5	10	60
NO_3-50								
0-20	tr	0	5-10	5	0	tr-10	10	0
15-20	tr	15	tr-0	5	7-15	20-0	10	15
15-10	tr	30	tr-0	5	15	0	10	15
20-25	tr	60	10-5	5	60	0-tr	10	50
NO_3-100								
50-30	tr	0	30-20	5	0	35-30	10	0
50-40	tr	15	20-10	5	7-15	25	10	15
40-30	tr	30	25	5	15-30	10-20	10	15
50-35	tr	60	30-25	5	60	25-30	10	60

*Two figures indicate duplicate treatment variation.

**Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 11. Average weight of corn after 58 days growth at the nutrient levels indicated. Grams per pot.

	P-0	P-5	P-10
	16.75*	17.00	23.25
	14.50	28.75	24.55
NO_3-0	16.50	27.75	22.50
	17.25	19.50	25.50
	57.00	86.5	69,5
	63.00	95.5	104.5
NO_3-25	54.25	124.5	109.5
	45.50	89.0	74.5
	60.50	68.5	76.5
	73.00	125.0	134.0
NO_3-50	58.00	118.5	126.0
	34.75	91.0	112.5
	53.0	66.5	66.0
	50.0	165.0	137.0
NO_3-100	49.0	109.5	105.5
	34.0	111.0	89.5

*Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 12. Average height of corn in centimeters after 58 days of growth as affected by the nutrient levels indicated.

	P-0	P-5	P-10
	47.5*	60.0	77.5
	57.5	80.0	75.0
NO_3-0	65.0	85.0	77.5
	75.0	65.0	90.0
	140.0	160.0	100.0
	170.0	185.0	82.5
NO_3-25	160.0	187.5	155.0
	140.0	182.5	160.0
	115.0	122.5	115.0
	160.0	185.0	192.5
NO_3-50	162.0	210.0	210.0
	100.0	142.5	180.0
	130.0	122.5	87.5
	142.5	200.0	135.0
NO_3-100	135.0	190.0	130.0
	70.0	160.0	82.5

*Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 13. Parts per million of Phosphorus in dry corn tissue as affected by the indicated nutrient levels.

	P-0	P-5	P-10
	1600*	4680	4520
	1400	3300	3840
NO_3-0	1080	3680	3840
	780	3220	1400
	1320	3540	3540
	1160	3080	4240
NO_3-25	1080	3300	3840
	1080	3160	160
	1160	3080	4300
	1460	3380	4300
NO_3-50	1400	3460	3920
	1000	3460	3680
	1240	4360	4440
	1080	3840	4760
NO_3-100	1080	3840	5060
	1400	3460	4000

*Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

Table 14. Parts per million of potassium in dry corn tissue as affected by the indicated nutrient levels.

	P-0	P-5	P-10
	13100*	11600	9200
	35200	30000	33200
NO_3-0	40400	39600	37600
	46800	59600	49600
	5000	4000	4800
	27300	23000	21200
NO_3-25	35600	27000	31600
	43600	40400	43600
	4000	3400	4000
	27000	20000	18600
NO_3-50	35200	31600	28700
	49600	39600	35600
	5800	5000	4500
	26700	17000	21100
NO_3-100	34000	26700	33600
	40400	34400	38000

*Columns divided on basis of desired phosphorus levels Rows divided on basis of desired nitrate levels. Within each NO_3-P group are the four desired levels of K-0, 15, 30, and 60 ppm.

RESULTS AND DISCUSSION

BEANS

As shown by the data in Table 3, the concentrations of phosphorus and potassium in the soils were maintained very close to the desired levels. This was not true, however, with nitrate. Where the level was supposed to be 25 ppm, in 12 combinations of nutrients, the actual test results varied from zero to 20 ppm. Even greater variations were found in the cultures which should have 50 ppm. There the test results varied from zero to 50 ppm.

After this first test an attempt was made to iron out these variations by making further additions of nitrogen fertilizer. Then the soils were again analyzed. The results presented in Table 4 show that nitrate levels were still somewhat inconsistent with the desired levels but that an improvement had been made.

It is common knowledge that beans are rather easily injured by too much fertilizer. This apparently happened in the first crop and to some extent in the second crop. In the first planting few plants emerged in the cultures which received the greatest concentrations of nutrients. Potassium in particular was injurious. It was thought that perhaps the soils had not been sufficiently well mixed before the first crop was planted so all cultures were remixed and replanted.

Again emergence was delayed and germination injured where nutrient concentrations were high. However, enough plants emerged to make a uniform stand of 8 plants per jar possible.

When the plants had reached a height of about 5 inches it was decided to run green tissue tests on them. One plant was taken from each jar for these tests. The results of the tests are reported in Table 5. It is interesting to note that phosphorus tests were low in all plants which had not received phosphorus fertilizer, and where, as shown in Tables 3 and 4, the soil contained only a trace of phosphorus. Where the phosphorus level in the soil, according to the Spurway test, however, was 5 ppm, the plants tested medium in phosphorus. Still higher tests were obtained where the phosphorus level was held at 10 ppm.

While it was not consistent in all cases, there was a tendancy for high levels of soil potassium to result in reduced levels of phosphorus in the plants.

The tissue tests showed quite decidedly that the smallest application of potash fertilizer, that sufficient to make a level of 15 ppm by the Spurway test, was sufficient to produce a high level of potassium in the green plants. It is not surprising then that the higher levels of potassium should cause injury.

Nitrate nitrogen was high to very high in the tissue of all plants which had received nitrate fertilizer, or in other words in all plants where the test levels were 25 ppm or higher.

The positive tests for nitrate in the plants grown in cultures where the soil tests for nitrate were zero can readily be explained on the basis of growth. There is a very good correlation between these nitrate tests and the yields of the corresponding plants reported in Table 6. The plants which tested low in nitrate were those which had made the greatest growth. They had used up the little nitrate in the untreated soil. Those plants which had made very little growth due to injury from potassium fertilizer, as again shown by the yields recorded in Table 6, had not yet used up the small quantity in the soil so they tested high or medium. In other words the tissue tests are easily explained when the final yields are considered.

Yields, as indicated in Table 6, increased with increases in nitrate applications until the highest rate was reached. In general the peak yields were reached where the soil contained 50 ppm of nitrate. It is of interest to note that the most difficult nitrate levels to maintain, where nitrates were applied, were those producing the larger yields. Nitrates applied sufficient to bring the soil test to 25 ppm increased the height of the plants, as shown in Table 7. Where 50 ppm and 100 ppm of nitrates were applied, height was decreased, with the exception of those plants grown on soil receiving 5 ppm of phosphorus. Plant coloration improved with each nitrate application, however.

Except in cases where the number of plants per pot were reduced, as for instance where the nitrate level was 100 ppm, the phosphorus level 10 ppm and the potassium level 15 ppm, larger phosphorus applications resulted in increased yields as well as in increased height and better coloration. As phosphorus applications were increased, it was noticed that the healthy green color associated with high nitrate levels developed on the lower applications of nitrate as well. This indicates that phosphorus and nitrates may serve somewhat similar purposes in the plant especially for coloration, with neither being able to replace the other.

Nitrate and phosphorus excess or unbalance did not appear too detrimental to the plants but any potassium excess or unbalance was very strikingly indicated by poor yield, reduced height, poor stand , and poor coloration.

Figure 1 shows this clearly. With zero nitrates (bottom row) and 5 ppm of phosphorus, each added increment of potassium resulted in increased injury. Where nitrate was applied to equal 25 ppm the first level of potassium actually increased the yield and the injury from the higher rates of application was less. Figure 2 shows that with phosphorus and nitrate levels at 10 and 25 ppm, respectively, potassium still caused injury when applied at the heavier rates. When the nitrate level was increased to 100 ppm, however, as shown in the top row, no injury resulted and even increases in yield and color were obtained.

This bears out the idea that potassium "injury" or "toxicity" may be due not entirely to a potassium excess but rather to a lack of balance between the three nutrients.

A summary of these ideas is available by referring to Figure 3. As shown by the picture and by the data reported in Table 6, growth increased as nitrate levels were increased. One can see also, that toxicity from the high potassium level was less where the nitrate level was high. Similar results were obtained as phosphorus levels were increased.

Now as nitrate and phosphorus levels were both increased, growth reached a maximum and the highest

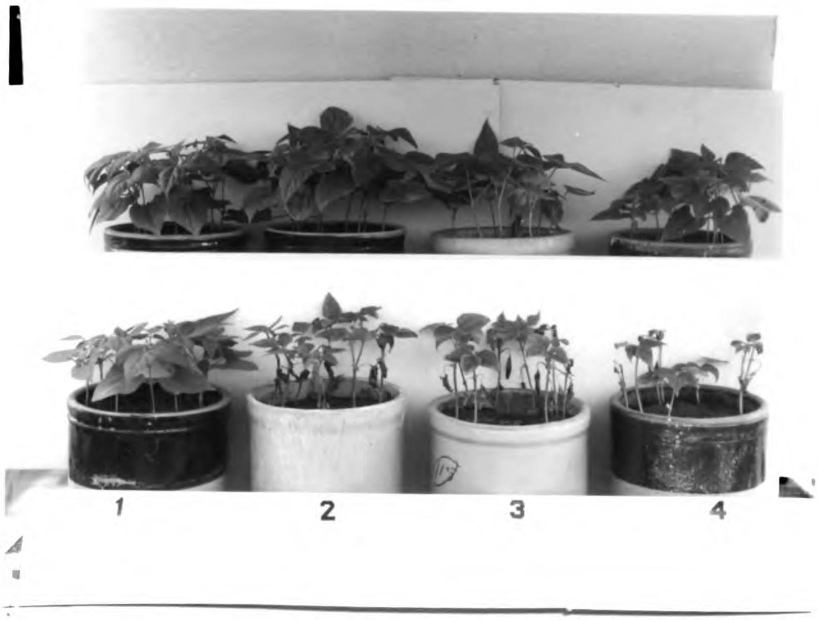

Figure 1. A comparison of potassium injury on 20 day old bean plants growing on Oshtemo sand which received 25 ppm of nitrates (top row) and zero nitrates (bottom row). Potassium increases from left to right with 0, 15, 30, and 60 ppm applications. Phosphorus was applied at 5 ppm on all cultures.

Figure 2. A comparison of 100 ppm applications of nitrates (top row) with 25 ppm (bottom row) in reducing potassium injury on beans grown 20 days on Oshtemo sand cultures. The potassium applications increased from left to right with 0, 15, 30, and 60 ppm. Phosphorus was applied at 10 ppm on all cultures.

Figure 3. The effects of the nutrient levels indicated on beans grown 20 days on Oshtemo sand. The pots in the odd numbered columns did not receive potassium; those in the even numbered columns received 60 ppm of potassium.

level of potassium did not reduce yields below those obtained where potassium was not applied. This interaction between nutrients is nicely shown in Figure 3.

It might be mentioned here that green weight did not correlate closely with yield since many cases were found where identical green weights gave wide differences in dry weights even from duplicate treatments. Color and height of the plants, however, did give a good indication of yields.

An analysis of the dry tissue for phosphorus, reported in Table 8, indicated that as nitrate levels were increased the phosphorus content of the plants decreased where the soil phosphorus levels were low but remained constant where the soil phosphorus level was 10 ppm. Where both phosphorus and nitrate were applied the lowest concentration of plant phosphorus was found in those plants which had received potassium sufficient to make the level in the soil 15 ppm. This was probably the result of maximum growth at those levels. As potassium was further increased to 30 and 60 ppm the phosphorus content of the plants increased again. This increase in phosphorus accompanied the decrease in yield and was previously indicated by the green tissue tests.

Where the levels of nitrate and phosphorus were maintained at the zero level, the application of potassium tended to reduce the phosphorus concentration in the plants. This was also true where the nitrate levels were raised to 25 or 50 ppm but did not hold for the highest potassium level.

As might be expected, as rates of phosphorus application increased, so also did the phosphorus content of the plant tissue. Phosphorus content and plant coloration were closely related but yields did not correlate with color.

In every instance, as shown by the data reported in Table 9, the potassium content of the bean plants increased with increased potassium levels in the soil. The plants grown on soil containing 60 ppm of potassium contained almost twice as much potassium as did those plants grown on soil which did not receive potassium fertilizer.

While in general the potassium test results seem a bit inconsistent, it is interesting to note that the potassium content of the higher yielding cultures fell between 37,000 and 50,000 ppm. Any content over or under this range was accompanied by a sizeable decrease in yield. It is further interesting to note that there are very few cases which approximate this range but do not enter it.

CORN

The data reported in Table 10 show that the concentrations of phosphorus in the soils were maintained very close to the desired nutrient levels. Potassium also was maintained very close with few exceptions, these being on the higher nitrate and 5 and 10 ppm phosphorus applications with 15 and 30 ppm of potassium. Only in one case was the 60 ppm of potassium level lowered. Nitrate levels, as with beans, varied widely and were very difficult to maintain. Variations ranged from zero to 25 ppm for both the 25 and 50 ppm levels and from 10 to 50 ppm for the 100 ppm level.

Additional applications of nitrate fertilizer had been applied previously in an effort to maintain the proper levels.

Potassium injury caused by the 60 ppm level was evidenced by slow emergence and poor germination but enough plants developed to obtain a stand of four per jar.

Yields, reported in Table 11, were increased by the application of nitrogen fertilizer. In the cultures where neither phosphorus nor potassium was applied and also in those where phosphorus was applied without potassium, corn yields were not increased by raising nitrate levels above 25 ppm. Where the phosphorus level was 5 ppm and the potassium was raised to 15 ppm, however, yields were consistently increased by each added increment of nitrogen, right up to and including the highest level. This again illustrates the need for balance among the nutrients.

Applications of phosphorus were not beneficial until nitrogen was applied and did not greatly increase yields until potassium was also applied. Furthermore, it was found that the potassium level could not be greater than 15 ppm if maximum yields were to be obtained. Where phosphorus levels were zero, the highest level of potassium actually depressed yields at all nitrate levels from 25 to 100 ppm. Where phosphorus was applied the high potassium levels did not depress yields below those obtained on cultures where potassium was not applied but there was a smaller increase in yield than occured where the potassium application was 15 ppm.

Since the detrimental effect of the 60 ppm potassium application was less as nitrates and phosphorus increased, there is a possibility that still higher levels of some of the nutrients might have resulted in further evidence of the importance of balance among the nutrients. For instance, would yields have been further increased by 15 ppm of phosphorus with the 50 ppm of nitrate and 60 ppm of potassium applications? Would they also have been increased by 150 ppm of nitrates with the 5 ppm of phosphorus and 60 ppm of potassium applications?

Here, as for beans, green weights did not indicate the dry weights since the percent of dry weight varied widely from equal green weight even from duplicate treatments. Those plants having weak stalks were found to have a very low dry weight.

Weak stems were common on those jars receiving either high nitrates and low potassium or high potassium and low nitrates indicating a need for a balanced condition of the two for sturdy stalk growth.

Height of corn, as reported in Table 12, followed somewhat the same pattern as yields. Nitrate either with or without phosphorus, increased height where the level was 25 ppm but no additional increase occured as a result of levels higher than 25 ppm.

The application of 5 ppm of phosphorus increased height but 10 ppm applications showed little increase over the lighter application.

The first increment of potassium caused an increase in height in almost all cases. Generally, however, the second increment did not cause a further increase and the highest potassium level resulted in smaller plants than did the 15 ppm level.

The height of stalk and the size of stalk, separately or together, gave only a very general correlation to yield.

Analysis of the dry tissue for phosphorus, the data being presented in Table 13, showed generally that phosphorus in the plants decreased with increasing nitrate levels in the soil. This did not hold for the higher levels of both nitrate and phosphorus, nor for the highest level of nitrate where phosphorus was not applied.

Increasing phosphorus applications, as one might expect, increased the phosphorus content, with very few exceptions.

Potassium levels of 15 and 30 ppm, in some cases, reduced phosphorus content, while in other cases, they increased it. Generally, the 60 ppm level of potassium decreased the phosphorus content with an extreme decrease in one instance.

Height and yield showed no correlation to phosphorus content of the dry tissue.

Table 14, which gives the data for the analysis of dry corn tissue for potassium, shows that increasing nitrate applications, in most cases, decreased the potassium content of the tissue. The exceptions, generally, were where the nitrate level was 100 ppm.

Phosphorus applications reduced the potassium content but the 5 ppm application caused a greater reduction than the 10 ppm. An examination of the data shows also in those plants where applications of phosphorus reduced the potassium content, the content of phosphorus was higher. This is shown by comparing the data in Tables 13 and 14. This indicates an interrelationship of the two nutrients.

Here, as with beans, as the potassium applications increased so also did the potassium content of the tissue. It was very interesting to note also that as nitrate levels increased and as phosphorus levels increased, the potassium levels in the plants decreased. This held for all of the potassium levels.

SUMMARY

In an effort to determine the optimum nutrient levels for corn and beans, it was decided to grow these plants in greenhouse cultures containing various levels of the plant nutrients, N, P, and K. The levels decided upon were 0, 25, 50 and 100 ppm of nitrate, 0, 5, and 10 ppm of phosphorus, and 0, 15, 30 and 60 ppm of potassium. Calcium was used to bring the soil to near neutrality and minor elements were added to prevent deficiency. Oshtemo sandy soil was used because of its lack of interfering nutrients. Michelite field beans, a commonly grown white bean in Michigan, and early hybrid # 11 field corn were the varieties used.

Phosphorus and potassium levels were fairly easily maintained but nitrate levels were very difficult to hold even close to the desired levels. The 60 ppm potassium application caused considerable injury to the beans and to some extent to the corn. Where higher applications of nitrates and phosphorus were made, however, this injury was reduced. This indicated that to prevent injury either both must be high with high K or if both are low, K must be low.

Green tissue tests correlated fairly well with yields. The highest yields in most cases occurred where

the tissue tests indicated high or very high nitrates, medium or high phosphorus, and high potassium.

A phosphorus application of 5 ppm appeared sufficient for optimum plant growth even though nitrates and potassium varied widely. The optimum nitrate level, in most cases, was 50 ppm, while the optimum potassium level appeared to be 15 to 30 ppm.

In the case of corn, however, there was some indication that other balances might be reached at higher levels than those used.

The phosphorus content of the dry plant tissue was increased with phosphorus applications but in many cases showed decreases where nitrates and potassium were applied.

Potassium content, likewise, increased with each potassium application but decreased with nitrate applications. Only the 5 ppm of phosphorus appeared to influence the potassium content, causing a reduction. Especially noticeable in the corn data is the relation that as potassium decreased in plants where the phosphorus level was 5 ppm there was an increase in their phosphorus content indicating an interaction of potassium and phosphorus at certain nutrient levels.

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