STUDIES ON THE INFLUENCE OF NITROGEN, PHOSPHORUS, AND POTASSIUM ON YIELD, AND OTHER FACTORS IN POTATOES

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INTRODUCTION

Except for trials carried on by Professor Ellis, of the University of Manitoba, little is known about the value of fertilizers as related to the potato crop in Manitoba. Trials were conducted by him in the areas of Dauphin, Bird's Hill, Stonewall, Carman and Whitemouth in past years.

In May of 1943, the first potato plots were planted at the University farm in connection with the Manitoba Potato Breeding Project which was commenced as a result of the formation of, and subsequent recommendations from the Manitoba Potato Committee in April of 1942. Foliage discoloration of some potato plants in the plots was first noticed in 1943 which was thought to be of possible nutritional origin. Since rogueing for virus diseases, and the selection and propagation of valuable potato seedlings were two important phases of the project, it was deemed necessary to have this material growing under ideal conditions. Rogueing proves difficult when such factors as nutritional disorders may complicate the usual visible symptoms of virus infection.

The acreage sown to potatoes in Manitoba averages between 32,000 and 34,000 acres per year over a ten-year period. A large proportion of this is located on the heavy soils in the Red River valley district. While the experiment was designed primarily to serve the needs of the Potato Breeding Project, it is hoped the results may help to stimulate future work with fertilizers on potatoes and root crops in the Red River valley. It is a hope, also, that it will invite further experimentation in the nutrition of other horticultural crops.

Problems of Potato Growing in the Red River Valley. Potatoes have been a minor crop in the Red River valley in Manitoba for some years. This is partly due to economic reasons, and to the heavy nature of the soils in this region. Potatoes compete with wheat and other small grains, sugar beets, and near Winnipeg, with other truck and market garden vegetables. Some of the land on which potatoes are grown is poorly drained - a condition which is decidedly unfavorable to raising this crop.

Low yields are partly due to planting poor seed. In recent years, the presence of late blight disease and bacterial ring rot has also been responsible for a serious reduction in potato yields. Growers' familiarity with control of these diseases has been inadequate largely because these diseases have not been here long enough to arouse the growers' serious attention.

Although there is a potential source of irrigation in the immediate vicinity of the Red River, this has not been exploited to advantage. The use of irrigation does tend to lower potato quality, but where seed potatoes are concerned, this need not be a serious problem. Proper use of manures and fertilizers with irrigation may help to offset this.

Potato quality and appearance is another factor in the discrimination of the local product. Generally, on heavier soils, and particularly when soil moisture and rainfall is high, these potatoes have poorer quality (higher water content and less starch). Their appearance is also less attractive, particularly because of the more attractive russet varieties of potatoes that are placed on Manitoba markets. Such varieties cannot be grown on the heavy Red River soils with any assurance of good shape and dependable yields. The proper use of fertilizers may afford means to improve this situation somewhat and the development of better adapted varieties would help immeasurably. Also selection of the well drained sites in the heavy soils area and better disease control would improve both these attributes considerably.

LITERATURE REVIEW

Results of Ellis' work (1) in several Manitoba districts indicate substantial increases from phosphate, some effect from nitrogen and no response to potash alone. In addition, fertilizer combinations with the three elements included gave responses above that of phosphate applied alone. Preliminary recommendations were made from these experiments suggesting the use of a complete fertilizer having the ratio of 1 part of nitrogen, 3 parts of phosphate and 1 part of potash for heavy soils; and for lighter soils a 1:3:3 ratio was advised.

Recent investigation by Rost, Kramer and McCall (5,2) on fertilizers for potatoes in the Red River valley in Minnesota also make separate recommendation for light and heavy textured soils. Superphosphate, containing 43 to 48 per cent phosphate is recommended as one alternative, or an application of a phosphate-potash mixture in the ratio of 2 to 1. An equivalent of 200 pounds of a 0-20-10 fertilizer is mentioned as example of the desirable application rate. In light textured soils a 1 to 1 ratio of phosphate to potash is advised. The equivalent of 0-12-12 at approximately 275 pounds per acre is the recommended application.

They report further that four years of trials with commercial fertilizers in this area has shown that on heavy-textured soils, approximately 13 per cent of the fields did not respond to fertilizers, 40 per cent gave greatest yield increases with superphosphate alone, and 47 per cent with a mixture of superphosphate and potash. This ran 16, 16 and 68 per cent respectively in the case of light textured soils. Potash alone did not increase yields.

MATERIALS AND METHODS

The plots were arranged in a factorial design as a 3 x 3 x 3 confounded experiment as outlined by Goulden (4), Fisher (3), and Yates (7). The three main elements nitrogen, phosphorus, and potassium were studied in all possible combinations at two levels of fertilization plus a check, or, in other words, at three treatment levels of the three main fertilizer elements making 27 different combinations in all.

In this thesis the fertilizer components N, P_2O_5, and K_2O will be referred to by means of the symbols N, P, K, respectively. The various levels of these components will be designated as follows: no fertilizer, N_0, P_0, K_0; first level, N_1, P_1, K_1; and second level N_2, P_2, K_2. Where it is desirable to abbreviate these symbols the letters will be omitted and the numbers will be understood to refer to the letters always in the same order, namely N, P, K.

For example 1 0 2 indicates N_1, P_0, K_2 meaning the first level of N, the absence of P_2O_5 and the second level of K_2O.

In supplying the application rate for 1944, the phosphate was set approximately at the rate advocated by Ellis (1) for the basic 1 1 1 treatment. The rate of 145 lb. per acre of 38% P_2O_5 then formed the basic phos-

Table I. Rate of application of the fertilizer constituents and combinations used at the various levels in 1944.

Levels # of N P K	Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Fertilizer applied per acre
	Pounds per acre			
0 0 0	0	0	0	0.0
1 0 0	54	0	0	270.0
2 0 0	108	0	0	540.0
0 1 0	0	54	0	145.0
1 1 0	54	54	0	415.0
2 1 0	108	54	0	685.0
0 2 0	0	108	0	290.0
1 2 0	54	108	0	560.0
2 2 0	108	108	0	830.0
0 0 1	0	0	54	115.0
1 0 1	54	0	54	385.0
2 0 1	108	0	54	665.0
0 1 1	0	54	54	260.0
1 1 1	54	54	54	530.0
2 1 1	108	54	54	800.0
0 2 1	0	108	54	405.0
1 2 1	54	108	54	675.0
2 2 1	108	108	54	945.0
0 0 2	0	0	108	230.0
1 0 2	54	0	108	500.0
2 0 2	108	0	108	770.0
0 1 2	0	54	108	375.0
1 1 2	54	54	108	645.0
2 1 2	108	54	108	915.0
0 2 2	0	108	108	520.0
1 2 2	54	108	108	790.0
2 2 2	108	108	108	1060.0

These levels were calculated on the basis of the analyses of the fertilizers used, which were as follows: ammonium sulphate - 20% N; triple super phosphate - 38% P_2O_5; and potassium chloride - 48% K_2O.

phate rate in this experiment. From this the other combinations were determined in such a way that at the 1 1 1 level of fertilization, this complete mixture would contain the three components nitrogen as N, phosphate as P_2O_5, and potash as K_2O in as close to a 1:1:1 ratio as possible. The second level was double this rate for all three elements. The rates and ratios of the elements supplied in the complete experiment for 1944 are found in Table I.

In 1945, the application rate for phosphate (P_2O_5) was left approximately the same as in 1944, but the rate for nitrogen (N) and potash (K_2O) was reduced to one-third. This gave instead of a 1:1:1 ratio at the 1 1 1 level, 1:3:1 for 1945. This arrangement conformed in all three elements with the recommendation of Ellis (1) for heavy soils. The rates for 1945 are shown in Table II. For example, reading from Table II, at the 1 1 1 level, the fertilizer combination was applied at the rate of 269.5 pounds per acre. The calculated ratio of this mixture is 6.7 : 20.0 : 6.7 of N : P_2O_5 : K_2O respectively, and at the rate applied is exactly equivalent to 9:27:9 at 200 pounds per acre. This rate is equivalent to that suggested by Ellis (1).

Table II. Rate of application of the fertilizer constituents and combinations used at the various levels in 1945.

Levels # of N P K	Pounds per acre Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)	Fertilizer applied per acre
0 0 0	0	0	0	0.0
1 0 0	18	0	0	90.0
2 0 0	36	0	0	180.0
0 1 0	0	54	0	142.0
1 1 0	18	54	0	232.0
2 1 0	36	54	0	322.0
0 2 0	0	108	0	284.0
1 2 0	18	108	0	374.0
2 2 0	36	108	0	464.0
0 0 1	0	0	18	37.5
1 0 1	18	0	18	127.5
2 0 1	36	0	18	217.5
0 1 1	0	54	18	179.5
1 1 1	18	54	18	269.5
2 1 1	36	54	18	359.5
0 2 1	0	108	18	321.5
1 2 1	18	108	18	411.5
2 2 1	36	108	18	501.5
0 0 2	0	0	36	75.0
1 0 2	18	0	36	165.0
2 0 2	36	0	36	255.0
0 1 2	0	54	36	217.0
1 2 2	18	108	36	449.0
2 1 2	36	54	36	397.0
0 2 2	0	108	36	359.0
1 1 2	18	54	36	307.0
2 2 2	36	108	36	539.0

These levels were calculated on the basis of the analyses of the fertilizers used, which were as follows: ammonium sulphate - 20% N; triple super phosphate - 38% P_2O_5; and potassium chloride - 48% K_2O.

PROCEDURE

The varieties chosen in 1944 were Bliss Triumph, a mid-season maturing variety and Houma, a late maturing variety. These two varieties were selected, not because of any preference, but because an ample supply of good seed was available.

The spring season of 1944 was a very good one for seeding operations. Both varieties were sown on May 9. The measured amounts of fertilizer were applied to the rows at planting time. Seed pieces or sets were sown three to four inches deep and the fertilizer was drilled by hand at about two or three inches on either side of the seed piece, and was placed at about the same depth. Rows were spaced at three feet apart and the seed pieces were planted in the rows approximately fifteen inches apart.

Twenty-four sets were planted per row per treatment. twenty-seven treatment combinations, and four replicates of each of these, and with two varieties, resulted in a total of 216 treatment plots. Guard rows were planted on either end of the plots.

The site selected for the plots was on a very heavy clay soil. The plots were bounded on the west by a fallow strip and were about thirty feet from a natural shelter-belt of trees (Plate 1). There was some natural protection from the north, but little from east and south. Unfortunately these plots were not sufficiently well provided with drainage for such a wet season and the crop suffered injury on the north end of the plots.

The crop on this land the previous year was a variety of vegetable seed crops. Sugar beets were raised for two years previous to the vegetable seed crops.

The potatoes got away to an excellent start that spring and growth was very rapid. Sprouting of the seed was practically one hundred per cent. Differences were soon noted in vigor between nitrogen and non-nitrogen treated plots. These were first noticed in the early maturing variety, and later appeared in the Houma. Differences became more pronounced as the season advanced. Maturity as indicated by ripening of vines was one to one-half weeks earlier with both varieties in nitrogen-treated plots.

The weather during 1944 was for the most part cool and the rainfall was more abundant than usual during June, and August. Rainfall during the fall hindered harvesting operations very considerably and harvesting had to be deferred till early November.

A major epiphytotic of late blight destroyed the vines in August. Wet, cool weather during that time encouraged rapid sporulation, dissemination and development of the blight fungus. Foliage died down prematurely, particularly in the case of the earlier variety, Bliss Triumph. The foliage of the Houma variety appeared to have more resistance to attack by the blight organism and remained green a longer time. Several applications of Bordeaux mixture combined with lead arsenate were made on these plots. However continuous wet weather washed the fungicide from the leaves very soon after each application, so that it had little effect in the control of blight.

Both varieties suffered very severely from tuber rot caused by late blight. One-half of the Bliss Triumph plots was submerged in water the latter part of the season and tubers in these plots began rotting. Yield results were not taken therefore on the Bliss Triumph variety and only results of the harvest from the Houma variety were retained. Harvesting of the Houma plots took place in early November.

The spring season of 1945 was very backward. The seed bed was in a lumpy, poor, hard condition by the time it was dry enough in the spring to plant. The varieties chosen for the 1945 plantings were Warba and Irish Cobbler. These two were selected because they more truly represent the most commonly grown early maturing and mid-season varieties grown in Manitoba. The same procedure was followed in planting the plots as in 1944, except that the ratios of the elements used were changed somewhat (page 9). Planting was done June 4 for Warba and June 5 for Irish Cobbler.

The separate sites were located for the two varieties on heavy clay soils on the University farm. The two varieties were planted in similar soils. A dry period followed the seeding, and sprouting was slow and was not as uniform as in the previous year.

The weather continued dry until the latter part of June when considerable moisture fell, after which it continued dry again until the latter part of July, when heavy rains came. This again fell off in early August. From the middle of August until the latter part of September, moisture was unusually abundant (Table III). Frost came early and froze partly exposed tubers before harvest operations commenced in early October.

A difference in plant vigor in the 1945 experiments as caused by the different treatments was not evident as in the previous year. Two replicates of the Irish Cobbler variety were flooded by rains during the latter part of the summer and, later, surface exposed tubers were slightly frozen, and the yield results for this variety had to be abandoned.

Late blight did not occur in the 1945 plots. Harvesting operations were carried out in the Warba plot in early October.

It is unfortunate that in both years conditions did not permit a careful study of the effect of the different

Table III. Mean Maximum and Minimum Temperature and Precipitation May 1 to October 15, 1944 and 1945, at the University of Manitoba, Compared with Average Normal Temperature and Precipitation.

	Precipitation (in inches)			Temperature (degrees F.)			
	1944	1945	Normal	1944		1945	
				min.	max.	min.	max.
May	2.12	.89	2.21	70	45	55	34
June	7.24	1.55	3.07	70	52	70	48
July	2.25	2.77	2.95	79	55	77	54
August	4.57	2.87	2.49	75	53	78	53
September	2.34	5.17	2.20	66	47	62	42
October (1-15)	1.26	.06		58	33	51	31

fertilizer treatments on the specific gravity of the tubers. It was hoped that this would be a major phase of the project, but this portion of the work had to be left out. Some preliminary specific gravity readings were made on the 1944 tubers, but results drawn from them were inconclusive because of incomplete data. Late blight injury to the tubers in 1944 and frost in 1945 as well as considerable drowning out were the major factors contributing to the exclusion of this phase of the experiment.

Yield results were recorded of the Houma variety in 1944 and of the Warba variety in 1945. These results were transposed to a bushels per acre basis for each treatment of these two varieties as found in Tables VI and IX. The same tables include these results on the basis of percentage increase of treatment over check plots.

DISCUSSION AND RESULTS

I. Observations on General Growing Conditions. A real nitrogen deficiency existed in the soil when the experiment was conducted in 1944, and was observed consistently throughout all plots of both varieties. Plots fertilized with nitrogen-containing combinations could, without question, be distinguished from those fertilized with non-nitrogen combinations by the color of the foliage (Plates 5 and 6) and by the vigor of the plants (Plate 6). The check plots compared favorably with those fertilized with non-nitrogen containing combinations in every case. The Bliss Triumph variety showed the characteristic deficiency symptoms very early in the growth of the plant. In the deficient plants, the first symptom was a gradual yellowing of the foliage, and in time the leaves curled upwards in a manner very similar to leaf roll, and the edges became bronzed or reddish in appearance. Conditions similar to these are described by Wallace (6). The differences in the variety Houma were not quite so pronounced. The foliage of the deficient plants was not as dark green in color, but there was neither any curling, nor any bronzy discoloration of the leaflets. However, there was a pronounced and noticeable difference in vigor between nitrogen and non-nitrogen fertilized rows. This is well illustrated in Plates 2, 3, 4 and 5.

The fertilizer applications did not seem to have any influence on the date of flowering. Both varieties dropped their blossoms and in no case was there any set of seed. However, there was a noticeable difference in maturity of the vines. Vines of the nitrogen-combinations matured up to a week earlier than those of the other plots in both varieties. There may have been some correlation between the severity of late blight tuber injury and the kind of fertilizer applied, but this was not considered in this experiment. Reports elsewhere also suggest that such correlation might exist.

II. Method of Interpretation of Data. This section is devoted to a discussion of interpreting the influence of the elements Nitrogen, Phosphorus and Potassium on the yield of potatoes in the light of the data collected in the field, subsequently summarized and statistically analyzed. (Tables IV and V give a statistical summary of the data collected in the two years).

Several important points must be kept in mind in this discussion: The first is that response, as ascertained by yields, can be influenced (1) by each element alone, and (2) by the elements in various combinations.

Secondly, response can be negative or positive, or there can be no response. Consider these hypothetical cases: (1) Suppose that statistical analysis indicated

Table IV. Summary of Significant and Non-Significant Single Element Responses.

1944	N	P	K
linear	**		
quadratic	**		
combined	**		
1945			
linear	*		
quadratic		*	
combined			

* significant beyond 5% level.
** significant beyond 1% level.

Table V. Summary of Significant and Non-Significant Interaction Responses Between Elements.

All Possible Interactions	1944 NxP	1944 NxK	1944 PxK	1945 NxP	1945 NxK	1945 PxK
lin. x lin.	**		**		*	
lin. x quad.		*				
quad. x lin.		*				
quad. x quad.						*
com. x lin.	**		**			
com. x quad.					*	
lin. x com.	**		*		*	
quad. x com.						
com. x com.	**		*			

Abbreviations: lin. = linear; quad. = quadratic; com. = combined linear and quadratic.

* significant beyond 5% level.
** significant beyond 1% level.

significant response for nitrogen and suppose that on examining yields this was found to be positive. Then it can be said that yield was increased as a result of the application of nitrogen alone. (2) The opposite would be true if a statistically-significant negative result occurred. (3) However, if statistical analysis showed no significant response, and that on examining the yields, little or no change was noted, then it could be said that this element when applied alone would neither depress nor increase yield. Such a case as the latter would most likely be hypothetical as it is probable that even small amounts of fertilizer can cause slight changes in yield. However, such differences may be so small that they would not exceed statistical error in the experiment.

This experiment is of factorial design. That is to say, it is designed in such a way that the three main elements are used at three different levels and in all possible combinations of these, i.e., 3 x 3 x 3 possible combinations, which are listed in their entirety in Tables I and II.

From this type of design, it is possible to study the response to the application of each element separately, or to the elements applied together, and used in various combinations. Further study can be made of the response to the elements at two different rates or levels of application or to combinations and levels where one or two elements are omitted.

When one element is considered separately, the response is quite simply explained. Yield may increase or be depressed at a proportionate rate from the 0 level through the first and second levels of fertilization. When this occurs, the term "linear response" is applied to the reaction. As an example, suppose the following yields were recorded for nitrogen: N_0, 240 bu., N_1, 260 bu., N_2, 280 bu. Plotted on simple graph paper, a straight line can be drawn through the three points.

However, if the change in yield from one level to the next was not in proportion, a curved line may fit these three points better. If such is the case, the response to the element is termed "non-linear", or "quadratic". Numerous types of curved lines are possible. An easy one to interpret would be the kind where the curved line starts from a low point at the 0 level, rises high at the first level and at the second level falls off to a point between that of the 0 and the first level. Such a condition could be interpreted as follows: the element in question gave greatest response at or near the first level applied, and it appeared that yields were depressed by greater additions such as that applied at the second level. Reactions of this type were found in this experiment.

The interpretation becomes more complex when the interaction between any two of the three elements is considered. One element may influence the response of the other either adversely or beneficially. Such responses are revealed in the study of the interactions. The statistical analysis of these interactions reveals whether these are statistically significant or not. Table IV and V list the various possible combinations of interactions and their significance in the two years' experiments.

Statistically significant interactions between two elements suggest definite relationship between the two elements in regard to their influence on yield. For example, if nitrogen responded in simple (linear) relationship in the interaction and phosphorus reacted in a more complex (quadratic) manner, then it could be said that

(1) there is some important relation between nitrogen and phosphorus which together affect yield, and

(2) that the response is greatly influenced by the proportions and quantities in which these two elements are combined.

In this example, nitrogen has caused yield responses that bear simple interpretation; those of phosphorus, more complex. It could then be said that yield was more critically affected by the proportion of phosphorus applied, then by the amount of nitrogen used in the experiment.

III. Discussion of Significant Results

1944 Experiment

1. Nitrogen

The potatoes responded very strongly to applications of nitrogen at both levels of application. Such evidence is seen graphically in Figure 1. That nitrogen response was not quite as pronounced at the second level of application is further revealed in the dotted line of the Figure. Such evidence suggests that an application at the first level would probably give the greatest returns per unit weight of fertilizer applied. Double this rate gave increased returns, but not quite in proportion to the first level increase.

Table VI. Yield of the Houma Variety of Potato Expressed as Calculated Total Yield (bushels) Per Acre with Different Fertilizer Applications, and as Per Cent Increase of Total Yield of Potatoes with Different Treatments over Non-fertilizer. 1944.

		K_0		K_1		K_2	
		bu.	%*	bu.	%*	bu.	%*
N_0	P_0	341	ch.	349	2	372	9
	P_1	341	0	390	14	330	-3
	P_2	348	2	372	9	363	6
N_1	P_0	453	33	448	31	388	14
	P_1	454	33	408	20	436	28
	P_2	374	10	427	25	476	40
N_2	P_0	494	45	399	17	444	30
	P_1	426	25	478	40	480	41
	P_2	430	26	432	27	450	32

*Percentage increase or decrease in yield over check 0 0 0.

Table VII. Analysis of Variance of Yield of the Potato Variety Houma, 1944.

Variation due to	D. F.	Variance
Blocks	11	26600 **
N	2	84897 **
P	2	630
K	2	684
N x P	4	7845 **
N x K	4	3993
P x K	4	5014 *
N x P x K	8	5744 **
Error	72	1696

* F value significant beyond the 5% point.
** F value significant beyond the 1% point.

Table VIII. Analysis of Variance of Yield of the Potato Variety Houma Showing Variance for Linear and Quadratic Simple and Interaction Effects and Variously Combined Interaction Effects, 1944.

Variation due to	D. F.	Variance
N regression	1	152027 **
deviation	1	17767 **
P regression	1	70
deviation	1	1190
K regression	1	1352
deviation	1	17
N x P Nr x Pr	1	29058 **
Nr x Pd	1	2217
Nd x Pr	1	43
Nd x Pd	1	63
N x K Nr x Kr	1	50
Nr x Kd	1	7571 *
Nd x Kr	1	8205
Nd x Kd	1	111
P x K Pr x Kr	1	16133 **
Pr x Kd	1	1573
Pd x Kr	1	0
Pd x Kd	1	2352
N x P Nr x P	2	15637 **
Nd x P	2	53
P x N Pr x N	2	14550 **
Pd x N	2	1140
N x K Nr x K	2	3810
Nd x K	2	4158
K x N Kr x N	2	4127
Kd x N	2	3841
P x K Pr x K	2	8066 *
Pd x K	2	1962
K x P Kr x P	2	8853 **
Kd x P	2	1176
Error	72	1697

* F value significant beyond 5% point.
** F value significant beyond 1% point.

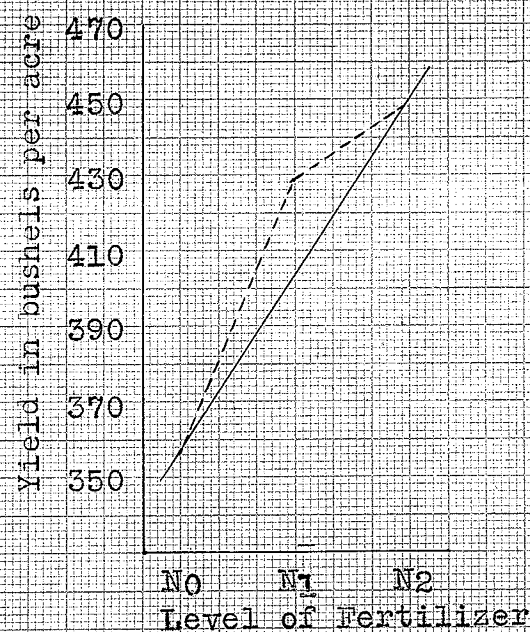

FIGURE 1. NITROGEN RESPONSES, 1944

2 and 3. Phosphorus and Potash

There were no statistically significant responses to either potash or phosphorus as considered in themselves in the 1944 experiments. This means that although there may have been slight changes, either positive or negative, in response to application of these elements as considered in themselves, the relative changes were not of sufficient amount to be considered important.

4. Nitrogen -- Phosphorus Interactions

4a. Nr x Pr. These interactions are illustrated in Figure 2a. As only linear interactions involved were significant only the 0 and 2 levels are graphed. Examining Figure 2, it is seen that the P_0 and P_2 lines cross one another. In other words, there is a certain point reached when these two elements are used together, that if a greater amount of either one is added, the yields will begin to fall off. Theoretically, the yield would fall off at any point above the point of intersection of the two lines. Thus any amount of phosphorus used above that theoretically used at the point of intersection would tend to suppress the yield in relation to nitrogen used alone. The information gained from this would be that phosphorus used with nitrogen at the second level in the experiment helped to increase yields up to the first level of phosphorus, but the addition of more phosphorus tended to depress the response in comparison to nitrogen used alone.

4b. Nr x P. The response to nitrogen was very marked whether without, or supplemented with phosphorus. This is seen in figure 2b. Examining the interaction of phosphorus and nitrogen at the second level, it is seen that phosphorus applied with it increased the yield over nitrogen used alone. When the second level of phosphorus was applied, the yield was suppressed below both the N_2P_0 and N_2P_1 levels. This significant interaction emphasizes further the point brought out in section 4a.

4c. Pr x N. An examination of Figure 2c shows that phosphorus used alone increased yields slightly, and statistical evidence suggests that this increase was not significant. Increase was obtained when phosphorus at the second level was applied with nitrogen at the first level. Additional response occurred when the second level of nitrogen was used, but the increase was not proportionate with the first increase. That is, following the response from nitrogen when added with phosphorus at the second level, the following yields were obtained: phosphorus at second level alone, 361 bu.; with nitrogen at the first level, 425 bu.; with nitrogen at the second level, 437 bu.

The observations made in sections 4a and 4b must also be kept in mind in the discussion. Under this section it will be noted that the yield at both the first and second levels are better when nitrogen is used alone, than when phosphorus is added at the second level with it. Phosphorus at the second level at both the first and second level of nitrogen depressed the response as compared with response from nitrogen alone. As was stated in 4a, if phosphorus is to be used in combination with nitrogen, it must be used at a rate near, or somewhat below its first level to give maximum response from it used together with nitrogen at the second level.

5a. Nitrogen -- Potassium Interactions

Figures 3a and 3b illustrate this interaction. Examining either figure, at the 0 level of nitrogen (N_0), potash at the 0 and second level depressed yield in comparison with potash at the first level. And at the second level of nitrogen (N_2), the opposite was true; potash at the first level depressed yields in comparison with potash at the first level.

Examining Figure 3a, it is seen that when potash is used alone, there is a response to it at the first level, which falls off at the second. In other words, when the potash is used alone, there is a point reached somewhere near the first level that gives greater yield, but more than that amount apparently causes the yield to drop as seen at the second level. Response from potash alone was not statistically significant, so the reaction to potash alone is not important. It is not this fact but how

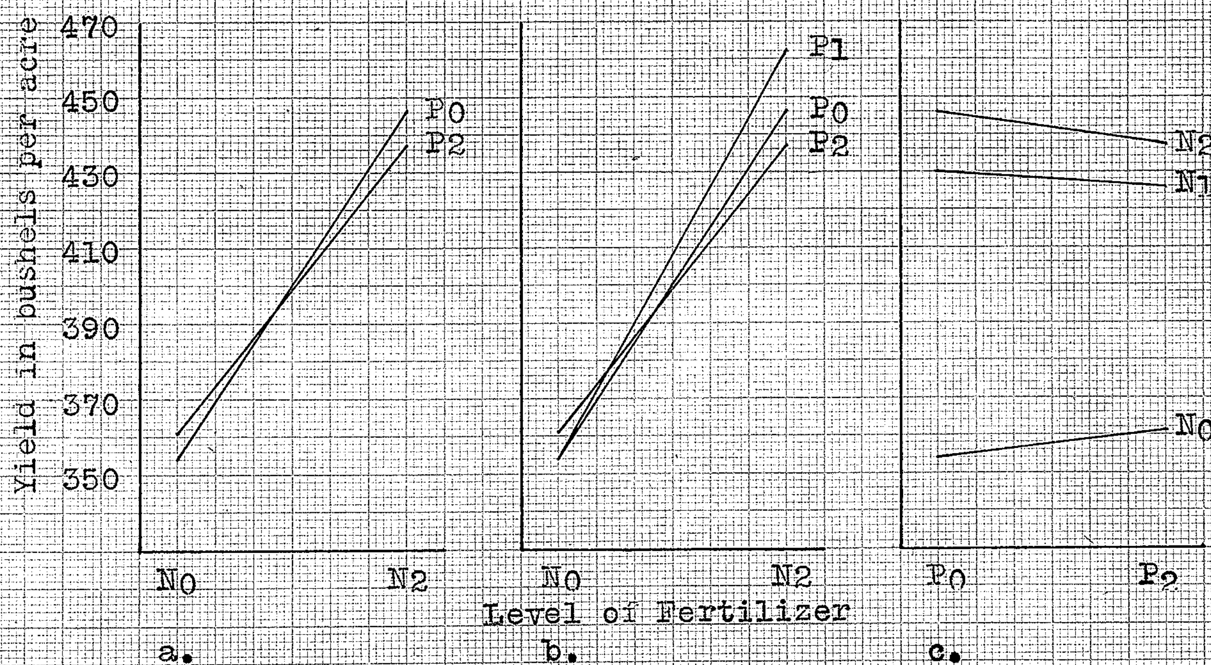

FIGURE 2. NITROGEN -- PHOSPHORUS INTERACTIONS, 1944

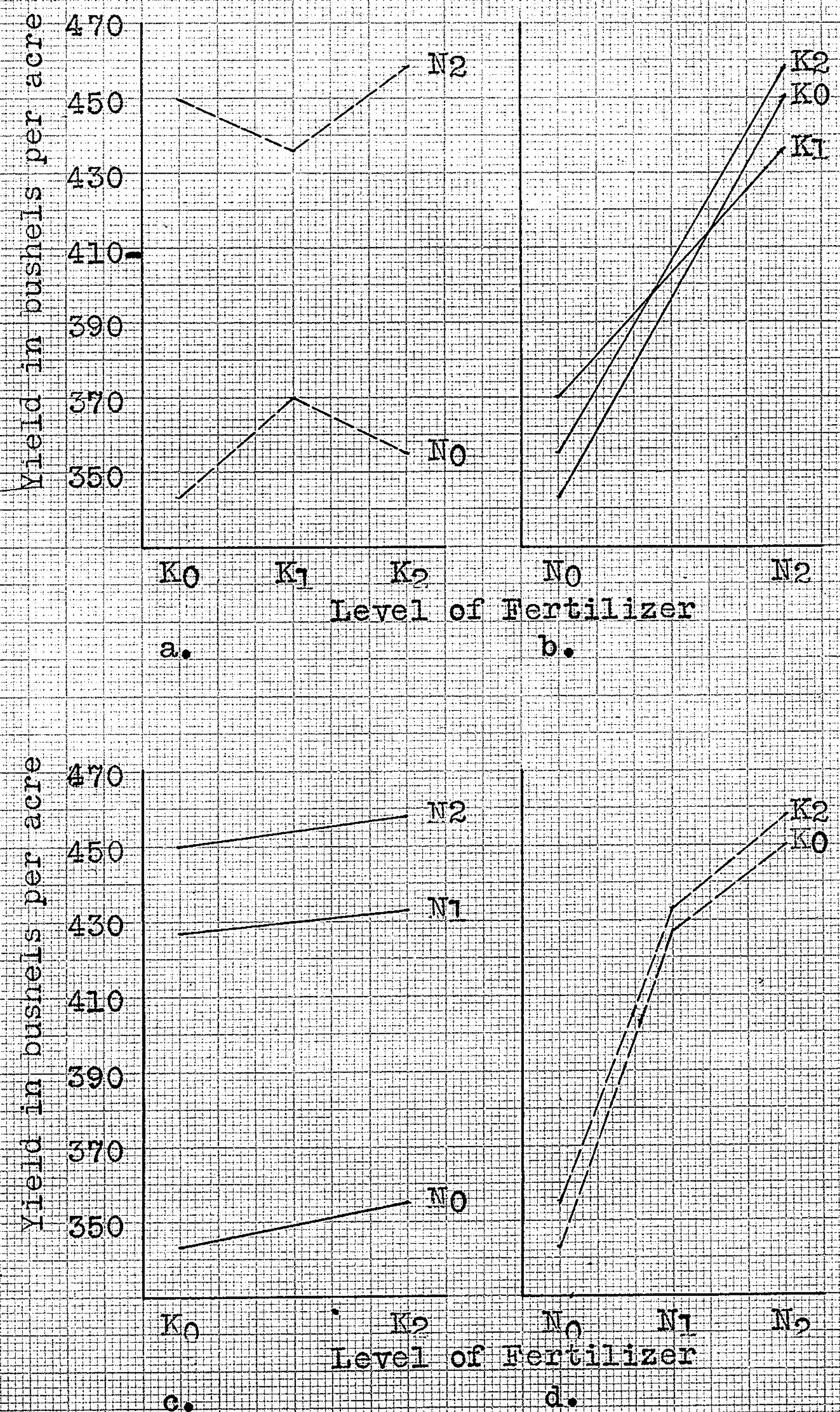

FIGURE 3. NITROGEN -- POTASH INTERACTIONS, 1944

nitrogen and potash influence the yield together that is the important point brought out in the interaction.

In this same figure the N_2 curve is in the opposite direction compared with the N_0 curve. Interpreting this from Figure 3a, yield is depressed when a little potash (at the first level) is added with nitrogen at the second level, but when more potash (at the second level) is added, the yield is increased above that of nitrogen at the second level applied alone.

This suggests a very important interaction between nitrogen and potash both of which when applied together influenced yield in different ways at different levels. Potash was more sensitive to changes in quantity of fertilizer used than was nitrogen. Nitrogen was more direct in its response, i.e., it increased yields more or less proportionately, regardless of the influence of potash. Potash depended on the presence of nitrogen to cause response in yield from it, or in other words potash depended on an interaction between it and nitrogen in order to cause response from it.

In concluding this section, the interaction suggests that either potash should be omitted or added in sufficient quantity to give greatest returns. Potash applied at or above the second level, it appears, would have given a greater return than nitrogen used alone at the second level. (Figure 3a). The combinations containing nitrogen and potash gave the highest yields.

5b. Nd x Kr. The fact that this interaction is significant tells us that response from nitrogen is influenced by the presence of potash. Figure 3c shows how potash has influenced response to nitrogen -- i.e., it has increased response to it. Figure 3d shows that nitrogen at the first level, whether at the K_0 or K_2 level, does not fall at all near the straight line if it were drawn from the N_0 to the N_2 level. As these curves lie, it shows that potash has not changed the curve significantly, except that nitrogen applied at each level with potash was a little better in yield in each case than when nitrogen was used alone. This does not take into consideration potash used at the first level, which has already been discussed in section 5a.

This interaction shows that nitrogen depended on the presence of potash to obtain greater yield responses than when used alone.

6. Phosphorus -- Potash Interactions

6a. Pr x Kr. According to the results seen in Figures 4a and 4b, the interactions between these two elements are quite important in regard to their influence on yields in the experiment. As seen in Figure 4a, potash applied alone, and at the second level, suppressed yields as compared with the check, but when both were applied in combination, the

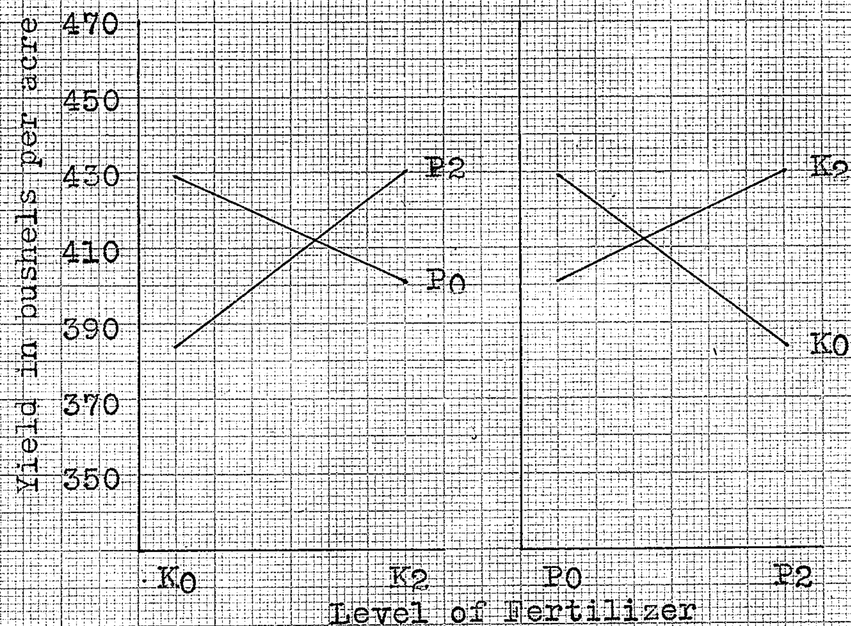

FIGURE 4. PHOSPHORUS -- POTASH INTERACTIONS, 1944

yield rose slightly higher than the 0 level alone. Apparently, then, the use of either these two elements alone would have been detrimental to yields. Applied together they would not give sufficient increase to justify their application under conditions represented by this season, unless, of course, they were used in combination with nitrogen.

6b. Pr x K. Phosphorus, Figure 4, applied alone gave a decided decrease in yield as compared with check. Increase was obtained when phosphate at the second level was applied with potash at the first level. Additional response was received when a second level of potash was applied, and the increase was nearly proportional to the first one. However, this application (K_2P_2) only equaled the check plot in yield. Thus no benefit was derived through their use, when not employed together with nitrogen.

6c. Kr x P. Similarly, potash applied alone gave a decrease in yield as compared with check. Increase was obtained when potash at the second level was applied with phosphate at the first level. Additional response occurred when a second level of phosphorus was applied and the increase was nearly proportional to the first increase. However, this application (K_2P_2) only equaled the check plot. Thus no benefit was derived through the use of potash and phosphorus applied alone or in combination unless applied with nitrogen.

The results show strong relationship between these two elements. When nitrogen is not considered, the two must be applied in combination to bring balance, and at applications near the second level of both elements in order to bring about a response equaling that from the application of no fertilizer. When applied below that level, there was a depression in yield, particularly when either one was applied without the other. The response from the two elements used together suggest the possible need for applying them with nitrogen to obtain maximum response.

1945 Experiment

1. Nitrogen Response

As seen in Figure 5, nitrogen increased yields. Response was proportionate with the amount of nitrogen applied, so the second level of nitrogen gave the greatest yield. It is possible that yield might have been even greater if nitrogen was applied in quantity greater than that applied at the second level. It will be remembered that only one-third as much of this element was used in the experiment this year.

2. Phosphorus Response

Yield was increased by the application of phosphorus, Figure 6. As for nitrogen, even better yields might have been expected if phosphorus was applied above the second

Table IX. Yield of the Warba Variety of Potato Expressed as Calculated Total Yield (bushels) Per Acre with Different Fertilizer Applications, and as Per Cent Increase of Total Yield of Potatoes with Different Treatments over Non-fertilizer. 1945.

		K_0		K_1		K_2	
		bu.	%*	bu.	%*	bu.	%*
N_0	P_0	200	ch	233	16	266	33
	P_1	223	12	260	30	252	26
	P_2	258	29	278	39	252	26
N_1	P_0	241	20	248	24	276	38
	P_1	247	24	276	38	248	24
	P_2	247	24	237	18	285	42
N_2	P_0	284	42	200	0	275	38
	P_1	274	37	282	41	258	29
	P_2	260	30	288	44	270	35

*Percentage increase in yield over check 0 0 0.

Table X. Analysis of Variance of Yield of the Potato Variety Warba, 1945.

Variation due to	D. F.	Variance
Blocks	11	21467 **
N	2	2582
P	2	3402
K	2	1901
N x P	4	2485
N x K	4	2181
P x K	4	2818
N x P x K	6	2653
Error	72	1164

* F value significant beyond the 5% point.
** F value significant beyond the 1% point.

Table XI. Analysis of Variance of Yield of the Potato Variety Warba Showing Variance for Linear and Quadratic Simple and Interaction Effects and Variously Combined Interaction Effects, 1945.

Variation due to	D. F.	Variance
N regression	1	5151 *
deviation	1	12
P regression	1	6517 *
deviation	1	287
K regression	1	3799
deviation	1	3
N x P Nr x Pr	1	33
Nr x Pd	1	2085
Nd x Pr	1	2791
Nd x Pd	1	61
N x K Nr x Kr	1	5064 *
Nr x Kd	1	2627
Nd x Kr	1	836
Nd x Kd	1	196
P x K Pr x Kr	1	352
Pr x Kd	1	4312
Pd x Kr	1	890
Pd x Kd	1	5720 *
N x P Nr x P	2	1059
Nd x P	2	1426
P x N Pr x N	2	1912
Pd x N	2	1073
N x K Nr x K	2	3845 *
Nd x K	2	1032
K x N Kr x N	2	516
Kd x N	2	2950
P x K Pr x K	2	2332
Pd x K	2	3305
K x P Kr x P	2	621
Kd x P	2	5016 *
Error	74	1164

* F value significant beyond 5% point.
** F value significant beyond 1% point.

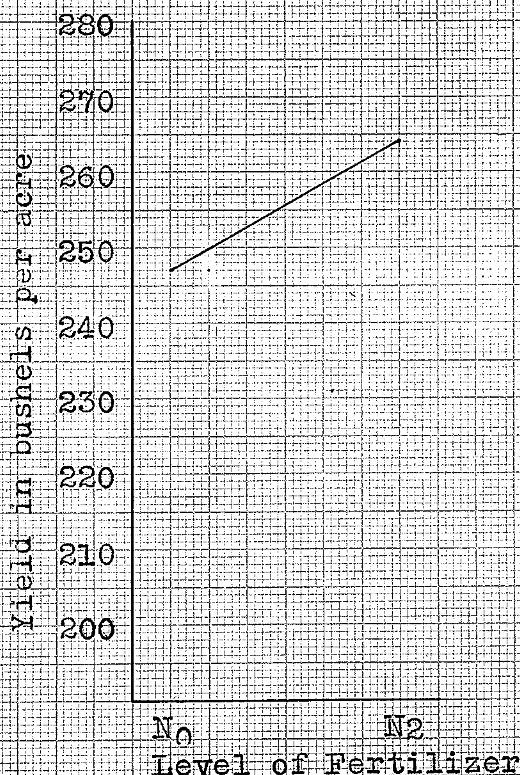

FIGURE 5. NITROGEN RESPONSE, 1945

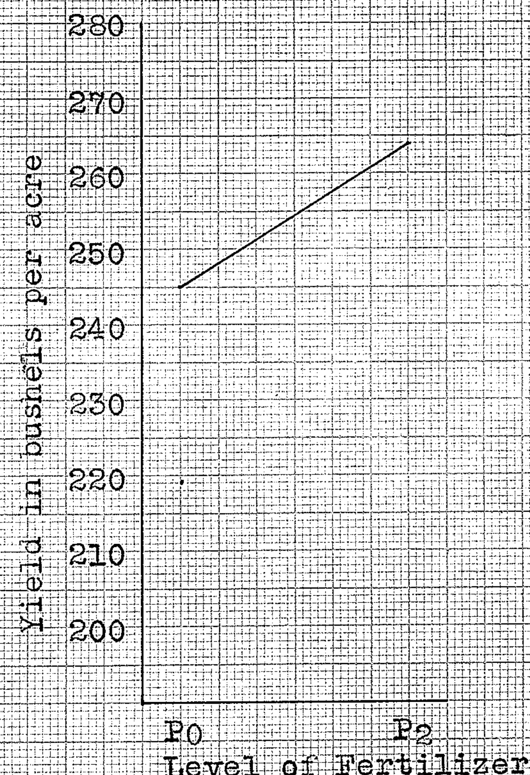

FIGURE 6. PHOSPHORUS RESPONSE, 1945

level without causing significant deviation or "tapering" off of yield.

Phosphorus alone did not show response the previous year. This might have been due to the very heavy response due to nitrogen overshadowing any response that might have been obtained from phosphorus alone. However, in 1944, there were significant interaction effects between phosphorus and nitrogen, and phosphorus and potash. Only the interaction between potash and phosphorus was significant. The two elements applied alone gave no response in 1945.

3. Potash Interactions

There was no significant response to potash application when considered separately in the 1945 experiments.

4. Nitrogen -- Phosphorus Interactions

There were no significant interactions between nitrogen and phosphorus in any combinations in the 1945 experiments.

5. Nitrogen -- Potash Interactions

5a. Nr x Kr. Figures 7a and 7b show the interactions in this section. Nitrogen alone increased yield, as did potash, although the latter was not significant. When the two elements are considered together, the yield from potash at the second level is considerably higher than check yield. However, when potash is applied at the second level with the second level of nitrogen, the yield is suppressed in

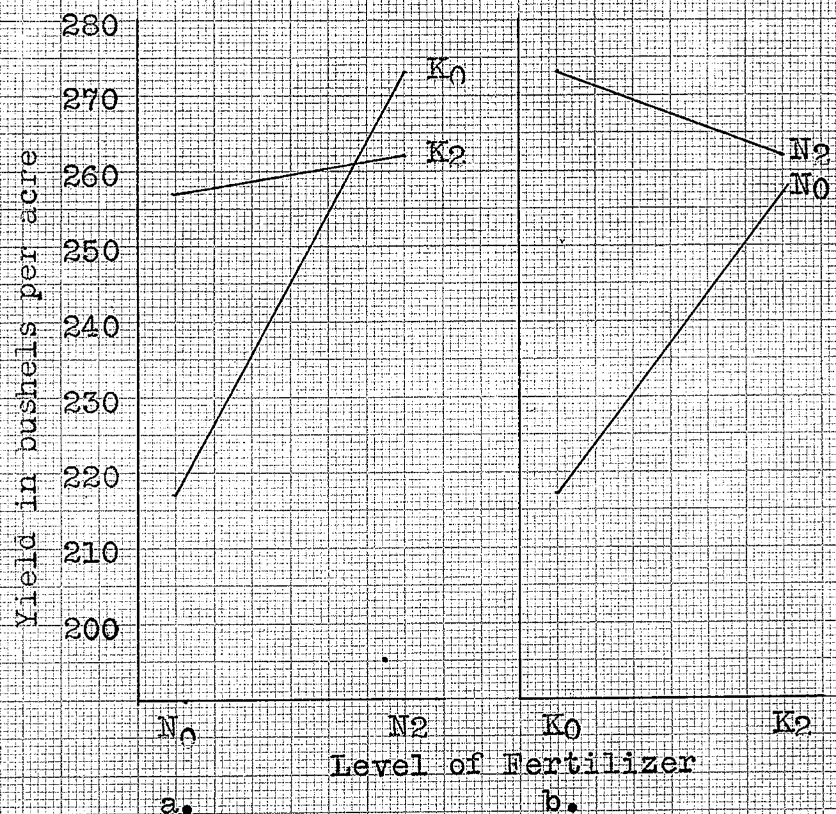

FIGURE 7. NITROGEN -- POTASH INTERACTIONS, 1945

comparison with nitrogen applied alone at the second level.

From an examination of Figure 7a, the point where the two lines intersect would theoretically be the point where the two elements when used in combination would give the greatest yield. Apparently an application somewhat below the second level of the two elements would then give greatest returns from the elements when applied together. This is not as great as the yield obtained from nitrogen alone, so it is possible that potash is not required, under the conditons of the experiment this season.

5b. Nr x K. Nitrogen alone gave considerable response. Increased response was obtained when nitrogen at the second level was applied with potash at the first level. However, the yield was depressed somewhat at a higher level of potash, but did not fall below the yield of nitrogen at the second level applied alone.

6. Phosphorus -- Potash Interactions

6a. Pd x Kd. A proper balance between the two elements was necessary to give greatest response from these two elements used together. As seen from Figure 8, combinations P_1K_1, P_2K_2, P_2K_1, and P_0K_2 in the order mentioned gave the greatest response over the check treatment, so these elements used together in the proper combinations gave increased returns that year.

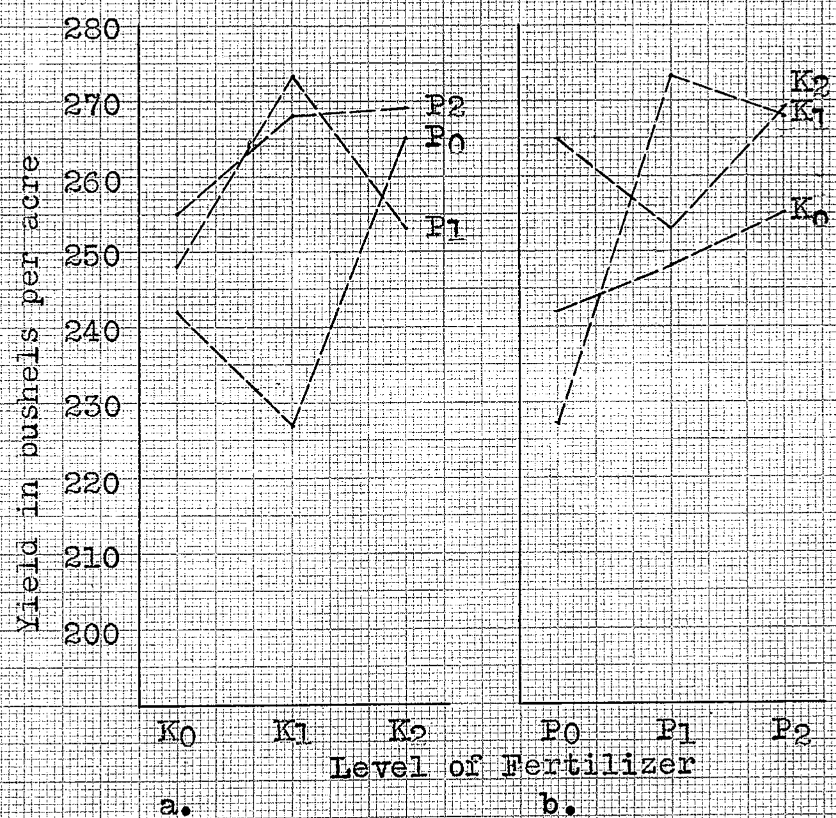

FIGURE 8. PHOSPHORUS -- POTASH INTERACTIONS, 1945

This interaction is the most complex one found in the two years' experiments. Considering potash when applied at the first level, it depressed yield below check; but when the second level was added, yield was increased above that of check. However, when a first level of phosphorus was introduced, the opposite occurred. Yield was increased at the first level, but fell when the second level of potash was used with the first level of phosphorus. When the second level of phosphorus was used, yield was increased when the first level of potash was added with it, and there was little additional response when the second level of potash was used with phosphorus at the second level. Thus, no benefit was gained from the second application of phosphorus. Examining Figure 8, phosphorus and potash added at the first level of each give best response.

6b. Examining Figure 8b there was some gain in yield from application of phosphorus alone and this gain was proportionate with the amount of phosphorus applied. When a first level of potash was added, the yield as a result of phosphorus applications fell below the yields due to potash used alone at the first level, but there was a slight increase over that when potash and phosphorus were applied both at the first level. At the second level of potash, yield increased, strongly when a first level of phosphorus was added with potash at the second level, but there was a slight drop when both were applied at the second levels in comparison with potash at the second level used alone.

IV. Comparison of 1944 and 1945 Results

1. Nitrogen

It will be noted that the nitrogen rate applied in the 1945 experiment was one-third of that applied the previous year at each level. In addition, rainfall was abundant during the growing season of the plants in 1944 and the reverse in 1945. The rate at the second level applied in 1945 is two-thirds that of the first level applied in 1944, and it is suggested that in the 1945 experiment the nitrogen rate could have been raised and at the same time increased yields. In the 1944 graph (Figure 1b), the yield at the second level began to show tapering off, as indicated in the significant deviation analysis, showing that the second rate applied did not increase the yield proportionately as much as the first. This falling off might have been even more acute if the rainfall had been closer to normal, or if weather similar to that in 1945 had prevailed in 1944. It seems then that a rate of nitrogen applied somewhere in the range between the second level of the 1945 experiment (Table II) and the first level of the 1944 experiment (Table I) would be expected to have given the most economical returns for either of the two years. That would range between 180 lb. and 270 lb. of ammonium sulphate (containing 20% N) per acre.

2. Phosphorus

During the season of heavy precipitation, 1944, the crop did not respond to applications of phosphorus alone. This might have been due to an acute lack of nitrogen during the growing season as suggested by phosphorus, nitrogen interactions. In the drier year, 1945, response to phosphate fertilization alone was evidenced and applications of 284 pounds per acre (of 38% P_2O_5) or better, would have given greatest returns.

3. Potash

Experimental evidence in both years suggest that potash alone did not increase yields in potatoes.

4. Nitrogen -- Phosphorus Interactions

It must be remembered that the interactions for the two years are not directly comparable. In the case of this interaction, as has been already mentioned, nitrogen was applied in 1945 at one-third the rate of the 1944 application. In 1945, none of the interactions between these two elements was significant, although both elements applied alone gave increased response. The results of 1944 suggest that if these elements are to be applied to give greatest returns they should be used at rates below the second level of both these elements. If this had been done, the results for 1944 probably would have compared favorably with those of 1945.

5. Nitrogen -- Potash Interactions

A study of the interactions for the two years, suggest that the amount of potash applied with nitrogen is very important to give the greatest returns. Potash did not seem to be greatly influential in increasing the yields, although it did stimulate yields when used in proper balance with nitrogen.

6. Phosphorus -- Potash Interaction

Considering again that both these elements were applied at one-third the rate in the 1945 experiment, some observations can be made. The interactions in 1945 are more complex. In 1944 the greatest increase in yield was obtained when the two elements were used both at the second level, i.e., at a high rate of application. The two elements used separately depressed yields. However, in 1945 best returns were obtained from several combinations of phosphorus and potash at the 0, first and second levels. Apparently the interaction between these two elements had a great deal of dependence on weather conditions and the rapidity in which they were made available to the plant. In any case, none of the yields obtained when these two elements were used together were greater than the yield of the check plot in 1944. In 1945, some of the combinations outyielded the check to some degree, suggesting that there might be greater response from these two elements used together in a drier year.

SUMMARY

Four potato varieties were grown in a factorial experiment comparing different fertilizers containing nitrogen, phosphorus and potash at two levels. The varieties used were Bliss Triumph and Houma in 1944 and Warba and Irish Cobbler in 1945. Yield results of the Houma and Warba were reported, Triumph and Cobbler were not discussed because of incomplete data. All the tests were carried out at the University of Manitoba.

On the soil in which this experiment was conducted, nitrogen was a limiting factor in the yield of potatoes during the year of abundant moisture. Significant response from this element during the two years of the experiment suggest this element is, without question, necessary for the proper nutrition of the potato plant on the particular soil type. Foliage symptoms corroborated this evidence during the wetter year.

Phosphorus applied alone gave response only in the drier year. In combination with nitrogen, it gave significant response in both years.

Potash applied alone did not increase yields. In combination with phosphorus some response was recorded, but this was negative in the wetter year, 1944 and positive in the drier year. In combination with nitrogen, increased yields were realized in both years.

In 1944, the fertilizer combinations represented per acre applications of 54 pounds of nitrogen (N), 54 pounds of phosphate (P_2O_5), and 54 pounds of potash (K_2O) for the 1 1 1 combination, and double that rate for the 2 2 2 combination. The 0 0 0 combination (no fertilizer) yielded 341 bushels per acre. The highest yields were realized from the following combinations: 2 0 0, 494 bu., 2 1 2, 480 bu., 2 1 1, 478 bu., and 1 2 2, 476 bushels per acre. These figures represent respectively 45, 41, 40 and 40 per cent increases in yield over check.

In 1945, the combinations were changed to 18 pounds nitrogen, 54 pounds phosphate, and 18 pounds potash per acre. Again the 2 2 2 combination was double the 1 1 1 rate. Two hundred bushels per acre were realized for the check yield. Highest ranking combinations yielded as follows: 2 2 1, 288 bu., 1 2 2, 285 bu., 2 0 0, 284 bu., 2 1 1, 282 bu., 0 2 1, 278 bu., and 1 0 2, 276 bushels per acre. These represent increases over check yield of 44, 42, 42, 41, 39, 38 and 38 per cent respectively.

The differences in interactions for the two years in which these potato fertilizer experiments were conducted, suggest that trials of this type must be carried for several years before definite conclusions, and specific recommendations can be made.

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Plate 1. General view of the potato fertilizer plots, looking north. The variety in the foreground is Houma and that in the background, Bliss Triumph. Photographed July 17, 1944 by Dr. S. W. Edgecombe.

Plate 2. Variety Houma, replicate IV. The treatments are from left to right 1 0 2, 0 2 1 (first label), 2 0 1, 2 2 2 and 1 1 1. Photographed July 17, 1944.

Plate 3. Variety Houma, replicate IV. The treatments are from left to right 2 2 1, 0 0 2 (first label), 0 2 0, 2 0 0 and 1 0 1. Photographed July 17, 1944.

Plate 4. Variety Houma, replicate 2. The treatments are from left to right 0 0 2, 0 1 0, and 2 0 0. See Figure 5. Photographed July 17, 1944.

Plate 5. Variety Houma, replicate 2. The treatments from left to right are 2 2 2, 0 0 2, 0 1 0, and 2 0 0. Notice the deeper coloration of the leaves in the nitrogen-treated plots. This corresponds to the black and white picture of the rows shown in Plate 4.

Plate 6. Typical plant of Bliss Triumph variety fertilized with the 0 2 2 combination, showing symptoms found in all plots having the non-nitrogen containing fertilizer combinations. Notice the much darker green color of a leaf from a plant fertilized with one of the nitrogen-containing combinations. The green leaf from the other plant is shown in the upper left hand corner of the photograph.