The Effect of Fertilizers on Sugar Beets Including an Economic Optima Study of the Response[1]

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Introduction

Sugar beets respond markedly to fertilizers under Michigan conditions. The degree of response depends on several factors: soil type, moisture, drainage, previous crop, rotation, the amount of fertilizer applied previously, and the amount and kind applied to the crop. Soil tests are used to determine the residual fertilizer in a particular soil and as a partial basis for recommending the amount and kind of fertilizer to be applied to a particular field.

In recent years considerable attention has been given to determining the optimum amount of fertilizer that can be used at different price levels for the fertilizer nutrients and for the price received for the crop. This type of computation generally involved functional analysis of data. Production functions are fitted to the data in order to estimate the yield response over the whole range of fertilizer applications and the optimal amounts of fertilizer under various price relationships can then be determined.

In general, the design of field experiments satisfactory for agronomists is not entirely adequate for an economic evaluation of the data based on functional analysis. More points on a surface are needed in the latter type of analysis than in that used in calculating the significance of data obtained in the older type of experiments.

The purpose of this experiment was to study the effects of rates of application of phosphorus and potassium on the yield, sugar content, purity, tissue tests, and soil tests, and at the same time to provide sufficient additional treatment points so that a reliable estimate of the production surface could be made.

Method of Procedure

An experiment was initiated in 1957 on a tile-drained, Parkhill clay loam soil located in Sanilac County. The field was severely infested with quack grass necessitating the use of TCA for control. Insecticides were applied to the soil for control of white grubs.

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The experiment consisted of a three-by-four PK factorial, replicated three times with plots one-tenth acre in size. The rates of P_2O_5 were 60, 150, 300, and 800 pounds per acre; and the rates for K_2O were 30, 150, and 400 pounds per acre. Three additional levels of P_2O_5, 100, 225, and 500 pounds; and two K_2O levels of 75 and 250 pounds were included so that an economic evaluation of the data could be made. These plots receiving the additional levels were replicated twice. Eight plots were not fertilized. These plots were randomly distributed within each half of the experimental area that contained the factorial.

All plots, with the exception of the checks, received 50 pounds per acre of 6-24-12 fertilizer applied one inch below the seed at planting time. Fifty pounds of nitrogen per acre in the form of anhydrous ammonia were applied June 12 as a sidedressing on all plots including the checks. The fertilizer, with the exception of that applied at planting time, was broadcast and plowed under at the time of the first planting on April 23. The nitrogen was applied as a sidedressing of anhydrous ammonia.

Minimum tillage method was used. Tillage prior to planting consisted of plowing, with a leveling device known as an E-Z Tiller attached to the plow. The beets were planted immediately with a four-row experimental beet drill.

Replanting was necessary because of a four-inch rain. The second planting of beets (5481 variety) was made on May 7, the same day the field was plowed.

The petioles of the leaves were sampled at three different dates: July 14, August 4, and August 28. The samples were analyzed for phosphorus and potassium and the results are expressed in parts per million of the fresh tissue.

Soil samples were obtained from each plot in August and tested by three different methods of extraction for phosphorus and one method for potassium. The phosphorus extractants used were .135 N HCl; .1 N HCl + .03 N NH_4F; and .025 N HCl + .03 N NH_4F. The potassium was extracted by .135 N HCl. Soil to solution ratios of 1:4 and 1:8 were used with the HCl and HCl plus fluoride extractants, respectively.

Sugar samples were taken from each plot at approximately weekly intervals beginning September 4 and continuing to October 21.

The beets were harvested at two different dates, October 17 and October 21. Two 1/200 acre areas were harvested from each plot at each of the two dates. The purity of the samples was obtained for each of the two dates of harvest.

The data from the factorial portion of the experiment were analyzed by analysis of variance.

Yield observations collected from all plots were used in an economic analysis of the results. This analysis was essentially of two parts. First, a statistical estimate was made of the yield response surface. Because of the difference in response between the two harvest dates it was necessary to estimate two response relationships. Polynomial equations were fitted to the data with first and second degree terms for P and K and a first degree cross product term. Second, the combinations of plant nutrients which produced maximum yields and those combinations of plant nutrients which produced maximum net returns were estimated for selected fertilizer and sugar beet prices.[3]

Experimental Results

The effect of treatment on the yield, percent sucrose, and percent purity is reported in Tables 1, 2, and 3. Table I shows the effect of time of harvest on the yield of beets. Beets harvested on October 17 yielded considerably less than did those harvested October 21. This difference could be explained in part as fol-

Table l.—The Effect of PK Levels on Yield, Percent Sucrose and Percent Purity of Sugar Beets on Parkhill Loam, 1957.

	Pounds Per Acre		Tons Per Acre[1]			Percent Sucrose	Percent Purity
	P_2O_5	K_2O	(1, 2, 3, 4)	(1, 2)	(3, 4)	(1, 2, 3, 4)	(1, 2, 3, 4)
P_1K_1	60	30	15.0	12.9	17.1	16.7	83.7
P_1K_3	60	150	17.9	14.0	21.9	16.8	83.4
P_1K_5	60	400	19.6	17.9	21.3	17.1	84.1
P_2K_2	100	75	15.2	12.5	18.0	16.5	84.0
P_2K_4	100	250	20.9	17.9	24.0	17.1	83.1
P_3K_1	150	30	16.9	14.0	19.8	16.7	84.1
P_3K_3	150	150	19.2	17.0	21.5	17.3	83.7
P_3K_5	150	400	22.3	20.9	24.0	17.6	83.8
P_4K_2	225	75	18.0	15.8	20.4	17.0	85.2
P_4K_4	225	250	20.1	18.1	22.1	17.2	83.7
P_5K_1	300	30	16.5	14.3	18.8	16.8	83.9
P_5K_3	300	150	17.6	15.9	19.4	17.1	83.0
P_5K_5	300	400	20.2	17.9	22.5	17.4	82.9
P_6K_2	500	75	17.5	16.3	18.7	16.8	82.0
P_6K_4	500	250	23.0	20.6	25.3	17.5	82.7
P_7K_1	800	30	17.0	14.1	19.8	16.6	82.8
P_7K_3	800	150	19.1	16.6	21.6	17.4	82.4
P_7K_5	800	400	20.7	19.8	21.8	17.0	83.2
	0	0	11.4	9.9	13.0	16.7	82.9
Average			18.3	16.1	20.6		

[1] Refers to averages of sample areas. 1 and 2 harvested October 17, and 3 and 4 on October 21.

[3] Baum, E. L., E. O. Heady and J. Blackmore, 1956. Methodological Procedures In The Economic Analysis of Fertilizer Use Data. Iowa State College Press, Ames, Iowa.

Table 2.—The Effect of PK Levels on the Yield, Sucrose Content, and Percent Apparent Purity of Sugar Beets.

	Pounds per Acre					
	P_2O_5	K_2O	Tons Per Acre[1]	Percent Sucrose	Percent Purity	Pounds Sugar Per Acre
P_1	60	......	17.5	16.9	83.7	4951
P_2	100	......	18.0	16.8	83.6	5056
P_3	150	......	19.5	17.2	83.9	5628
P_4	225	......	19.1	17.1	84.5	5520
P_5	300	......	18.1	17.1	83.3	5156
P_6	500	......	20.2	17.2	82.4	5726
P_7	800	......	18.9	17.0	82.8	5321
K_1		30	16.3	16.7	83.6	4551
K_2	......	75	16.2	16.8	83.7	4556
K_3	......	150	18.4	17.2	83.1	5260
K_4	......	250	21.3	17.3	83.2	6132
K_5	......	400	20.7	17.3	83.5	5980
	0	0	11.4	16.7	82.9	3157
LSD (5% level)		P	1.5	0.39	......	
		K	1.3	0.33		

Table 3.—Mean Squares for Analysis of Variance Data of Yields, Sucrose Content, and Percent Apparent Purity of Sugar Beets, 1957.

		Number of Areas[1] Tons per Acre			Percent	Percent
Source of Variance	D.F.	(1, 2, 3, 4)	(1, 2)	(3, 4)	Sucrose	Purity
Replication	2	21.64[4]	67.18[4]	34.37[4]	2.05[4]	4.41
Treatment	11	12.75[4]	19.20[4]	10.52	.32	.90
P	3	6.82	9.72[3]	5.45	.19	2.09
P_1 vs. $P_3 + P_5 + P_7$	1	11.69[3]	21.60[3]	5.88	.38	1.02
P_3 vs. $P_5 + P_7$	1	5.74	4.51	7.26	.17	4.17
P_5 vs. P_7	1	3.04	3.04	3.21	.01	1.08
K	2	57.23[4]	85.71[4]	38.55[4]	1.04[3]	.77
K_1 vs. $K_3 + K_5$	1	83.64[4]	108.04[4]	67.09[4]	1.98[4]	.72
K_3 vs. K_5	1	30.83[4]	63.38[4]	10.01	.09	.81
PK	6	.89	1.78	3.71	.15	.36
Error	22	2.28	2.57	5.23	.18	1.62
Total	35					
Error of general mean		12.3	15.8	25.1	1.1	1.9

[1] 1, 2, 3, 4—average of 4, 1/200 acre plots; 1, 2—average of 2, 1/200 acre plots harvested October 17; 3, 4—average of 2, 1/200 acre plots harvested October 21.

[2] r (1, 2 vs. 3, 4) = 0.9024

[3] Significant at 5% level

[4] Significant at 1% level

lows: after an extended dry period more than two inches of rain fell between the two harvest dates. The difference in yield would in part reflect the growth and also the absorption of water by the beet root. Another possibility is the difference in location of the various harvest areas on the plots and the possibility of more dirt clinging to the roots on the later harvest date. Because of the non-significant value for the PK interaction, the various potassium and phosphorus levels data were averaged. As indicated in the method of procedure, a factorial of three potassium levels and four phosphorus levels was included in the experimental design. The analysis of variance of this factorial is summarized in Table 3. The analysis of the data indicates that a comparable type of response resulted from data calculated from four harvest areas and that obtained from two areas, harvested October 17. The analysis of the October 21 data shows less response to phosphate levels than when the other two sets of data were used. The difference due to treatment was apparently minimized at the latter date of harvest.

Limiting the analysis of the data to that obtained from the 3 x 4 factorial, the following interpretation is suggested. Yields, where the fifth level of K_2O was used, were significantly higher than where the third level was applied. Consequently, it can be assumed that if higher amounts of potash had been applied a further increase in yield might have resulted. The test for the unfertilized soil indicated a medium to high level for phosphorous and a low level for potassium, an indication that potassium is a first limiting factor. The yields bear out this indication.

A significant increase in percent sucrose was obtained from the use of potash. A significant difference at the 1% level was indicated when the sucrose content of the beets produced at the first level of potassium was compared to those obtained from the third and fifth levels.

Treatment had no apparent effect on the purity of the beets.

A relatively high degree of correlation was obtained between the yields taken at the two dates of harvest. An r value of 0.9024 and a regression equation of $\hat{Y}$ 3,4 = 5.22 + 0.9418 x1.2 was calculated.

As the season progressed the percent of sucrose increased. This increase was approximately 5% sucrose between the first and last dates of sampling, September 4 and October 21, respectively.

The effect of treatment on the potassium and phosphorus contents of sugar beet petioles is shown in Table 4. These data show a wide variation in contents of both the phosphorus and potassium in sugar beet petioles with date of sampling. The results from the tissue analysis show that phosphorus within the ranges

Table 4.—The Effect of Rates of Application of Phosphorus and Potassium on the Phosphorus and Potassium Contents of Sugar Beet Petioles, 1957.

Pounds per Acre		Parts per Million (Fresh Tissue)					
		July 14		August 4		August 28	
P_2O_5	K_2O	P	K	P	K	P	K
60	30	152	4584	83	2988	40	2484
60	150	107	4668	73	3366	92	3912
60	400	116	4668	91	3956	45	3660
100	75	110	4668	69	2820	87	2820
100	250	90	4920	79	3240	71	3072
150	30	152	4206	76	3156	77	2484
150	150	104	4332	82	3324	71	3828
150	400	127	4332	74	3618	70	4500
225	75	162	4558	102	2904	75	2988
225	250	142	4248	62	2652	76	2820
300	30	134	4122	73	2652	73	2652
300	150	95	4332	84	3240	80	3324
300	400	125	4500	86	3198	83	3240
500	75	162	4042	101	2820	85	2484
500	150	125	4206	74	3072	87	3828
800	30	140	3828	103	3072	90	3240
800	150	162	4374	111	3240	85	4080
800	400	142	4416	66	3240	93	3744
0	0	82	4206	101	3450	48	2652

of applied phosphate in this experiment did not appreciably affect the phosphorus content of the tissue. The potassium content of the tissue tended to increase where the applied potash to the soil increased. The greatest increase occurred where the tissue content from the low level of application plots is compared with those obtained where the higher rates of potash were applied. In some cases the potassium content of the petioles was higher from samples obtained from unfertilized plots than those from plots that had received an application of potash. This situation might be accounted for in part by the dilution factor in that the top growth on the plots that had received the potash application was much greater than that on unfertilized areas. Under the conditions of this experiment, tissue tests would be of limited value in predicting yields or suggesting possible nutrient deficiencies of potassium and phosphorus.

Soil samples were obtained in August and were extracted by three different methods. The relationship between the amount of potassium applied and phosphorus applied to the amount extracted in the soil test by the different methods is indicated in

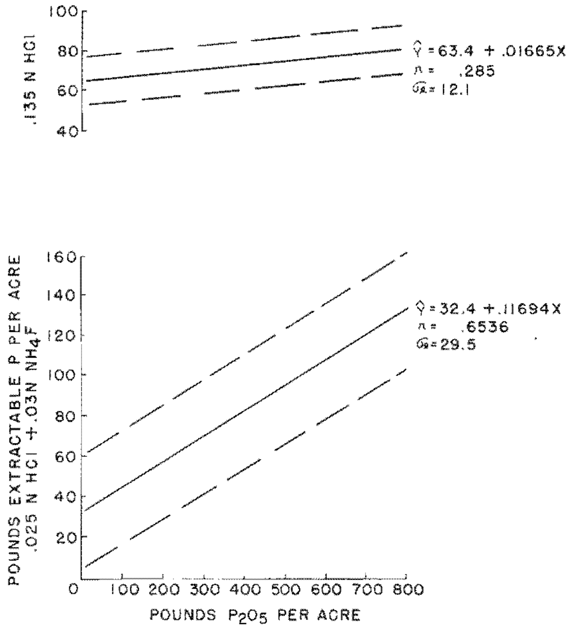

Figure 1.—The effect of extractant on the extractable phosphorus in soils receiving different amounts of phosphate.

Figures 1 and 2. From these data the two phosphorus extracting methods employing the ammonium fluoride reagent provide a closer correlation between applied P and extractable P than does the value obtained from extracting the soil with a .135 normal hydrochloric acid. The relationship between the applied potassium and that found in the extract, using .135 normal hydrochloric acid, was satisfactory.

The estimated yield response from P_2O_5 and K_2O using continuous function analysis is shown in Equation 1 for the crop harvested October 17.

$$\text{Equation 1: } y_{12} = 10.258 + \underset{(.005882245)}{.014355957}\,P - \underset{(.000006887)}{.00003207}\,P^2 + \underset{(.010842768)}{.031194077}\,K - \underset{(.000025213)}{.000034072}\,K^2 - \underset{(.000009152)}{.000002663}\,PK$$

Numbers listed below the estimated coefficients in the equation are standard errors of these coefficients. The adjusted coefficient of multiple correlation, $\bar{R}$, was 0.75 and the coefficient of multiple

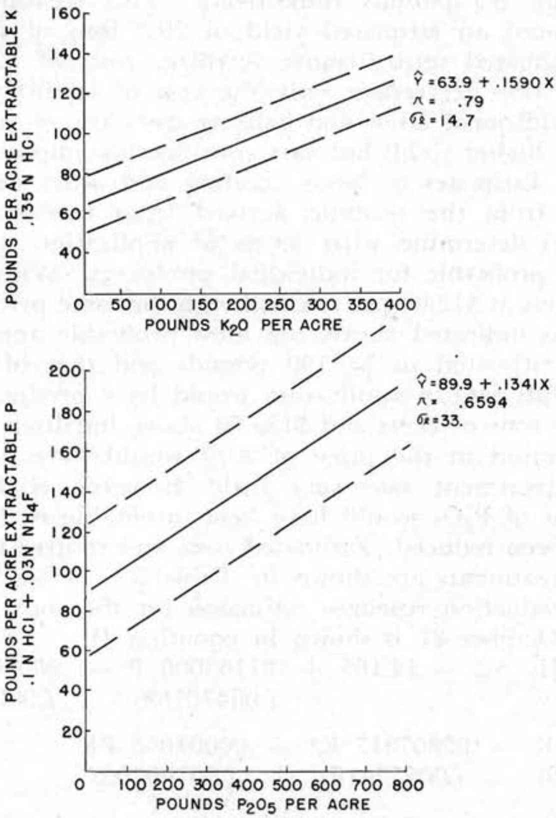

Figure 2.—The effect of extractant on the extractable phosphorus and potassium in soils receiving different amounts of phosphate and potash.

determination, $\bar{R}^2$, was 0.56, indicating that well over half of the variance in yield was associated with variables specified in the equation. Coefficients in the equation appear small, however, these coefficients indicate the yield response in tons to plant nutrient applications in pounds and are expected to be very small.

Check plot yields for this sample averaged about 10.5 tons per acre while the estimated maximum yield was about 20.5 tons. This maximum yield was estimated to occur with about 400 pounds of applied K_2O and 500 pounds of P_2O_5. The big yield response, however, was due to K_2O and despite the slight response to high levels of P_2O_5, the response from applications above 150-250 pounds of P_2O_5 was so small that only these lower treatment levels were profitable.

With nitrogen applications held constant at 50 pounds per acre and with nitrogen priced at \$0.11, P_2O_5 at \$0.10, and K_2O at \$0.05 per pound and sugar beets at \$15.00 per ton, the most profitable application rates of P_2O_5 and K_2O were estimated to be 250 and 395 pounds respectively. This treatment would have produced an estimated yield of 19.8 tons of sugar beets and an estimated return above fertilizer costs of $247.00. In calculating this net return only the cost of fertilizer was considered. Additional labor and hauling costs are, of course, associated with higher yields but vary considerably among individual producers. Estimates of labor, hauling and other costs can be subtracted from the revenue derived from use of additional fertilizer to determine what levels of application would have been most profitable for individual producers. With the price of sugar beets at $12.00 per ton and with the same price for plant nutrients as indicated above, the most profitable application of P_2O_5 was estimated to be 190 pounds and that of K_2O, 390 pounds. This rate of application would have produced an estimated 19.3 tons of beets and $188.00 above fertilizer costs.

A reduction in the price of K_2O would have affected the optimum treatment rate very little, however, slightly larger applications of P_2O_5 would have been profitable if the price of P_2O_5 had been reduced. Estimated costs and returns for selected fertilizer treatments are shown in Table 5.

The production response estimated for the sugar beet crop harvested October 21 is shown in equation II:

Equation II: $y_{31} = 14.165 + \underset{(.06472159)}{.01163000\,P} - \underset{(.00075772)}{.00000906\,P^2} +$

$\underset{(.11930159)}{.05009595\,K} - \underset{(.00277416)}{.00007817\,K^2} - \underset{(.00100703)}{.00001068\,PK}$

The adjusted coefficient of multiple correlation, $\bar{R}$, for this equation was 0.72 and the coefficient of multiple determination, $\bar{R}^2$, was 0.51. The estimated maximum yield for this sample was about 24.1 tons per acre. This maximum yield was estimated to occur with P_2O_5 applications of about 470 pounds and K_2O applications of about 300 pounds. As in the case of the previous sample, however, the big yield increase came from K_2O and the yield response due to P_2O_5 was small for P_2O_5 applications in excess of 100 pounds per acre.

Using the response equation for the second sample, Equation II, the response surface was estimated and is illustrated in Figure 3. By viewing the visible edges of this surface it can be seen that K_2O applications produced larger yield increases than did those of P_2O_5. Furthermore, it should be noted that the scale of K_2O applications is double that of P_2O_5 applications. Thus the response due to K_2O is even greater relative to P_2O_5 than the slope of the surface indicates.

With N, P_2O_5 and K_2O priced as previously at $0.11, $0.10 and $0.05, respectively, and with sugar beets at $15.00 per ton, the applications of P_2O_5 and K_2O giving the largest return above

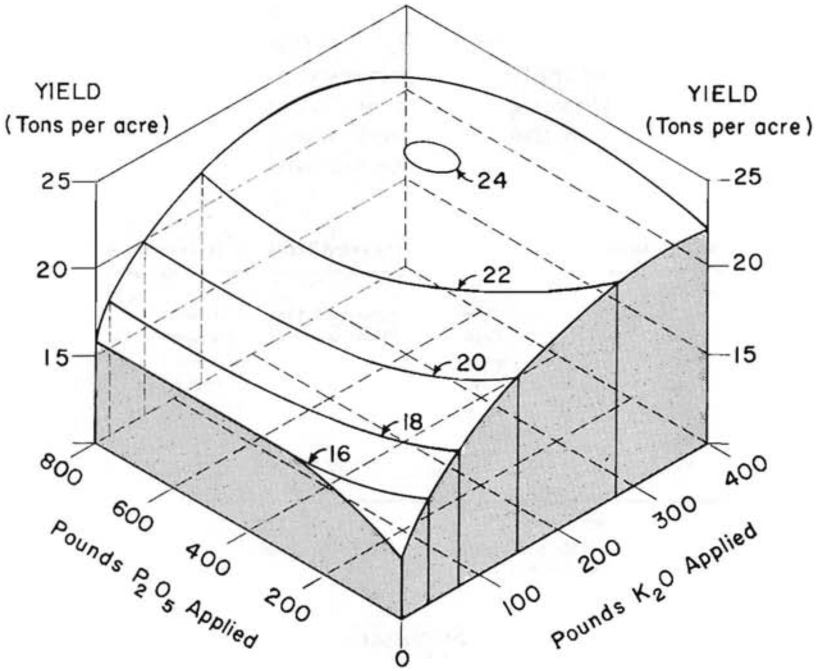

Figure 3.—Estimated response surface for sugar beets with variable applications of P_2O_5 and K_2O.

fertilizer costs were 100 and 290 pounds, respectively. This fertilizer treatment produced an estimated yield of 22.9 tons of sugar beets per acre and $313.00 per acre above fertilizer costs.

Estimated costs and returns for selected fertilizer treatments from the second sample are shown in Table 6.

Absolute yields and relative yield response differ for the yield samples acquired for the two different harvesting dates. However, the response is sufficiently similar to warrant some generalizations applicable to both sets of data.

Table 5.—Estimated Costs[1] and Returns for Selected Fertilizer Treatments, Sample 1.

Fertilizer Treatment			Cost of Fertilizer[2]	Estimated Yield (Tons per Acre)	Gross Returns[2]	Returns Above Fertilizer Costs
P_2O_5	K_2O	N				
50	50	50	$13.00	12.41	$186.00	$173.00
100	100	50	20.50	14.31	215.00	194.50
100	200	50	25.50	16.38	246.00	220.50
200	300	50	40.50	18.73	281.00	240.50
250	395	50	50.25	19.78	297.00	246.75

[1] Costs of plant nutrients only.

[2] With N, P_2O_5 and K_20 priced at $0.11, $0.10 and $0.05 per pound, respectively and sugar beets priced at $15.00 per ton.

Smaller applications of P_2O_5 (50-100 pounds) were very profitable. Larger applications increased yields but did not produce a very significant change in net returns. Yield response to K_20 applications, on the other hand, was quite large with applications of 250-325 pounds of K_2O yielding returns substantially in excess of costs.

Table 6—Estimated Costs[1] and Returns for Selected Fertilizer Treatments, Sample 2.

Fertilizer Treatment			Cost of	Estimated Yield	Gross	Returns Above
P_2O_5	K_2O	N	Fertilizer[2]	(Tons per Acre)	Returns[2]	Fertilizer Costs
50	50	50	$13.00	17.01	$255.00	$242.00
100	100	50	20.50	19.36	290.00	269.50
100	200	50	25.50	21.92	329.00	303.50
100	290	50	30.00	22.88	343.00	313.00

[1] Costs of plant nutrients only.

[2] With N, P_2O_5 and K_2O priced at $0.11, $0.10 and $0.05 per pound, respectively, and sugar beets priced at $15.00 per ton.

Summary

The effect of 7 phosphate levels and 5 potash levels applied to a Parkhill clay loam on the yield, sucrose content and purity of sugar beets was determined. The petioles were analyzed for phosphorus and potassium at 3 dates. The effect of different extractants on the phosphorus and potassium extracted from the soil was investigated. In addition, an economic analysis of the yield data was made to estimate optimum nutrient combinations with current sugar beet and fertilizer prices.

Sugar beet yields increased slightly with large P_2O_5 applications (150 pounds or more) but only smaller applications (50-100 pounds) produced yield responses which were profitable with current prices. Yields responded markedly from large applications of K_2O. Top yields were obtained from K_2O applications in excess of 300 pounds per acre. With current fertilizer and sugar beet prices, the most profitable K_2O applications were in the range of 250-325 pounds per acre.

Potash increased the percent sucrose in the roots by 0.5% with no evidence of a significant decrease in purity.

The phosphorus and potassium contents of the petioles were erratic and varied markedly with date of sampling.

The amount of phosphorus found in extractants containing ammonium fluoride was more closely correlated with the amount of phosphate applied to the soil than where it was omitted from the extracting solution.