tilization factor except with the yields where some slight modification was determined. 80 far as the numbers of marketable roots, sucrose percentages, and apparent purity coefficients were concerned, the two factors apparently operated entirely independently of each other.

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Yield, Percentage of Sucrose, and Coefficients of Apparent Purity of Sugar Beets as Affected by Rotational, Manurial, and Fertilizer Practices at the Dominion Experimental Station, Lethbridge, Alberta

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The Dominion Experimental Station is located near the city of Lethbridge, Alberta, which is 200 miles northwest of Great Falls, Mont. The Station is approximately in the center of the sugar beet growing area of Southern Alberta which annually produces about 30,000 acres of sugar beets. Nine year production averages (1936-1944) for the area are: Tons of beets per acre, 12.18; percentage of - sucrose, 17.85; sugar extracted per ton of beets, 302.76 pounds.

The purpose of this paper is to present information from some of the sugar beet cultural experiments which have been conducted almost continuously through the 4 decades of the Station's existence. The results discussed herein were secured from a long-term rotational experiment which was originally laid down on an old alfalfa field known to have some phosphorous deficiency. This deficiency now has been accentuated to the extent that sugar beet production on some of the check plots is decidedly uneconomic.

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Data from three rotations will be presented, viz.:

8-year alfalfa rotation—alfalfa, alfalfa, alfalfa, wheat, sugar beets, sugar beets, wheat, wheat seeded down to alfalfa.

4-year cereal rotation—wheat, barley, sugar beets, sugar beets.

4-year sweet clover green manure rotation—wheat seeded down to sweet clover, clover hay, sugar beets, sugar beets.

Each rotation was subjected to the following four fertility treatments: Barnyard manure only, phosphatic fertilizer only, both barnyard manure and phosphatic fertilizer, and no fertilization. Green manure plus phosphatic fertilizer, and green manure alone, were two additional treatments used in the green manure rotation.

Materials and Methods

Manure.—In the 8-year rotation 30 tons of barnyard manure per acre were added once in the rotation cycle, and in the 4-year rotations 20 tons of barnyard manure per acre were added once in 4 years. In all cases the weighed quantity of manure was applied to the grain or clover stubble on the appropriate plot and plowed under the fall before planting the first crop of beets in each rotation cycle. The barnyard manure used had originated in the dairy and horse barns on the Station and had been fairly well preserved in large compost piles until the time of application when it contained approximately 50 percent dry matter.

Phosphatic Fertilizer.—Triple superphosphate (0-43-0) was applied to half of each phosphate-treated plot by drilling this fertilizer at the rate of 100 pounds per acre with the seed each year that sugar beets were sown.

Design of Experiment.—The design of the experiment as it was laid down in 1929 was relatively simple. Duplicate plots were selected at random (i. e., for the 8-year rotation 16 plots were required). Each plot was divided longitudinally and the phosphate fertilizer application assigned at random to one side. In addition each plot was bisected transversely and the barnyard manure application assigned at random to one end. Each rotational treatment plot thus quartered included four sub-treatments:

1. 30^2 tons barnyard manure and 100 pounds triple superphosphate per acre.
2. 30 tons barnyard manure only.
3. 100 pounds triple superphosphate per acre only.
4. No manure or fertilizer added.

These sub-treatments have been identified by a 3-figure number. For example, in treatment No. 821 the first digit gives the duration of the rotation in years, the second gives the year of beets in the cycle

[a]In the 4-year rotations the amount is 20 tons.

(either first or second) and the third digit identifies the number of the manurial sub-treatment as listed above. In the 4-year green manure rotation the identification number was prefixed by the letter "G" and two additional treatments were included, namely, No. 5, green manure (second crop of sweet clover plowed under) and 100 pounds triple superphosphate per acre added, and No. 6, green manure only. In the other treatments of this rotation, i. e., Nos. G 411, G 412, G 413, G 414, both crops of sweet clover were taken off for hay.

This experimental design satisfied all biometrical requirements for individual analysis of each rotation. However, the treatments of each rotation were randomized separately on blocks which were not contiguous, although they were very near each other in an extremely uniform field. This fact made a combined analysis of the three rotations somewhat unorthodox. In spite o£ this weakness in design the results from the three rotations are thought to be strictly comparable.

Experimental Results

Data for the 10-year period 1936-45 inclusive have been summarized, and means for tons of beets per acre, percentage of sucrose, and coefficients of apparent purity are shown in table 1. The results of the statistical analyses are presented in tables 2, 3, and 4.

Discussion of Results

Yield of Roots.—Highly significant differences occurred between yields of roots on the different treatments within each rotation and also less striking differences between some of the comparable treatments in the three rotations.

Yield of Roots as Affected by Manure.—The addition of barnyard manure produced a significant increase in yield over the untreated plots and also over the plots which received phosphate fertilizer alone. This was true in all rotations. Furthermore the significantly beneficial effect of the barnyard manure was carried over into the second year of beets under all manuriai treatments. In all rotations the addition of both barnyard manure and phosphatic fertilizer produced higher mean yields than those produced when barnyard manure alone was added. However, the increase was not sufficiently great to be statistically significant. On those crops which were further removed from the year of manure application, significantly higher yields were obtained which were attributable to the phosphatic fertilizer application in addition to manure. This was true particularly of alfalfa.

Yield of Roots as Affected by Phosphatic Fertilizer.—The application of 100 pounds of triple superphosphate per acre in each of the 2 years of sugar beets gave highly significant increases over the check

Table 1.—Ten-year summary means of sugar beets grown at Lethbridge, Alberta, on plots receiving various applications of barnyard manure anrl phosphatic fertilizer.

Treatments	Root yield per acre (Tons)	Sucrose content of roots (Percentage)	Coefficient of apparent purity (Percentage)
811 -30 T/Man & 100 pounds T.S.P.	19.31	15.72	S5.81.
812-30 T/Man.	18.00	15.75	85.77
813-100 pounds T.S.P.	12.81	15.78	85.84
814-No Additions	3.47	14.90	84.75
Means of first crop	13.62	15.54	85.83
S21	.19.32	16.26	85.99
822	18.79	16.46	86.24
823	16.05	16.23	85.92
824	3.32	15.33	85.22
Means of second crop	14.87	16.12	85.84
Means of 8-year rotation	•14.25	15.83	85.84
411-20 T/Man 100 pounds T.S.P.	19.93	17.30	86.78
412-20 T/Man.	19.26	17.42	86.96
413-100 pounds T.S.P.	13.63	17.09	87.09
414- No additions	6.50	16.54	86.33
Means of first crop	14.83	17.09	86.79
421	19.11	17.18	87.31
422	17.88	16.47	86.18
423	15.07	16.93	86.82
424	7.38	16.73	86.75
Means of second crop	14.86	16.83	86.74
Means of 4-year cereal rotation	14.85	16.96	86.77
G-411	20.36	16.73	86.17
G-412	20.27	16.54	86.57
G-413	15,92	16.35	86.16
G-414	6.34	15.86	86.1.3
G-415	16.17	16.57	86.18
G-416	7.42	16.13	85.38
Means of first crop	14.41	16.36	86.10
G-421	19.56	17.07	85.78
G-422	17.64	17.06	86.97
G-423	15.26	16,28	85.93
G 424	7.58	16.06	85.63
G-425	15.97	16.54	85.49
G-426	7.50	15.83	85.01
Means of second crop	13.92	16,47	85.80
Means of 4-year G.M. rotation	14.17	16.42	85.95

plots but without barnyard manure maintained only fair sugar beet yields which are continuing to retrogress. The companion crops in the rotation cycle, particularly alfalfa, showed a much poorer relative performance than the sugar beets.

Yield of Roots as Affected by Green Manure.—In the green manure rotation the plots receiving 100 pounds of triple superphosphate per acre as the only addition (Nos. G 413 and G 423) produced considerably higher yields than similarly fertilized plots in the other rotations. This increase may have been attributable to the benefits derived

Table 1 (a).—Comparison of sugar beet yields grown on manured and unmanured plots, and also on fertilized and unfertilized plots under three different rotations at the Dominion Experimental Station, Lethbridge, Alberta. (All figures are 10-year summary means.)

Treatments	Root yield per acre (Tons)	Sucrose content of roots (Percentage)	Coefficient of apparent purity (Percentage)
Eight-year alfalfa rotation			
Average of all manured plots	19.08	16.05	85.95
Average of all unmanured plots	0.41	15.01	85.43
Average of all fertilized plots	16.87	10.00	85.89
Average of all unfertilized plots	1! .02	15.66	85.80
Pour-year cereal rotatiou			
Average of all manured plots	19.05	17.09	86.81
Average of all unmanured plots	10.05	10.82	86.75
Average of all fertilized plots	16.93	17.13	87.00
Average of all unfertilized plots	12.70	16.79	86.56
Four-year sweet clover green manuire rotation			
Average of all manured plots	19.43	16.85	86.37
Average of all unmanured plots	11.28	10.14	85.96
Average of all fertilized plots	17.78	16.60	86.01
Average of all unfertilized plots	12.90	10.3S	86.32
Average of all G.M. & fertilized plots	10.07	16.50	85.83
Average of all green manured plots	7.40	15.98	85.19

from the partial summer-fallow after the second crop of hay was removed. No significant advantage was observed from the plowing under of the second crop of clover as green manure (cf. G 415 vs. G **413** and G 425 vs. G 423).

Yield of Roots on Untreated Plots.—The check plots, which received no barnyard manure or phosphatic fertilizer, yielded as low as one half ton per acre, and extreme difficulty was experienced in securing a satisfactory stand in the spring. Although emergence usually was satisfactory, the seedlings displayed much more susceptibility to seedling diseases and insect injury than did seedlings growing on the fertilized plots.

Percentage of Sucrose.—The percentages of sucrose of beets produced on the various treatments are most interesting although quite at variance with results reported from more southerly areas. First, percentage of sucrose was not depressed by the application of manure, and second, percentage of sucrose was markedly affected by a deficiency of phosphorus.

Percentage of Sucrose as Affected by Manure.—In earlier work at this Station Palmer (7)[3] has shown that the percentage of sucrose was not depressed by the annual application of 15 tons of **manure** per

"Italic numbers in parentheses refer to literature cited.

Tabic 2.—Analyses of variance of yield, percentage of sucrose, and apparent purity of sugar beet roots grown in an 8-year alfalfa rotation on plots variously treated with barnyard manure and phosphalic fertilizer.

Sources of variation	D.E.	Tons of roots per acre: Mean squares	Tons of roots per acre: Calculated F values	Percentage of sucrose: Mean .squares	Percentage of sucrose: Caluolat.od F values	Coefficient of apparentpurity: Mean squares	Coefficient of apparentpurity: Calculated F values
Between rep-lications	10	9.20		1.67		1.70	
Between years	9	82.84	1*.02**	32.52	18.48**	47.35	15.34**
Between crops	1	02.40	1 t.02**	14.04	7.98*	3.56	
Crops X years	9	20.24	5.90**	2.93		0.54	
Error (a)	10	4.45		1.70		3.08	
Manure vs. no manure	1	3791.*4	1723.50**	7.31	9.88**	10.72	4.72*
Ferti lizer vs. no fertiliser	1	1103.73	501.70**	4.29	5.80*	6.16	
Manure X fertilizer	1	913.40	415.21**	7.83	10.5S**	10.00	4.40*
Treatments X crops	3	7.48	3.4 *	.13		.43	
Treatments X years	27	9.15	4.16**	1.84	2.49**	5.09	
Fertilizer X crops X years	9	14.39	6.54**	2.42	3.27**	2,75	
Manure X crops X years	9	5.10	2.32*	.48		1.81	
Error (fa)	09	2.20		.74		2.27	
Total	1M						

*—Exceeds the 5 percent point of signiticance.
**—Exceeds the 1 percent point of significance.

Table 3.—Analyses of variance of yield, percentage of sucrose, and apparent purity of sugar beet roots grown in a 4 year cereal rotation on plots variously treated with barnyard manure and phosphatic fertilizer.

Sources of variation	I>.F.	Tons per acre: Mean squares	Tons per acre: Calculated F values	Percentage of sucroso: Mean squares	Percentage of sucroso: C. Undated 1 values	Coefficient of apparent purity: Mean squares	Coefficient of apparent purity: C ileulated V values
Between rep lications	10	14.40		1.18		2.64	
Between years	9	72.N7	11.4!)**	21.08	4.33*	30.24	17.58**
Between crops	1	.03		2.65		.01	
Crops X years	9	17.08		.65		1.28	
Error (ai	10	0.34		4.87		1.72	
Manure vs. no manure	1	2822.98	559.01**	2.92		.20	
Fertilizer vs. no fertilizer	1	098.68	138.35**	4.49	4.45*	7.88	4.53*
Manure X fertilizer	1	418.19	82.81**	.06		.003	
Treatments X crops	3	18.08	3.58*	2.33		3.82	
Treatments X years	27	5.40		.97		1.67	
Fertilizer X crops X years	9	7.04		1.07		3.33	
Manure X crops X years	9	3.01		8.37	8.29*	.65	
Error (b)	69	5.05		1.01		1.74	
Total	159						

-Exceeds the 5 percent point of significance.
**—Exceeds the 1 percent point of significance.

acre to sugar beets for 7 consecutive years. Average results for 7 years are shown in the subjoined table 4:

Table 4.—Yield, percentage of sucrose, and coefficients of apparent purity of beets grown on plots variously treated with manure and fertilizer.

Treatment	Tons per acre	Percentage of sucrose	Coefficient of apparent purity
15 tons manure' per aero annually	21.53	17.0	85.2
15 tons manure and 100 pounds triple superphosphate	22.01	17.1	S6.9
100 pounds triple superphosphate onlj	10.00	10.9	87.1
Xo additions	8.80	16.6	85.G

The data in table 4 do not agree with results reporled by Nuckols *(5, 6)* in Nebraska or with the work of many other investigators. However, it is felt that this contrariety can be understood in some measure in view of the difference in climate between the localities. The extensive photoperiod of Southern Alberta (latitude 49^{1}/2°) and other climatic differences have generally been given credit for the fact that sugar production per acre in Alberla ranks favorably with any of the States of the Union except California, despite a growing period which is up to 1 month shorter than that of many areas of Idaho. Utah, or Colorado.

The comparatively high percentage of sucrose in beets grown in Alberta has been in evidence since the inception of the industry in this locality. This favorable condition is usually explained by reference to the combination of photoperiodism and other climatic factors, such as cool fall weather, which seem to be exceptionally well suited to the synthesis of sucrose. It has been suggested that because of these conditions beets are able to utilize relatively large quantities of plant nutrients and this utilization is expressed in the production of sucrose at a comparable rate with the production of tissue. Under less favorable climatic environment the presence of extensive nutrients brings about increases in size of beet while synthesis of sucrose fails to show a commensurate gain. Under Alberta conditions it appears that any improved agronomic practice such as manure application or better distribution of irrigation water which is reflected in better than average yields does not necessarily depress sucrose percentage below the average. In fact the weight of available evidence in Alberta seems to indicate that the sucrose percentage is increased as the yields are increased above the average by better field husbandry.

Percentage of Sucrose as Affected by Phosphorus.—Minimum significant differences between rotations have not been calculated because of the limitations of the experimental design mentioned above. However, the superiority of the percentage of sucrose of the 4-year

cereal rotation over the 8-year alfalfa rotation is so consistent that its interpretation as real even without benefit of statistical significance seems justified.

The mean percentage of sucrose for these two rotations is compared below by years:

	1936	1937	1938	1939	1940
	16.02	15.00	15.44	15.08	13.70
4-year rotation	16.00	16.24	17.64	15.63	16.15
	1941	1942	1943	1944	1945
	17.01	17.64	13.97	17.70	16.74
4-year rotation	17.72	17.25	16.14	19.47	17.25

The fact that the 8-year alfalfa rotation as a whole displayed an apparently significantly lower sucrose percentage than the 4-year cereal rotation while the yields were strictly comparable has proven rather difficult to explain.

It will also be noted that the first year of beets on the alfalfa rotation displayed a significantly lower percentage of sucrose than the second year of beets. This did not occur in the other rotations. The fact that percentages of sucrose were almost identical for the three treatments—manure only, manure and fertilizer, and fertilizer only in the first crop year as well as the second crop year established that in this experiment the application of manure had no depressive effect on percentage of sucrose. It appeared that the alfalfa, even though separated by a crop of wheat, had the effect of significantly lowering the percentage of sucrose of the beet crop in comparison with the cereal rotation. This deleterious influence was still in evidence in the second crop of beets. There is also some suggestion that sweet clover has a similar effect in a reduced degree, since the percentages of sucrose and coefficients of apparent purity of beets grown on the sweet clover rotation are consistently midway between the comparable values for the 8-year alfalfa rotation and the 4-year cereal rotation.

It has been calculated by the use of prepared tables *(1, 2)* that the total of all of the crops grown on the manured and fertilized plots of the 4-year rotation during two cycles consumed more phosphorus than the total of all crops grown on the comparable plots of the 8-year rotation. The calculated consumption per acre of P_2O_5 and the amount added in manure and fertilizer, disregarding that which remains in the cereal stubble (less than 2 pounds per acre), was as follows:

	Phosphate (P_2O_5) consumed	Phosphate (P_2O_5) added
8-year rotation	804 pounds	236 pounds
4-year rotation (2 cycles)	368 pounds	372 pounds

A superficial appraisal might suggest that the gradual depletion of the phosphorus by the 8-year rotation was the cause of the lower sucrose percentage. However, this explanation is not tenable unless it is conceded that a mild phosphorus deficiency is first expressed by a depression in sucrose percentage rather than by a depression in yield of roots, since the tons of beets per acre in the two rotations are quite comparable. The usually accepted contention *(3)* that sugar beets give a poorer performance after alfalfa than many other crops because the alfalfa has depleted the readily available P_2O_5 and left the remaining phosphorus in Jess soluble compounds, useable by oats, potatoes, etc. but not sugar beets, does not provide an explanation for the same reason.

Percentage of Sucrose as Affected by Nitrogen.—According to calculations *(1, 2)* 45 percent of the total amount of nitrogen consumed by the crops in the 8-year rotation and 43 percent of the consumption in the 4-year rotation has been returned in the form of manure. Hence it docs not appear that there is sufficient difference in the nitrogen supply to const-Mute a full explanation of the difference in sucrose percentages. Undoubtedly on some of the plots the balance between nitrogen and phosphorus is so disturbed as to affect normal physiologic processes in the beet seriously.

Future plans include increased attention to chemical analyses of soils from these plots, and these analyses may provide helpful information toward the explanation of the significant differences in sucrose percentages.

Coefficient of Apparent Purity.—The coefficients of apparent purity showed a rather narrow variation, being affected significantly only by wide differences in available nutrient such as occurred in comparisons between the check plots and the fertilized plots or between the alfalfa rotation and the cereal rotation. This is in accordance with usual results in Alberta where even extensive variety tests frequently fail to display significant differences in coefficients of apparent purity.

Incidental Consideration

Potassic Fertilizer.- -No benefit in sugar beet yields or percentages of sucrose has ever been noted from the addition of potash in the dozens of tests conducted in this area. There were no indications that any potash deficiency existed under conditions of this experiment.

Value of Farm Manure.—The value of the increases in the production of all crops in the rotation due to the application of barnyard manure in addition to phosphatic fertilizers has been calculated *(4)* and, based on 1945 prices, these increases in yield have shown the fol-

lowing- money value per ton of manure applied for each of the three rotations:

Rotation	Value of each ton of barnyard manure applied
8~year rotation"	$5-50
4-year cereal rotation	7.17
4-year green manure rotation	5.35

Summary

Ten years' results of yields, percentages of sucrose and coefficients of apparent purity of sugar beets grown under three rotational .systems with addition of barnyard manure, phosphatic fertilizer, and green manure are presented.

The addition of barnyard manure brought about substantial increases in yield in all rotations and did not depress percentages of sucrose. The value of farm manure was in excess of $5 per ton in all rotations.

The application of phosphatic fertilizer in addition to manure seems justified on the basis of long-term policy and in this experiment produced increased yields which, however, were not significant.

Phosphatic fertilizer produced significantly higher tonnages in all rotations in the absence of manure but failed to maintain better than mediocre yields.

Evidence is presemed which suggests considerable divergence from the usual behaviour of percentage of sucrose as related to yield. It is suggested that these differences may be ascribed to climate.

When neither manure nor phosphate fertilizer was added, the yields of roots and percentages of sucro.se were disappointingly low and the young plants displayed marked susceptibility to seedling diseases and insect injury.

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