A Regression Study on Tare Samples of Sugar Beets In Relation to Factors Influencing Productivity and Quality

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Introduction

Many factors affect the yield and quality of the sugar beet. Researchers have studied various factors separately and others collectively. The ultimate in sugar production cannot be attained until all the important factors of growth and their interactions are recognized, measured and controlled.

Multiple regression procedures can be used to establish an equation for the prediction of maximum sugar yields. Modern computers can easily handle complicated multiple models involving large matrices including linear and nonlinear relationships and interaction terms (7)[2].

In 1958 and 1959, the Nyssa-Nampa Beet Growers Association made sugar determinations on tare samples of roots from each load delivered to the Doles Station, Nyssa, Oregon. This was an undertaking of the growers in the district with the major objective of determining some factors influencing the sugar percent of the sugar beet.

Materials and Methods

For the harvest seasons of 1958 and 1959, Dr. J. H. Roblyer[3] set up a laboratory close to the Doles station and each tare sample of roots was analyzed for sucrose percent. A sample of 26 gm of pulp was digested in 177 mm of water, cleared with Horne's lead subacetate and filtered. The sugar percent of the clear solution was determined by use of a saccharimeter[4]. Average sugar percent was calculated for each field from these root samples. Yield of roots was obtained from factory records. Acreable yield of roots and gross sugar were calculated for each grower.

All growers were asked to supply information on each field of sugar beets delivered to the station. In 1959 the question-

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[2] Numbers in parentheses refer to literature cited.

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[4] Loaned to the Nyssa-Nampa Growers Association under Memorandum of Understanding with the Crops Research Division, Agricultural Research Service, U. S. Department of Agriculture.

Table 1.—Quadrant groupings from scatter diagrams, Doles Station, 1958.

	Gross sugar	Tons beets	Sugar percent	Acres planted	Pounds Units N	Pounds Units P_2O_5	No. growing days	Percent of total: Times* watered 5 to 12	Percent of total: Times* watered 13 to 19	Percent of total: Planting dates Before March 21	Percent of total: Planting dates After March 20	No. fields
Quadrant I												
+ avg. sugar %												
+ avg. tons/acre												
Maximum	6.253	37.7	17.9	32.0	240	265	234					
Minimum	4.883	29.6	16.4	4.2	67	40	201					
Mean of Quadrant	5.384	32.2	16.7	15.6	146	132	217	44	56	35	65	21
Quadrant II												
— avg. tons/acre												
+ avg. sugar %												
Maximum	4.984	28.2	17.7	29.6	216	180	243					
Minimum	2.873	16.8	16.4	3.5	34	70	193					
Mean of Quadrant	3.963	23.5	16.9	13.6	133	111	215	23	77	59	41	32
Quadrant III												
— avg. tons/acre												
— avg. sugar %												
Maximum	4.596	29.0	16.2	47.0	224	160	244					
Minimum	3.429	21.7	14.2	3.5	72	81	192					
Mean of Quadrant	4.210	26.8	15.7	19.0	161	127	221	50	50	57	43	18
Quadrant IV												
+ avg. tons/acre												
— avg. sugar %												
Maximum	6.440	40.8	16.3	54.8	250	160	251					
Minimum	4.543	29.5	14.9	2.0	68	60	199					
Mean of Quadrant	5.235	33.4	15.7	21.0	169	112	221	55	56	57	43	29

* Estimation based on last date of irrigation.

naire covered information as to acres planted, date planted, soil type, stand, type of spring work, units nitrogen and phosphate applied, previous cropping history, dates of first and last irrigation, including number of irrigations and evidence of considerable field flooding. In 1958 the questionnaire did not include plant stand, type of spring work or number of irrigations.

For both years Dr. J. H. Roblyer supplied data on sugar and gross yield, together with all information in the grower's questionnaire, for statistical analysis. This information was coded, when needed, and punched on IBM cards (12). Tables of means were obtained from various card sortings (Tables 1 to 6). These tables vary in the number of observations, because complete information on the variables was not reported by all the growers.

Table 2.—Means of groups on five different cultural treatments, Dolcs Station, 1958.

Group	Cultural treatment	Number of fields	Acre yield		Percent sugar
			Gross sugar	Tons beets	
	ACRES HARVESTED				
1	5-10	28	4.766	29.06	16.4
2	10.1 to 20	32	4.708	29.23	16.1
3	20.1 to 30	15	4.622	28.60	16.2
4	over 30	10	4.933	30.57	16.1
	UNITS NITROGEN				
1	below 99	12	4.963	30.0	16.58
2	100-150	32	4.427	27.1	16.42
3	151-200	32	4.804	30.2	15.91
4	above 201	9	4.711	28.8	16.42
	UNITS P_2O_5				
1	below 99 units	22	4.550	28.04	16.3
2	100 to 150	50	4.732	29.1	16.20
3	151 to 200	11	4.752	29.4	16.2
4	above 200	2	5.635	33.9	16.6
	DATE OF LAST IRRIGATION				
1	9/10 to 9/15	7	4.544	27.7	16.44
2	9/16 to 9/21	29	4.842	30.4	15.94
3	9/22 to 9/27	34	4.530	27.0	16.30
4	9/28 to 10/7	19	4.851	29.4	16.54
	PLANTING DATE				
0	3/1 to 3/6	12	4.624	28.6	16.30
1	3/7 to 3/13	8	4.584	29.0	15.85
2	3/14 to 3/20	32	3.586	28.4	16.19
	Mean of early date	52	5.589	28.67	16.15
3	3/21 to 3/27	13	5.003	30.9	16.18
4	3/28 to 4/3	11	5.138	31.6	16.27
5	4/4 to 4/10	10	4.349	26.2	16.63
6	4/11 to 4/17	1	4.477	27.3	16.40
7	4/18 to 4/25	4	4.339	25.6	16.90
	Mean of late date	39	4.661	28.32	16.48

Table 3.—Means of groups on soil type and crop rotation, Doles Station, 1958.

Group	Cultural treatment	Number of fields	Acre yield		Percent sugar
			Gross sugar	Tons beets	
	TYPE OF SOIL				
1	Light	13	4.860	29.8	16.44
12	Light to medium	1	4.601	29.1	15.80
2	Medium	30	4.800	29.7	16.18
	Mean Medium		4.754	29.8	16.14
3	Heavy	36	4.568	28.1	16.29
23	Medium to heavy	6	5.134	32.6	15.83
13	Light to heavy	2	3.952	24.0	16.50
	Mean Heavy		4.551	28.2	16.21
	CROP ROTATION				
1	Forage	19	4.281	26.1	16.32
2	Beets	23	4.566	28.3	16.18
3	Grain	9	5.004	30.7	16.32
4	Potatoes	36	4.902	30.4	16.15

Six variables that seemed to be the most accurate and apparently to have some influence on tonnage or sugar percent were selected for the regression study. Consideration also was given each year to only those fields wherein complete information for the six variables was available. This reduced the observations to 85 for 1958 and to 83 for 1959. The six independent variables were: (A) acres harvested; (B) units nitrogen applied; (C) units P_2O_5 applied; (D) number of irrigations, coded 1 to 4 in increasing order (1959) or date of first irrigation coded 1 to 4 earliest date first (1958); (E) date of planting grouped 0 to 7, 0 assigned to earliest date and 7 to the latest; and (F) total number of growing days. The growing days were estimated as the days from planting to the date that the greatest number of loads of beets was delivered to the weighing station.

To obtain a regression model, the first step would be to study two-dimensional and three-dimensional scatter diagrams. A more realistic model can be written when these are observed, and at the same time much additional information can be obtained about the independent variables.

In order to project a regression model as precisely as possible, a three-dimensional graphic analysis was made[5] (8). The punched cards that carried values for the six independent variables and for the dependent variables (Y_1, gross sugar per acre, Y_2, tons of roots per acre and Y_3, sugar percent) were sorted into ascending

[5] Machine method developed by Dr. Rex Hurst, Head, Applied Statistics Department, Utah State University, Logan, Utah.

Table 4.—Quadrant groupings from scatter diagrams, Doles Station, 1959.

	Gross sugar	Tons beets	Sugar percent	Acres planted	Pounds Units N	Pounds Units P_2O_5	No. growing days	Beet stand	No. samples	Percent of total: No. fields	Times watered: 5 to 12	Times watered: 13 to 19	Planting dates: Before March 21	Planting dates: After March 20
							Total		Total	Percent of fields				
Quadrant I														
+ avg. sugar %														
+ avg. tons/acre														
Maximum	6.928	42.5	17.2	40	200	240	238	100	80					
Minimum	4.379	27.2	16.1	5	60	60	194	71	15					
Mean of Quadrant	5.160	31.2	16.5	17.4	151	122	229	88	943	21	50	50	87	13
Quadrant II														
+ avg. sugar %														
— avg. tons/acre														
Maximum	4.409	26.5	17.3	23.2	375	240	240	100	45					
Minimum	2.837	16.7	16.1	2.5	60	20	189	57	3					
Mean of Quadrant	3.815	23.0	16.6	12.1	154	127	217	80	638	21	56	44	40	60
Quadrant III														
— avg. tons/acre														
— avg. sugar %														
Maximum	4.214	26.6	16.0	63.0	300	240	234	119	130					
Minimum	2.108	13.6	15.2	5.0	40	80	190	67	11					
Mean of Quadrant	3.691	23.8	15.5	16.5	167	136	210	81	996	24	77	23	48	52
Quadrant IV														
+ avg. tons/acre														
— avg. sugar %														
Maximum	5.936	37.1	16.0	62.5	288	196	240	100	288					
Minimum	4.112	26.7	15.0	1.2	96	44	198	68	96					
Mean of Quadrant	4.670	30.2	15.5	19.6	178	109	218	82	1171	23	55	45	61	39

Table 5.—Means of groups on five different cultural tretatments, Doles Station, 1959.

Group	Cultural treatment	Number of fields	Acre yield		Percent sugar
			Gross sugar	Tons beets	
	ACRES HARVESTED				
1	5-10	35	4.299	26.75	16.06
2	10.1 to 20	34	4.094	25.94	16.13
3	20.1 to 30	20	4.436	27.87	15.89
4	over 30	8	4.576	28.76	15.90
	UNITS NITROGEN				
1	below 99 units N	13	4.632	28.45	16.29
2	100 to 150 units N	26	3.949	24.61	16.08
3	151 to 200 units N	45	4.429	27.56	16.05
4	201 and above	12	4.179	26.50	15.79
	UNITS P_2O_5				
1	below 99 units	14	4.728	29.8	15.9
2	100 to 150 units	56	4.165	26.0	16.0
3	151 to 200 units	9	4.424	27.3	16.2
4	above 200 units	4	4.380	27.1	16.1
	NUMBER OF IRRIGATIONS				
1	5 to 8	18	3.904	24.0	16.2
2	9 to 12	34	4.243	26.7	15.9
3	13 to 15	16	4.171	25.8	16.2
4	16 to 19	20	4.785	29.9	16.1
	PLANTING DATE				
0	March 1-6	3	5.631	34.13	16.57
1	March 7-13	12	5.038	31.38	16.03
2	March 14-20	35	4.340	27.05	16.04
	Mean early plantings	50	5.006	30.85	16.20
3	March 21-27	10	3.985	25.33	15.82
4	March 28-April 3	8	4.078	25.93	15.74
5	April 4-10	7	3.657	23.01	15.96
6	April 11-17	7	3.474	21.30	16.26
7	April 18-25	6	4.009	25.16	15.90
	Mean later plantings	38	3.841	24.14	15.94

order for each of the independent variables and recoded by thirds. Number 1 was assigned to the lowest third; 2, to the next lowest; and 3, to the highest. Then by controlling for all possible two-way combinations of the recoded independent variables, cell totals of the dependent variables were obtained for each two-dimensional, independent variable combination. This reduced the graphic analysis to plotting only nine points for each two-dimensional combination and 15 three-dimensional graphs for each dependent variable (8).

After studying the graphs, several multiple regression models were selected for the 1959 data and R^2 values were obtained. Simple correlation values, means, standard deviations and coefficients of variation were also calculated.

Table 6.—Means of groups on six additional cultural treatments, Doles Station, 1959.

Group	Cultural treatment	Number of fields	Acre yield		Percent sugar
			Gross sugar	Tons beets	
	SOIL TYPE				
1	Light, sandy	5	4.415	26.90	16.48
2	Medium	58	4.455	27.55	16.15
3	Heavy	28	4.364	27.95	15.68
	PREVIOUS CROP				
1	Forage	14	4.529	28.1	16.1
2	Beets	29	4.103	25.9	15.8
3	Grain	14	3.864	24.0	16.2
4	Potatoes	16	4.481	27.5	16.3
5	Corn	11	4.116	26.1	15.8
	IRRIGATED BEFORE THINNING				
1	Yes	50	4.348	27.2	16.0
2	No	43	4.218	26.2	16.1
	IRRIGATED UP				
1	Yes	62	4.156	25.9	16.1
2	No	33	4.528	28.2	16.0
	SPRING WORK				
1	Yes	66	4.314	27.00	15.98
2	No	30	4.215	26.02	16.19
	DATE OF SIDE DRESSING				
1	No side dressing	36	4.175	26.14	16.0
2	May	2	4.658	30.00	15.4
3	June	30	4.457	27.7	16.1
4	July	5	3.480	22.3	15.7

Experimental Results

General observations from means for 1958

The scatter diagram of average tons roots per acre and average sugar percent shows the production of each field with respect to the general mean of the two variables in 1958 (Figure 1). Of the 50% of the fields that produced below-average tons of beets per acre (quadrants 2 and 3), 32% had the highest sugar percent (mean 16.9) but produced only 3.963 tons of gross sugar per acre (Table 1). The other 18% had a mean sucrose of 15.7% sugar and 4.210 tons of gross sugar per acre. The fields (quadrants 2 and 3) with the highest and lowest average sugar percent also produced the lowest and next to lowest average gross sugar per acre.

Of the 50% of all the field that produced above-average tons of roots per acre, 29% (quadrant 4) produced below-average percent (15.68) and produced next to the highest gross sugar per acre (5.235 tons). The other 21% (quadrant 1) produced the highest tons of roots per acre with above-average sugar percent (16.72) and highest gross sugar per acre (5.384 tons).

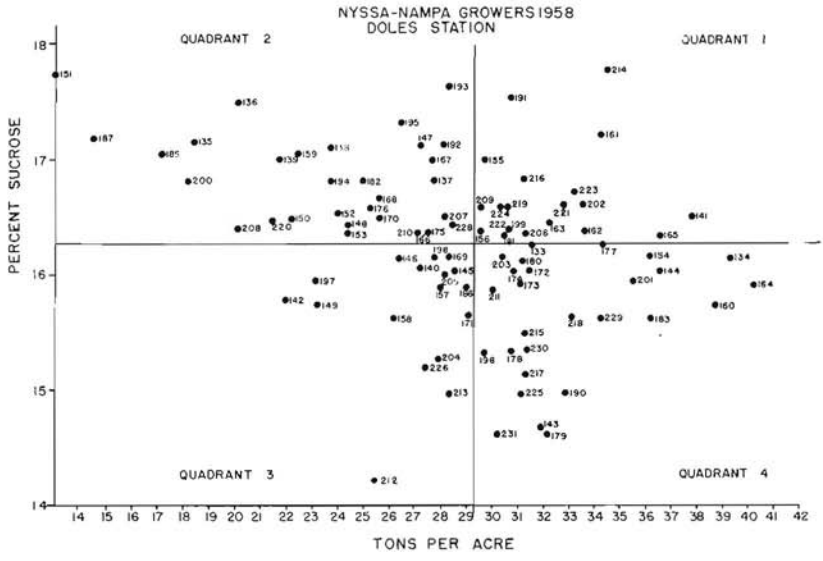

Figure 1.—Scatter diagram—Doles Station, 1958.

Gross sugar per acre was influenced largely by tons of roots per acre, not by sugar percent. Above-average yields did not tend to show a decrease in sugar percent until applications of nitrogen exceeded 150 units of N per acre, as in quadrant 4 (Table 1). Quadrant 3, with next to the highest nitrogen application (161 units N), produced below-average tons per acre and, as expected, below-average sugar percent.

Acres harvested 1958

Fields of 5 to 10 acres averaged 29.06 tons roots per acre, and fields above 30 acres averaged 30.57 tons roots per acre. The small difference, probably is not significant but shows that field practices may have been different (Table 2).

Fertilizer applied 1958

Units of nitrogen and units of phosphate per acre showed very little differences because the lowest application seemed to be as effective as the highest (Table 2). The residual fertility in the various fields was not known and could have been a factor. The association of high tonnage with high P_2O_5 was not significant, because only two fields fell into this group.

Date of last irrigation or number of irrigations

In 1958 there were only slight differences due to the number of irrigations or to late watering. Average sugar percent did show increases in favor of late irrigations (Table 2).

Planting date

The dates of planting in 1958 ranged from March 1 to April 25. The earliest plantings, however, did show some improvement over the latest in average tonnage and average gross sugar. Intermediate dates of planting, March 21 to April 3, gave the highest yield of roots and gross sugar (Table 2).

Other observations

Soil type was difficult to judge from simple observations. Medium to heavy soil types with 32.6 tons of roots per acre and 15.83% sugar produced the highest gross sugar or 5.134 tons (Table 3).

Beets following grain produced 30.7 tons of roots per acre with 16.32% sugar. Beets following potatoes ranked next with 30.4 tons of roots per acre and 16.15% sugar (Table 3).

General observations from means for 1959

The scatter diagram (Figure 2) shows how the respective fields placed in relation to the mean yield of tons per acre and sugar percent of all the fields in 1959. Quadrant 1, which is above average for both sugar percent and tons per acre, yielded 5.160 tons of gross sugar per acre and 31.2 tons roots per acre with 16.5% sugar (Table 4). Eighty-seven percent of the acres in quadrant 1, which comprised 20% of the total in 1959, was planted before March 21. This gave an average growing season of 229 days, or the longest growing season of all quadrants. A good stand of beets was also maintained in these fields. The

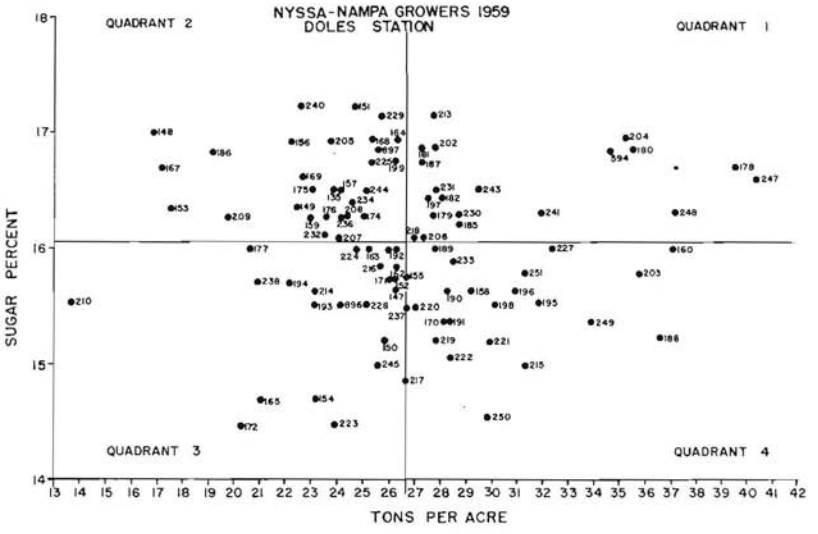

Figure 2.—Scatter diagram—Doles Station, 1959.

average stand of 88 plants per 100 feet of row is higher than that of any other quadrant.

Quadrant 2, with above-average sugar percentage and below-average tonnage, yielded 3.815 tons of gross sugar and 23 tons of roots per acre with 16.6% sugar. These fields represented 24.6% of the total acres planted. The average stand was 80 plants per 100 feet of row for this group. The growing season was 217 days, a comparatively short growing period inasmuch as 40% of the fields were planted before March 21.

Quadrant 3, with both low tonnage and low sugar percentage when compared with the means of all fields, represented 24.9% of the total acres planted. Only 48% had been planted by March 21, which could be the major factor in the low yields. Stands were down to 81 plants per 100 feet of row, and the group produced 3.961 tons gross sugar and 23.8 tons of roots per acre with 15.5% sugar during an average growing season of 210 days.

Quadrant 4, characterized by high tonnage but low sugar when compared with the mean of all fields, produced 4.760 tons of gross sugar per acre, 30.2 tons of roots per acre and 15.5% sugar. This quadrant had 218 growing days, with 61% of the fields planted by March 21, and represented 28.4% of the total acres planted. An average of 178 units of N per acre, the highest for all the quadrants, could be the contributing factor for the low sugar percentage, especially if the nitrogen level in the soil was high before application and late rains or irrigations made the nitrogen available late in the season. The comparatively good stand of 82 beets per 100 feet of row helped maintain tons of roots per acre.

Acres harvested 1959

Small fields (under 20 acres) produced, on an average, 2 tons of roots per acre less than fields larger than 20 acres, with an increase in sugar percent (Table 5). This could be due to some inherent field practice on small fields.

Fertilizer applied 1959

A decrease in sugar percentage was associated with an increase in nitrogen application (Table 5). This decrease occurred without an increase in average tons of roots per acre; in fact, the highest tonnage was obtained from fields with the lowest application of nitrogen. However, the initial level of nitrogen fertility in these fields was not known.

The lowest P_2O_5 application averaged the highest gross sugar and tons of roots per acre (Table 5). This must be due to the level of soil fertility before the applications of P_2O_5 and N were used.

Date of last irrigation or number of irrigations

The number of irrigations was associated with gross sugar and root yield. The highest number of irrigations increased the average yield of gross sugar and roots 0.881 tons and 5.9 tons per acre, respectively, over the lowest number of irrigations. Number of irrigations had little or no effect on sugar percent (Table 5).

Date of planting

Early planting, March 1 to March 20, increased production. These early plantings averaged 6.71 more tons of roots and 1.165 more tons of gross sugar per acre than the later plantings.

Other observations

Heavy soils were associated with highest yield of roots per acre, but sugar percent was somewhat higher in sandy soils (Table 6). Slight increases in yield were obtained when the preceding crops were forage or potatoes (Table 6). An average increase of one ton per acre was obtained when the sugar beets were irrigated before thinning, but when it was necessary to irrigate for germination, there was a reduction in yield of 2.3 tons per acre (Table 6). Fields that received mechanical work early in the spring had a one-ton advantage over fields that did not receive this practice (Table 6). There were indications that late side dressings in July decreased tonnage, sugar percentage, and gross sugar (Table 6).

Date of harvest

The effect of date of harvest on sugar percent during the delivery period at the Doles station for 1958 and 1959 was evidenced by the increased sugar percent obtained at the later harvest dates (Table 7). The scatter diagram between date of harvest and daily sugar percent indicates that the relation was not linear over the time included in the study (Figure 3). A

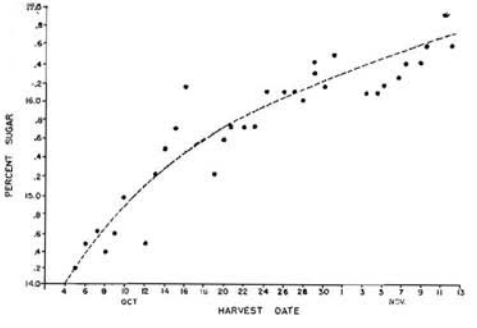

Figure 3.—Percent sugar by days—Doles Station, 1959.

Table 7.—Means of daily sugar percent.

Doles Station, 1958			Doles Station, 1959		
Date	No. samples	Sugar percent	Date	No. samples	Sugar percent
10/6	24	14.7	10/5	9	14.3
10/8	74	14.4	10/6	37	14.5
10/9	69	15.1	10/7	59	14.6
10/10	102	15.8	10/8	52	14.4
10/11	198	16.3	10/9	25	14.6
10/13	69	15.7	10/10	34	15.0
10/15	49	15.6	10/12	60	14.5
10/16	25	16.3	10/13	74	15.2
10/20	140	16.1	10/14	65	15.5
10/21	186	16.1	10/15	68	15.7
10/23	182	16.2	10/16	117	16.1
10/24	188	16.3	10/19	129	15.2
10/25	184	16.5	10/20	196	15.6
10/27	179	16.5	10/21	187	15.7
10/28	177	16.5	10/22	210	15.7
10/29	189	16.2	10/23	161	15.7
10/30	180	16.3	10/24	172	16.1
10/31	176	16.4	10/26	187	16.1
11/1	172	16.5	10/27	196	16.1
11/3	147	16.2	10/28	222	16.0
11/4	139	16.3	10/29	186	16.3
11/5	126	16.3	10/30	216	16.2
11/6	123	16.6	10/31	202	16.5
11/7	106	16.4	11/2	200	16.3
11/8	81	17.1	11/3	156	16.1
11/10	49	18.0	11/4	186	16.1
11/11	15	17.6	11/5	106	16.2
			11/6	130	16.3
Total	3349		11/7	154	16.4
			11/9	129	16.4
			11/10	62	16.6
			11/11	39	16.9
			11/12	12	16.6
			Total	4038	

regression model, using dates and dates squared as independent variables and sugar percent as the dependent variable, gave an R^2 value of 0.26. This R^2 value and both terms were highly significant, giving significance to a curvilinear relationship (3).

Statistical Results

Typical three-dimensional graphs for the 1959 data, showing the effect of field practices on yield of roots per acre, are given in Figure 4. Figure 4a shows a probable curvilinear relationship between yield of beets and units of nitrogen applied per acre. This probable curvilinear relationship is affected by units of P_2O_5 added per acre. This suggests that both linear terms, units of nitrogen and units of P_2O_5, and the interactions (units of

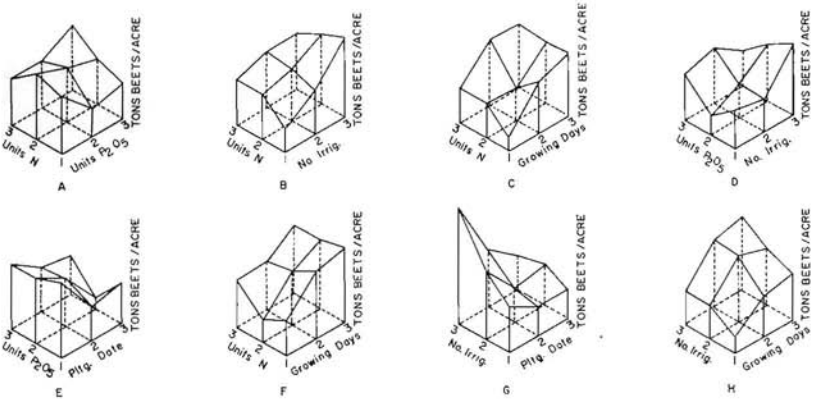

Figure 4.—Typical three-dimensional graphs showing acre yield of sugar beets, 1959 data.

nitrogen times units of P_2O_5 and units of nitrogen squared times units P_2O_5) should be included in the mathematical model. The curvilinear relationship with units of N is not so clear in Figure 4b and 4c; however, the interactions units of N times number of irrigations and units of N times length of growing season should be included. In Figures 4d and 4e, an uncertain relationship is shown between yield and units of P_2O_5, but the interaction, units of P_2O_5 times number of growing days, should be included in the model.

Figures 4g and 4h show a curvilinear relationship between yield and number of irrigations and that the relationship is affected by date of planting and number of growing days. These independent variables should be included in the model as linear and quadratic forms, together with all their interactions. The negative relationships are due to the coding of planting date with number one being the earliest date (Figures 4c and 4g).

The three-dimensional graphs with Y_1 (gross sugar per acre) were similar to those with Y_2 (tons of roots per acre), due to the high correlations of 0.97 and 0.08 between Y_1 and Y_2 (Table 8). The surfaces obtained with Y_3 (sugar percent) were quite flat, probably due to the low coefficient of variation and the low number of points plotted.

The multiple-linear model gave an R^2 value of 0.270 with Y_1 (gross sugar per acre), 0.253 with Y_2 (tons roots per acre) and a small value of 0.184 with Y_3 (sugar percent) (Table 9).

A regression model of 18 terms was then tried (Table 10). It was felt that the terms included in this model were the ones most evident from the 15 possible three-dimensional graphs with

Table 8.—Simple correlations, 1958-1959.

		1	2	3	4	5	6	Y_1	Y_2	Y_3
Acres harvested - 1	1958		.075	.179	.056	—.106	.096	.051	.085	—.152
	1959		.121	.079	.049	—.209	.276*	.062	.078	.082
Unit "N"/acre - 2	1958			.266*	.119	.184	—.202	.006	.068	—.289**
	1959			.317*	.005	.029	.010	.052	.032	—.109
Units P_2O_5 - 3	1958				.062	.008	—.004	.045	.030	.132
	1959				.096	.059	.069	—.001	—.018	—.042
Date of 1st irr. - 4	1958					.384**	—.193	.057	.007	.212*
No. of irrigations - 4	1959					—.249**	.149	.324**	.334**	.042
Planting date - 5	1958						.796**	—.055	—.132	.318**
	1959						.766**	—.453**	—.445**	.073
No. growing days - 6	1958							.114	.158	—.174
	1959							.410**	.356**	.290**
Gross sugar/acre - Y_1	1958								.971**	—.101
	1959								.979**	.168
Tons beets/acre - Y_2	1958									—.332**
	1959									—.033
Sugar percent - Y_3										

Y_2 (tons roots per acre). The "B" model produced an R^2 value of 0.393, an increase in precision of 13.9% over the multiple-linear model.

Since there were 10 more interaction terms that seemed probable, a "C" model with all 28 terms was set up and an R^2 value of 0.463 was obtained, an increase in precision of 21.0% over the linear model (Table 11).

While all the R^2 values gave an increase over linear Model A, the change to Model C did not improve the relationship enough to justify the loss of 22 degrees of freedom. The F

Table 9.—Regression analysis linear model, 1959 data.

Source of variation	Degree of freedom	Mean[1] square	Calculated F value
Y_1 - Gross sugar/acre			
Total	82	0.7065	
Acres harvested - 1	1	0.1328	
N/acre - 2	1	0.1000	
P_2O_5/acre - 3	1	0.0030	
No. irrigations - 4	1	2.9329	5.26*
Date of planting - 5	1	1.4770	2.65
Days season - 6	1	0.8576	
Model	6	2.6041	4.67**
Error	76	0.5567	
R^2		.2697	
Y_2 - Tons beets/acre			
Total	82	26.3567	
Acres harvested - 1	1	0.7745	
N/acre - 2	1	0.4568	
P_2O_5/acre - 3	1	0.3419	
No. irrigations - 4	1	113.4976	5.35*
Date of planting - 5	1	97.0650	4.57*
Days season - 6	1	3.8633	
Model	6	91.2491	4.30**
Error	76	21.2336	
R^2		0.2533	
Y_3 - Sugar percent			
Total	82	0.4182	
Acres harvested - 1	1	0.8215	2.23
N/acre - 2	1	0.5076	1.38
P_2O_5/acre - 3	1	0.1560	
No. irrigations - 4	1	0.0272	
Date of planting - 5	1	1.7974	4.88*
Days season - 6	1	5.1635	14.01**
Model	6	1.0512	2.71*
Error	76	0.3683	
R^2		.1839	

* Signifirant at 5% point.
** Significant at 1% point.
[1] Single d.f. mean square is that which would not have been accounted for by regression had the variable been omitted.

Table 10.—Regression analysis model B, 1959 data.

Total	DF	Mean Sq.[1]	F. Value	Total	DF	Mean Sq.[1]	F. Value	Total	DF	Mean Sq.[1]	F. Value
Y_1 Gross sugar/acre				Y_2 Tons beets/acre				Y_3 Percent sugar			
Total	82	0.7065		Total	82	26.3567		Total	82	0.4182	
Acres har. - 1	1	0.4885		Acres har. - 1	1	28.2145	1.37	Acres har. - 1	1	0.3811	
N/acre - 2	1	0.3584		N/acre - 2	1	21.5259	1.05	N/acre - 2	1	0.3320	
P_2O_5/acre - 3	1	1.0532	2.00	P_2O_5/acre - 3	1	42.7191	2.03	P_2O_5/acre - 3	1	0.0012	
No. irr. - 4	1	4.3654	8.30**	No. irr. - 4	1	189.6255	9.24**	No. irr. - 4	1	0.2835	
Date pltg. - 5	1	0.1748		Date pltg. - 5	1	0.0317		Date pltg. - 5	1	1.1926	3.01
Days season - 6	1	0.0728		Days season - 6	1	16.6700		Days season - 6	1	1.8488	4.66**
1 × 2	1	0.0021		1 × 2	1	0.0002		1 × 2	1	0.0695	
1 × 4	1	0.2448		1 × 4	1	18.8499		1 × 4	1	0.6531	
1 × 5	1	0.2648		1 × 5	1	0.8309		1 × 5	1	0.0016	
2 × 3	1	1.2905		2 × 3	1	50.0181		2 × 3	1	0.0002	
2 × 4	1	0.7570		2 × 4	1	33.1031		2 × 4	1	0.0394	
2 × 5	1	0.7838		2 × 5	1	31.1375		2 × 5	1	0.0032	
2 × 6	1	0.2923		2 × 6	1	19.9013		2 × 6	1	0.4324	
4 × 5	1	4.1431	7.87**	4 × 5	1	137.2023	6.69*	4 × 5	1	0.2270	
5 × 6	1	0.1423		5 × 6	1	0.0782		5 × 6	1	0.8098	
1 sq. × 2	1	0.0741		1 sq. × 2	1	8.2990		1 sq. × 2	1	0.6070	
1 sq. × 4	1	0.0361		1 sq. × 4	1	5.5895		1 sq. × 4	1	0.5435	
2 sq. × 3	1	0.4987		2 sq. × 3	1	23.2563	1.13	2 sq. × 3	1	0.0683	
Model	18	1.3479	2.56**	Model	18	47.1149	2.29**	Model	18	0.4959	1.25
Error	64	0.5261		Error	64	20.5184		Error	64	0.3964	
R^2		0.4188		R^2		0.3924		R^2		0.2604	

* Significant at 5% point.

** Significant at 1% point.

[1] Single mean (d.f. mean) square is that which would not have been accounted for by regression had the variable been omitted.

Table 11.—Regression analysis model C, 1959 data.

Total	DF	Mean Sq.[1]	F. Value	Total	DF	Mean Sq.[1]	F. Value	Total	DF	Mean Sq.[1]	F. Value
Y_1 Gross sugar/acre				Y_2 Tons beets/acre				Y_3 Percent sugar			
Total	82	0.7065		Total	82	26.3567		Total	82	0.4182	
Acres har. - 1	1	0.2565		Acres har. - 1	1	11.4000		Acres har. - 1	1	0.4182	
N/acre - 2	1	0.1631		N/acre - 2	1	25.0390	1.17	N/acre - 2	1	0.3514	1.04
P_2O_5/acre - 3	1	1.2133	2.17	P_2O_5/acre - 3	1	21.3809	1.01	P_2O_5/acre - 3	1	2.3482	6.95*
No. irr. - 4	1	0.2169		No. irr. - 4	1	20.2812		No. irr. - 4	1	1.0547	3.12
Date pltg. - 5	1	0.0001		Date pltg. - 5	1	0.5515		Date pltg. - 5	1	0.5594	
Days season - 6	1	0.1309		Days season - 6	1	3.0611		Days season - 6	1	0.2201	
1 × 2	1	0.0088		1 × 2	1	0.0896		1 × 2	1	0.0458	
1 × 4	1	0.0983		1 × 4	1	5.4056		1 × 4	1	0.0583	
1 × 5	1	0.2528		1 × 5	1	4.4210		1 × 5	1	0.3389	
2 × 3	1	0.8082		2 × 3	1	32.3616	1.51	2 × 3	1	0.0154	
2 × 4	1	0.2884		2 × 4	1	13.9001		2 × 4	1	0.1318	
2 × 5	1	0.0505		2 × 5	1	2.1847		2 × 5	1	0.0003	
2 × 6	1	0.1441		2 × 6	1	1.4407		2 × 6	1	0.5567	1.65
3 × 4	1	0.1063		3 × 4	1	12.1437		3 × 4	1	1.1185	3.31
3 × 5	1	0.0002		3 × 5	1	3.2539		3 × 5	1	1.5604	4.62*
3 × 6	1	0.9259	1.65	3 × 6	1	14.0665		3 × 6	1	2.4034	7.11**
4 × 5	1	1.6372	2.92	4 × 5	1	84.5334	3.93	4 × 5	1	0.6516	1.93
4 × 6	1	0.0138		4 × 6	1	0.3314		4 × 6	1	0.7744	2.29
5 × 6	1	0.0061		5 × 6	1	0.4560		5 × 6	1	0.0056	
5 sq. × 1	1	0.3753		5 sq. × 1	1	5.3385		5 sq. × 1	1	0.6931	2.05
1 sq. × 2	1	0.0060		1 sq. × 2	1	0.4565		1 sq. × 2	1	0.0147	
1 sq. × 4	1	0.0012		1 sq. × 4	1	0.3888		1 sq. × 4	1	0.0652	
1 sq. × 5	1	0.0146		1 sq. × 5	1	0.3567		1 sq. × 5	1	0.0168	
2 sq. × 3	1	0.3906		2 sq. × 3	1	17.2263		2 sq. × 3	1	0.0707	
2 sq. × 4	1	0.0411		2 sq. × 4	1	1.9362		2 sq. × 4	1	0.0435	
3 sq. × 4	1	0.1022		3 sq. × 4	1	15.9820		3 sq. × 4	1	2.0945	6.20*
3 sq. × 5	1	0.1062		3 sq. × 5	1	13.7736		3 sq. × 5	1	0.5616	4.62*
4 sq. × 6	1	0.6274	1.12	4 sq. × 6	1	37.8391	1.76	4 sq. × 6	1	0.3204	
Model	28	0.9887	1.76*	Model	28	35.7472	1.66	Model	28	0.5736	1.69*
Error	54	0.5602		Error	54	21.4875		Error	54	0.3377	
R^2		.4778		R^2		.4631		R^2		.4683	

* Significant at 5% point.
** Significant at 1% point.
[1] Single d.f. mean square is that which would not have been accounted for by regression had the variable been omitted.

values were all reduced for Model C except with Y_3 which barely reached the 5% level (Table 11). The models used were not expected to be the complete answer. To obtain this, one would have to use a stepwise procedure to find the terms and interactions of most significance.

Discussion

Much has been written on the problems involved in producing a high quality sugar beet. The continual downward trend of recoverable sugar is of great concern to both the producer and the processor (1) (2) (6) (10) (13) (15). It is felt that part of the problem is due to the single factor approach of most investigators, with not enough study given to the variations and interactions caused by local climate, crop history and cultural practices at each location. Variety differences should always be ionsidered, since hybrids behave differently when they are grown in different locations (9) (10) (11) (14) (15) (16) (17).

The survey type of approach to the problem gives an opportunity to establish the interaction relationship between the variables observed or measured. Very close supervision must be made in obtaining the data, and full cooperation of each grower should be obtained. This type of study would not take the place of controlled experiments, but could give additional information as to interactions between variables under normal farm conditions and at a nominal cost, especially when a large number of variables appear.

The simple means of all the variables in the Nyssa-Nampa data did show trends, but they were not significant. However, simple correlations in 1958 showed significant negative association between units of N applied and sugar percent, and a positive association between sugar percent and date of planting and date of first irrigation. This did not hold for the 1959 data, but a significant correlation was obtained between sugar percent and number of growing days (Table 8). The author feels that the correlation between sucrose percent and beet weight or tons beets per acre is very unreliable, since it is controlled largely by the season or the location or by both. Others have found no correlation between sucrose percent and beet weight (9).

The most significant independent variables of the six used in the regression study were: number of irrigations; date of first irrigation; number of growing days; and date of planting (Table 9). Haddock found similar significance (6).

Taking the regression model in its linear form for 1959 (Table 9), the most significant measurements were for Y_1, gross

sugar per acre, and Y_2, tons roots per acre, number of irrigations and date of planting. For sugar percent the most significant measurements were planting date and number of growing days.

Regression model "B" for 1959 data (Table 10) also gives significance to the interactions of number of irrigations and date of planting for Y_1, gross sugar per acre, or Y_2, tons of roots per acre. Model "C" (Table 11) shows the same significant trends with Y_3, sugar percent. The significant interactions between P_2O_5 per acre, planting date and growing season with sugar percent, were surprising, but it is possible that the nitrogen and P_2O_5 balance was disturbed by the phosphate treatments.

It is clear from the regression models and three-dimensional graphs that interactions were present, which should be considered, and these relationships are not strictly linear. More work needs to be done, because the regression models used are not the most significant ones and the F values for models B and C increased the odds over the linear regression models with all dependent variables except Y_3, sugar percent. It is evident that in addition to the six field practices evaluated in this study the association of other factors of production (such as weather measurements, soil type, soil preparation, cropping history and genetic factors) should be appraised. Elimination of terms by regrouping those with significant individual F values and those with known correlation values in a systematic and stepwise procedure could reduce the number of necessary terms in the regression model (7).

In this study the effect of length of harvest season on sugar percent was very evident. This effect has also been shown by others (5) (3) (4). The R^2 value obtained, although only .26, was of very high significance (F value $B_1 = 18.05$ and $B_2 = 15.83$). The low R^2 value must be due to the large variation in sugar percentage within days.

Summary

In this study, the means clearly show that high acreable yield of gross sugar was due to high tonnage of roots and not to sugar percent. This was substantiated by a highly significant correlation between gross sugar and tons of roots.

The significance of cultural practices (such as units of nitrogen and P_2O_5, total number of irrigations, length of growing season and date of harvest) was established by multiple regression and the use of three-dimensional graphs. The importance of interactions of these variables and their relationship to each other is shown.

The use of regression models on survey type of data, to establish the variables of most importance, is suggested.

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