A Weather Index Method and Temperature Distribution Applied to Sugarbeet Yields and Sugar Percentage[1]

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Introduction

Throughout the years there has been interest in the influence of weather on various crops. Early sugarbeet (*Beta vulgaris* L.) production tests suggested areas suitable for sugarbeet culture. Correlations of temperature, rainfall, or both with sugarbeet yield have been studied in certain areas (6, 7, 9, 11, 18, 27, 34, 35).[3] Because of the increased quantity of weather data and the ease of computations by computers, interest has increased in recent years in correlating weather factors with crop production. The science of bioclimatology has developed greatly, and the understanding of photosynthesis and energy requirements has also increased (2, 3, 4, 19, 24, 25). Although some of these studies show good correlations, results were limited to a single location and a few years' observation. Also, the weather factors were averaged over comparatively long periods without consideration for the distribution of the weather measure within the seasons (6, 9, 20, 21, 33, 34).

Shaw and Durost's weather-index method (28, 29, 30) used an established trend to determine all unaccountable variation. It appealed because of the possibility of evaluating the weather effect without actual weather measurements. To solve the problem of what variables to include, they called all unaccounted-for variation "weather effect." The accuracy depended on the establishment of a true trend. Thus, yields under very uniform cultural conditions must be available. Stallings (31) established the trend by using linear regression models on years. However, this method would make it hard to adjust for years.

Wallace (36) studied the influence of weather on yields of corn and wheat. He used selected weather measurements averaged over comparatively long periods. Fisher (12, 13) thought that the increments of time should be small to represent the distribution of temperature or rainfall on a crop. He called attention to the use of orthogonal polynomials (uncorrelated independent variables) of whatever degree

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[3]Numbers in parenthesis refer to literature cited.

wanted. This method reduces the number of variables to a suitable size for a regression analysis over as long a period as possible. When Fisher used this method to compare wheat yields with rainfall, results were good.

Neither the weather-index method nor the use of orthogonal polynomials has been applied to sugarbeet yields. The purpose of this paper is to report the results of these methods on sugarbeet-yield data, to develop predictive procedures, and to establish the relationship of yield and sugar percent with weather.

Materials and Methods

A trend was established with a 9-yr moving average of the variety trial yields. Terminal years were calculated as given by Shaw and Durost (29). An index was then calculated by division of the yearly trend into the actual variety trial averages. To determine abnormal years from this index, values of 85 to 115 were assumed to be a normal index range. Any yield not in that range was adjusted as described by Shaw and Durost.

A new series was formed with actual variety trial yield in normal years, and the adjusted yields for abnormal years. A final weather index was calculated with a 5-yr moving average on this adjusted series as the trend, the terminal years being calculated as before. Divided into actual variety trial yields, this new trend gave the final weather index.

It was assumed that variety trial-yield averages, with varieties similar to the commercial varieties in the area, would have a gradual effect on yield that might be removed by a trend. Better-than-average farmers would be uniform in cultural practices. Any changes in soil moisture and moisture reserves would be likely to have a gradual effect on yields, one that could be removed by a trend. Other cultural effects such as fertilizer application, plant population, and soil changes by rotation could be held constant or assumed to be changed only gradually by a controlled group of better-than-average farmers.

A pilot study on the weather-index method was made on data from sugarbeet yields in the West Jordan, Utah, area. It was felt that this location fit the conditions cited above. Two farms were used repeatedly for variety testing. The first farm had a heavy clay soil, whereas the second farm had sandy soil. Cultural practices were similar on both farms.

Variety trials and factory-district average yields for Nampa, Idaho; Nyssa, Oregon; and West Jordan, Utah, were obtained through the courtesy of the Amalgamated and Utah-Idaho Sugar Companies, respectively. The variety trial data for the West Jordan district were from the Granger-Taylorsville area records of the ARS, USDA, field station, now located at Logan, Utah.

The effect of weather on sugarbeet yield was studied at three sites, Nampa, Nyssa, and West Jordan, because factory-district averages and variety yield-trial data were available for at least 20 years at these sites.

Temperature data at these sites were obtained from published climatological data for each state (8). The weather station used in Utah was at the Midvale smelter[4] and at the other two sites at sugar factories. When the published data were not complete, unpublished daily maximum and minimum temperatures were used from the same weather stations to complete the series of years.[5]

The first calculations were made using 40 periods of 5 days each, starting at the variety trial planting dates for each year. To obtain the orthogonal polynomial distribution coefficients, Fisher and Yates' (13) tabular values were used for each season. A fifth-degree orthogonal polynomial on time was used. In the regression on models, adjustments were made for length of season. The second calculations were made from a starting point of March 5 of each year, with the time divided into 54 five-day periods. For more adjustments, the linear trend over years was removed in the regression models. The data were calculated at the Computer Center, Utah State University Applied Statistical Laboratory, under the direction of Dr. Rex Hurst.[6]

To obtain information about the best form of measure to express the temperature, seven arrangements were used:

(a) Degree days, as given by Bager (5), with a base of 86-50°F; maximum temperature was always entered as 86°F or less and minimum as 50°F or more. Examples: A cool day of 64°F maximum and 40°F minimum would be $\frac{(64 + 50)}{2} = 57 - 50 = 7$°F. A warm day with a maximum of 90°F and a minimum of 64°F would be $\frac{(86 + 64)}{2} - 50 =$ 25°F.

(b) The same as (a), with a base of 80-45°F.

(c) The same as (a), with a base of 75-40°F.

(d) Differences of daily maximum and minimum temperature.

(e) Daily average.

(f) Daily maximum.

(g) Daily minimum.

Regression models were built with these temperature arrangements and four dependent (Y_k) measurements: yearly average district yields, yearly average variety trial yields, yearly average district sugar percentage, and yearly average variety trial sugar percentage.

The regression methods used to study the effect of temperature distribution on the yield of sugarbeet roots and sugar percentage are described by Fisher (12). Houseman (16) and others (10, 15, 7) applied and simplified calculations. Briefly, the method consists of first establish-

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[4]Daily temperature records for the Midvale smelter were not published after October 1958. The daily temperatures from November 1958 to 1960 were obtained from Arlo E. Richardson, Utah State Climatologist, Logan, Utah.

[5]Nampa daily temperature records, Sugar Factory Station, were not published after 1960. Daily temperatures from 1961 to 1969 were obtained from the factory station through the Amalgamated Sugar Company.

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ing distribution coefficients for each year. These distribution coefficients can be obtained with the 54 five-day totals for each year as dependent variables (Y) and the orthogonal polynomial table values (1, 12) as the independent variables (X). The regression coefficients obtained from the above multiple regression model are the orthogonal polynomial distribution coefficients for each year (Table 3). These distribution coefficients are then used in a multiple-regression model as X_i variables, with annual yields and sugar percentages as the dependent Y_k variables. These regression coefficients (A_i) are used to obtain delta values (Δ_i = effect of one degree rise in temperature measurement above average on yields or sugar percent) over the 54 periods of time by the following formula:

$$\Delta_i = \frac{A_O}{N} + \frac{A_1t_1}{\sum t_1^2} + \frac{A_2t_2}{\sum t_2^2} + \frac{A_3t_3}{\sum t_3^2} + \frac{A_4t_4}{\sum t_4^2} + \frac{A_5t_5,}{\sum t_5^2}$$

where the t_i's are the same orthogonal-polynomial table values used above. These 54 delta values are used over time to plot the delta curves.

Models with a season of seven monthly totals of daily temperature also were calculated for West Jordan.

Results and Discussion

Weather indices

A trend was established by the method described by Shaw and Durost (29); indices were calculated as given in Table 1 for the Granger-Taylorsville area in the West Jordan district. Figure 1 shows the plotted variety trial and trend yields, adjusted district yields (by division with the weather-index percentage), and linear regression lines. The linear regression of these variety trial yields on years was established as $Y = 15.06 + 0.1521 \times$ for 1936-1960. The weather indices obtained over-adjusted district yields in 1942-45 and again especially in 1955-1958.

To test the indices, a regression model was calculated using district yields in tons per acre as the dependent (Y) variables and linear trend over years and the calculated weather indices as independent (X_i) variables. This model was significant at the 1% level, with an R^2 value of 0.46. By itself, the weather index term was significant, with a single degree of freedom, at the 5% level.

One use of weather index estimates was to obtain an indication of how much of the yield resulted from technology and how much from weather. The method used is shown in Table 2. The changes due to technology and weather all seem reasonable except for the last period of 1956-1960. In this period, the variety trials were a change from one farm with heavy soil to another with sandy soil. A better overall measure would probably be the 1936-1956 period, if one ignores the effects of a farm change. This period gives an average increase of 0.195 T/yr

Table 1.—Calculated weather index for Granger-Taylorsville area, West Jordan, Utah, district.

Year	Variety trial yield average 1	9-yr moving average 2	First index[1] 3	Average weather years[2] 4	5-yr moving average 5	Final index[3] 6	District yield 7	Adjusted yield[4] 8
	T/A	T/A	%	T/A	T/A	%	T/A	T/A
1936	23.40	23.20	100.86	23.40	24.77	94.47	13.95	14.76
37	24.32	23.90	101.75	24.32	25.29	96.16	12.38	12.87
38	26.94	24.20	111.32	26.94	25.69	104.87	16.89	16.11
39	26.04	24.90	104.58	26.04	26.55	98.08	12.66	12.91
40	27.75	25.56	108.56	27.75	26.74	103.78	12.44	11.99
41	27.68	26.39	104.89	27.68	26.23	105.53	13.97	13.24
42	25.28	26.96	93.77	25.28	25.89	97.64	13.96	14.30
43	24.38	27.78	87.76	24.38	26.50	92.00	15.86	17.24
44	24.34	27.69	87.90	24.34	26.84	90.69	13.88	15.30
45	30.80	28.08	109.69	30.80	27.24	113.07	14.81	13.10
46	29.39	28.22	104.15	29.39	27.39	107.30	13.68	12.75
47	34.40	28.66	120.03	27.27	28.78	119.53	16.31	13.65
48	25.15	28.73	87.54	25.15	28.40	88.56	11.76	13.28
49	31.30	29.85	104.86	31.30	28.38	110.29	16.97	15.39
50	28.90	29.87	96.75	28.90	27.93	103.47	14.38	13.90
51	29.30	29.62	98.92	29.30	28.50	102.81	16.41	15.96
52	25.00	28.73	87.02	25.00	28.44	87.90	13.69	15.57
53	34.40	28.82	119.36	28.00	28.08	122.51	15.53	12.68
54	31.00	28.73	107.90	31.00	27.50	112.73	16.20	14.37
55	27.10	29.59	91.58	27.10	28.10	96.17	15.84	16.47
56	26.40	30.38	96.90	26.40	28.67	92.08	17.04	18.51
57	26.00	31.23	83.25	28.42	29.80	87.26	16.94	19.42
58	30.45	32.06	94.98	30.45	31.67	96.15	14.33	14.90
59	36.65	32.89	111.43	36.65	32.05	114.35	19.14	16.74
60	36.45	33.72	108.10	36.45	33.05	110.29	17.51	15.88

[1]Items in column 1 divided by items in column 2 are expressed in percentage (column 3).
[2]Years are considered average if they are between a first index value of (85-115); if over or under year is adjusted by use of average of year before and year after.
[3]Items in column 4 divided by items in column 5 are expressed in percentage.
[4]District yields are divided by final index in percentage.

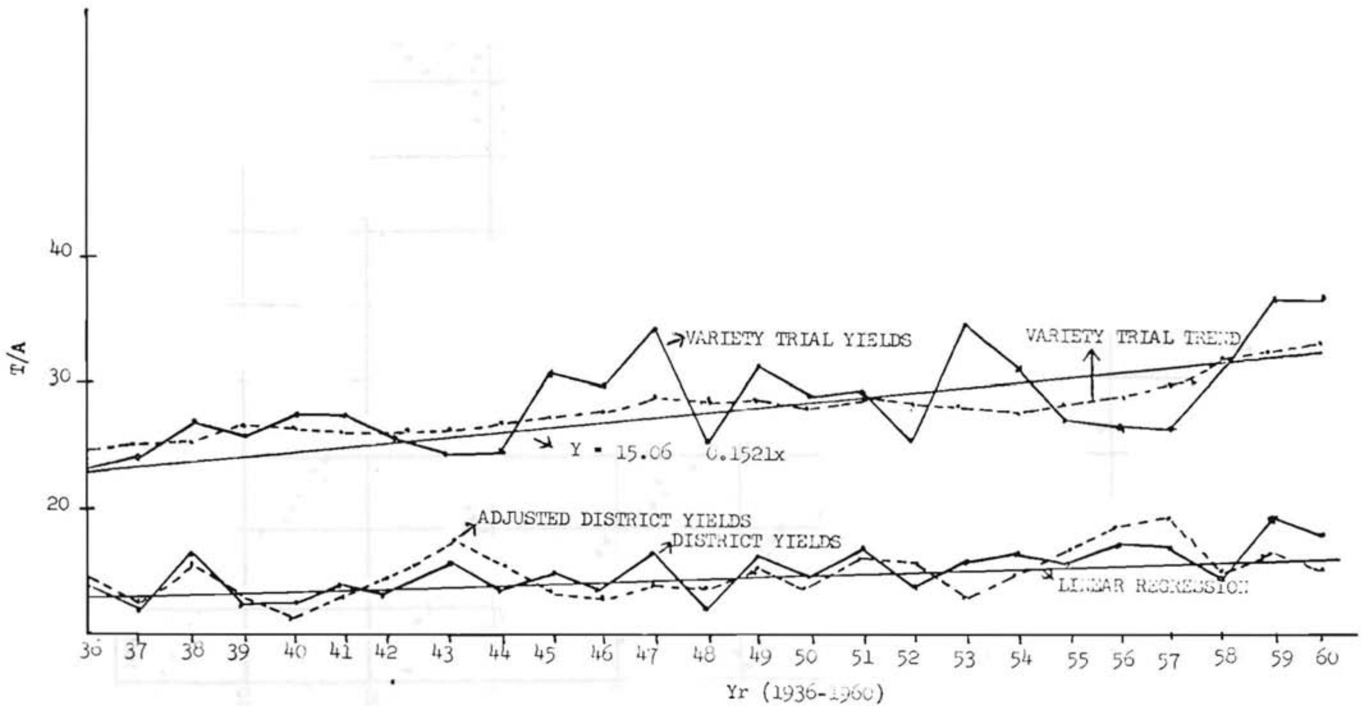

Figure 1.—Granger-Taylorsville root yield in tons per acre.

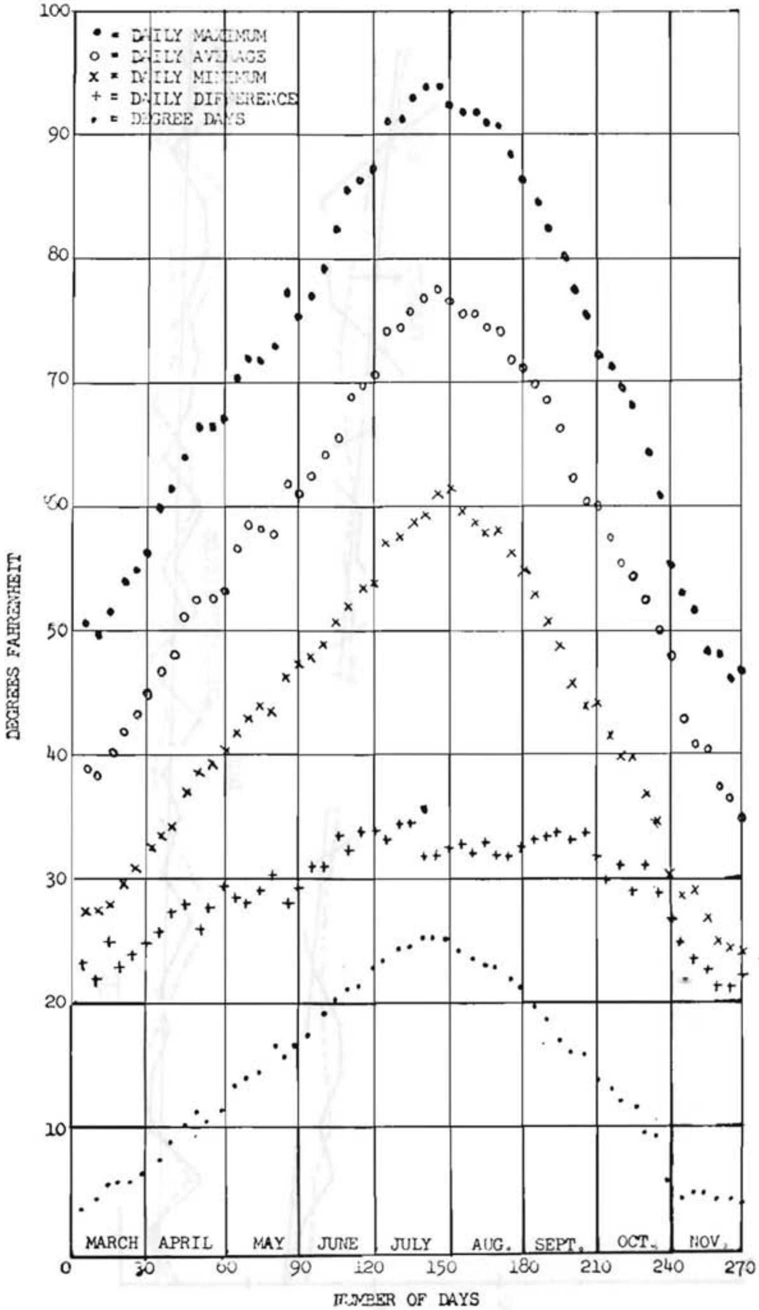

Figure 2.—Average temperature measurements for West Jordan, Utah, district, for the 54 five-day periods for 25 years (1936-1960).

Table 2.—Average yield changes caused by technology and weather, calculated by use of weather-index adjusted yields.

			For period	Average for one year
Period	(1936)	(1941)		
Actual yield	13.95	13.97	0.02	0.004
Changes caused by technology (-adjusted)	14.76	13.24	−1.52	−0.30
Changes caused by weather	−0.81	0.73	1.54	0.31
Period	(1941)	(1946)		
Actual yield	13.97	13.68	−0.29	−0.06
Changes caused by technology (-adjusted)	13.24	12.75	−0.49	−0.10
Changes caused by weather	0.73	0.93	0.20	0.04
Period	(1946)	(1951)		
Actual yield	13.68	16.41	2.73	0.55
Changes caused by technology (-adjusted)	12.75	15.96	3.21	0.64
Changes caused by weather	0.93	0.45	−0.48	−0.10
Period	(1951)	(1956)		
Actual yield	16.41	17.04	0.63	0.13
Changes caused by technology (−adjusted)	15.96	18.51	2.55	0.51
Changes caused by weather	0.45	−1.47	−1.92	−0.38
Period	(1956)	(1960)		
Actual yield	17.04	17.51	0.47	0.12
Changes caused by technology (−adjusted)	18.51	15.88	−2.63	−0.66
Changes caused by weather	−1.47	1.63	3.10	0.77
Period	(1936)	(1960)		
Actual yield	13.95	17.51	3.56	0.14
Changes caused by technology (−adjusted)	14.76	15.88	1.12	0.04
Changes caused by weather	−0.81	1.63	2.44	0.10
Period	(1936)	(1956)		
Actual yield	13.95	17.04	3.09	0.15
Changes caused by technology (−adjusted)	14.67	18.51	3.84	0.20
Changes caused by weather	−0.72	−1.47	−0.75	−0.04

for technology, with weather effect averaging near zero. This average is too low. The weather index obtained must not represent a large enough sampling, because it was based on only one trend at one site in the district.

Temperature measurements

The average of the temperature measurements used for each of the 54 five-day periods for the 25 years is shown in Figure 2 for the West Jordan district. These curves are similar and vary primarily in the range of temperatures considered. The most drastic effect was seen in the daily differences between daily maximum and minimum temperatures. Although these curves are all of the same form, one should not expect their effect to be the same on yield factors, because they are averages and do not reflect yearly differences. These curves were similar for all three sites.

Nampa's 20-year average for all measurements was lower than Nyssa's except for the daily difference, which was about 1° larger. West Jordan's 25-year averages were close to Nyssa's, except for the daily difference and the maximum, which were higher than Nyssa's.

Table 3.—Orthogonal polynomial distribution coefficients for 54 five-day periods for 25 years, West Jordan, Utah.

Year	Var. trial yield T/A	District yield	Distribution coefficients (maximum-minimum) = daily difference[1]					
			a_0	a_1	a_2	a_3	a_4	a_5
1936	23.40	13.95	78.63	0.2415-01	-0.1707-01	-0.1290-03	-0.6162-04	-0.5100-05
1937	24.32	12.38	77.76	0.4479-02	-0.2873-01	-0.4148-03	-0.3885-04	-0.7649-05
1938	26.94	16.89	73.48	0.2508-01	-0.3227-01	-0.3097-03	0.4929-04	0.1191-04
1939	26.04	12.66	80.46	0.7897-01	-0.1471-01	0.4872-03	0.6712-04	0.5612-05
1940	27.75	12.44	77.39	-0.5380-01	0.3692-01	0.9877-05	0.5854-04	-0.1107-04
1941	27.68	13.97	70.06	0.1382-02	0.2253-01	0.1709-03	0.4571-04	-0.9055-05
1942	25.28	13.96	75.44	0.6579-01	0.3156-01	-0.7819-03	0.2673-04	0.9440-05
1943	24.38	15.86	75.42	0.8202-01	-0.2312-01	-0.5446-03	0.5255-04	0.2013-04
1944	24.34	13.88	72.59	0.1832+00	-0.4086-01	-0.1426-02	0.4397-04	0.1605-04
1945	30.80	14.81	70.19	-0.1285-01	-0.3178-01	-0.5158-03	0.1392-04	0.1078-04
1946	29.39	13.68	65.70	-0.8601-01	-0.2126-01	-0.3187-03	0.4558-04	0.2094-04
1947	34.40	16.31	61.29	-0.5709-01	-0.2215-01	-0.1106-02	-0.1130-02	-0.1365-04
1948	25,15	11.76	66.55	0.5252-01	0.3002-01	-0.5179-03	-0.8071-04	-0.1098-05
1949	31.30	16.97	64.56	0.1131+00	-0.1537-01	0.7322-04	0.7623-04	0.2529-04
1950	28.90	14.38	66.56	0.8006-01	-0.2191-01	-0.9542-04	0.3510-04	-0.3867-05
1951	29.30	16.41	72.56	0.5148-01	-0.2190-01	-0.1265-02	-0.2365-04	0.5595-05
1952	25.00	13.69	73.30	0.1957+00	-0.3539-01	0.9835-03	-0.2978-03	-0.1751-04
1953	34.40	15.53	76.67	0.2512-01	-0.2499-01	-0.1063-02	0.8341-05	-0.1544-04
1954	31.00	16.20	75.85	0.6613-01	-0.2215-01	-0.1795-03	-0.3222-04	-0.1862-04
1955	27.10	15.84	73.49	0.8922-01	-0.2909-01	-0.6767-03	-0.1127-03	-0.2187-05
1956	26.40	17.04	79.62	0.5126-01	-0.2987-01	-0.1083-02	0.1879-04	0.1681-04
1957	26.00	16.94	70.30	0.9927-01	-0.3392-01	0.9888-03	0.2496-04	0.9626-05
1958	30.45	14.33	78.74	0.1976+00	0.4169-01	0.6313-03	-0.1625-03	-0.2637-04
1959	36.65	19.14	78.10	0.1392+00	-0.2013-01	0.3306-03	0.1100-03	-0.1312-04
1960	36.45	17.51	80.94	-0.3831-02	-0.4350-01	0.3839-03	0.6100-04	0.1146-05

[1] a_1 to a_5 given in computer "E" notation: 0.2415-01 = 0.2415×10^{-1} = 0.02415, etc.

Monthly totals at West Jordan

For West Jordan, a stepwise regression[7] study was made with the seven monthly totals of each temperature measurement. Among the five temperature measurements in Fig. 3, the daily differences were the only significant models (Table 4). For district yields in tons per acre, the stepwise models on daily differences gave R^2 values of 0.58 for all 7 months to 0.17 for one month only (May). The most complete model (all 7 months) gave significance for May and July at the 1% point and accounted for 57% of the variability. When only May and July data were in the model, they accounted for 46% of the variability, with both terms significant at the 1% point. Thus, variation in daily differences affected district factory yield the most at West Jordan during May and July. The study with variety trial tons per acre was different. The complete model accounted for 50% of the variability, and the months most significant with the daily difference measure were July, August, and September. These three months alone accounted for 38% of the variability (Table 4).

The results obtained by average district yields and variety trial yields can be explained only by the difference in the two averages. The district was over a broad base, and the variety trial average was over a limited base. The effect of correlations between the X_i variables also explain part of the fact that district average yield and variety trial yields differed.

Temperature distribution delta curves

The resulting delta curves, from variety trial planting data with 40 five-day periods, were not as consistent as the delta curves from the data with 54 five-day periods. Therefore, the results reported will all be on the full-season curves, with March 5th as the starting date. The regression models were corrected for length of season (based on variety trial planting dates for the district involved) and linear trend over years.

One familiar with the sugarbeet can postulate how a unit increase of 1° above average of any temperature measurement affects the yield of sugarbeet roots or sugar percentage. We know that such factors as soil fertility, soil texture, and moisture also have considerable influence on beet yield and sugar percentage. A temperature increase in the first part of the season would be expected to increase root yield. This increase in root yield could last at least until periods of highest temperature. Afterwards, the effect of a temperature increase above average would decrease the yield until sometime during September. An increase in temperature then would also increase the yield until harvest. For sugar percentage, such factors as soil texture and fertility and moisture content have a somewhat greater influence. The influence of temperature alone on yield factors would be confounded considerably. Suc-

[7]Statistical Program Package (STATPAC) by Dr. Rex L. Hurst, Utah State University Computer Center, Logan, Utah.

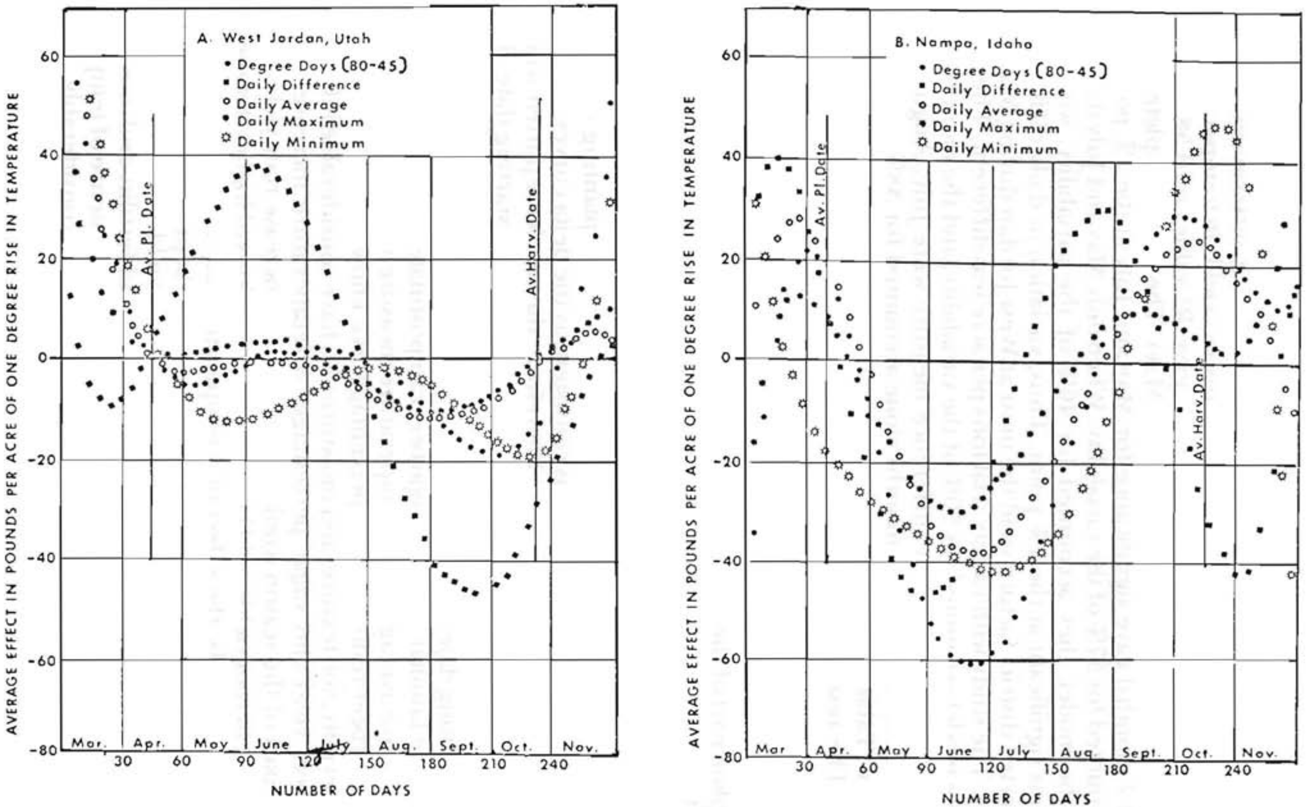

Figure 3.—Variety trial yield at two sites and all temperature measurements.

Table 4.—Stepwise linear regression models with monthly totals of daily difference between maximum and minimum temperature, West Jordan, Utah.

Source of variation	Degrees freedom	Mean square[1]	Reg. coef.	F values
		District yields tons per acre		
Total	24	3.4945	12.9040	
April	1	4.4314	0.0132	2.11
May	1	23.4627	−0.0264	11.16**
June	1	0.0739	0.0017	
July	1	20.7476	0.0320	9.87**
August	1	4.9500	−0.0149	
September	1	1.6528	−0.0060	
October	1	1.0949	0.0041	
Model	7	6.8764		3.27*
Error	17	2.1019		
R^2			0.5739	
Total	24	3.4945	13.3222	
May	1	32.2420	−0.0259	15.63**
July	1	24.0795	0.0257	11.67**
Model	2	19.2372		9.32**
Error	22	2.0632		
R^2			0.4588	
		Variety test tons per acre		
Total	24	14.9290	35.9149	
April	1	1.8552	0.0085	
May	1	26.5562	−0.0280	2.51
June	1	7.6265	0.0175	
July	1	103.9592	0.0716	9.84**
August	1	51.6519	−0.0482	4.89*
September	1	96.3797	−0.0456	9.13**
October	1	4.2981	0.0080	
Model	7	25.5411		2.42
Error	17	10.5593		
R^2			0.4990	
Total	24	14.9290	33.4347	
July	1	103.9037	0.0690	9.85**
August	1	63.6482	−0.0428	6.04*
September	1	76.9127	−0.0397	7.29*
Model	3	45.6225		4.33*
Error	21	10.5442		
R^2			0.382	

* Significant at 5%.
** Significant at 1%.
[1] Single degree of freedom mean square is that which would not have been accounted for by regression, if the variable had been omitted.

rose is expected to increase gradually throughout the season if nitrogen level decreases towards harvest. However, the optimum air temperature for sugarbeet yields and sugar percentage is questionable. In the greenhouse studies of root temperature in culture solutions. Radke and Bauer (23) established that the optimum root temperature of culture solutions for high sugar percentage was between 66 and 90°F, whereas the greenhouse air temperature was held at 72 to 75°F. At other air temperatures, these temperature ranges could change, because optimum temperatures have not been established under field conditions (14, 15, 32).

The individual terms of the orthogonal polynomial regression models can help interpret the resulting curves (Table 5). A_0 is the total temperature for the season. If yield is positively correlated with A_0, then the highest yields are associated with the highest temperature within the season. A_1 is the linear component and is proportional to the regression coefficient of a straight line. If A_1 is positively correlated to yield, higher yields are related to seasons, with the highest average temperature per 5-day period. A_2 can be fitted to a parabola that opens upward if positive and downward if negative. The amplitude of the parabola depends on the value of A_2. Positive correlation of A_2 with the yield would mean that the highest yield is associated with seasons, and the lowest temperature is in the middle of the season. A_2 would generally be negative. A_3, the cubic term, can be shown to be associated with seasons in which the curve reaches a maximum during the first half of the season and a minimum during the last half, if positively correlated with yield. The reverse is also true.

At West Jordan, the delta curves for each measurement were similar for variety test yields (Fig. 3A). The degree-day, daily average, and maximum curves were essentially the same. The amplitude of the maximum and minimum points in the daily-difference curve was larger than that of any other measurements. This is true for all sites. The daily-minimum curve differed also in the timing of maximum and minimum points; otherwise it was the same as for the other measurements. Points at the first and last of the season are not dependable, because they are regulated by the form of the curve fitted. The curve that most nearly fits our postulation is probably the daily-maximum measurement. It shows a small increase in yield shortly after the average planting date until about the second week in July, a decreasing effect until the first part of September (during the time of rapid top growth after thinning), and then a rapid increase until harvest. All other measurements follow the same form, but timing of maximum and minimum points differ somewhat.

At Nampa, the curves for each measurement were also close to the same form, but they did not follow our postulation (Fig. 3B). This difference must have been caused by soil, fertility, varietal differences, or all three. This influence was shown by Fisher (12) in his studies on wheat and rainfall. He found that the delta curves could be grouped according to fertility level in all instances. The only significant curve at Nampa is for the minimum measurement with an R^2 value of 0.68. This significance was caused mostly by the indivdual polynomial term A_4. This curve showed a decreasing effect until mid-July for a unit increase above average of minimum temperature and then a rapid increase until the latter part of October. The orthogonal polynomial

Table 5.—Regression analyses, orthogonal polynomial models, with all measurements at Nampa, Idaho, corrected for linear trend and length of season.

	Degrees freedom	District sugar Mean square[1]	District sugar Regression coefficient	District sugar F value	Variety trial sugar Mean square[1]	Variety trial sugar Regression coefficient	Variety trial sugar F value
80-45							
Total	19	0.2694	23.1637		1.2424	24.9995	
A_0	1	0.1508	0.0399	2.19	2.9622	-0.1768	9.07*
A_1	1	0.49×10^{-4}	0.0269		0.0671	0.9973	
A_2	1	0.8063	25.7520	11.72**	0.1097	9.4983	
A_3	1	1.0314	726.7796	14.99**	4.4805	1,514.8050	13.72**
A_4	1	0.0618	-582.3451		0.0022	109.7838	
A_5	1	0.4108	13,304.0000	5.97*	0.2485	10,347.3300	
Years	1	0.1244	−0.0194	1.81	3.9958	0.1100	12.23**
No. days	1	0.2235	0.0082	3.25	1.8856	0.0238	5.77*
Model	8	0.5451		7.92**	2.5015		7.65**
Error	11	0.0688		$R^2 = 0.85$	0.3267		$R^2 = 0.85$
Difference							
Total	19	0.2694	22.6136		1.2424	18.8889	
A_0	1	0.1901	0.0440	1.64	1.0748	-0.1044	1.45
A_1	1	0.0242	0.4799		0.1224	1.0787	
A_2	1	1.8647	61.5828	15.99**	1.5799	56.6860	2.13
A_3	1	0.0045	39.1116		0.3562	346.5165	
A_4	1	1.1358	2,530.0940	9.74**	1.6137	3,015.8266	2.17
A_5	1	0.0199	2,588.3160		1.9769	25,770.1600	2.66
Years	1	0.0396	−0.0102		8.6916	-0.1508	11.70**
No. days	1	0.0338	−0.0106	2.90	2.9908	0.0314	4.03
Model	8	0.4795		4.11*	1.9295		2.60*
Error	11	0.1166		R^2 0.75	0.7427		R^2 0.65
Average							
Total	19	0.2694	27.1391		1.2424	30.9950	
A_0	1	0.2284	-0.0299	2.28	1.1668	−0.0675	2.41
A^1	1	0.0003	0.3607		0.1141	−0.0656	
A^2	1	0.0605	4.5716		0.1404	0.6967	
A_3	1	1.0669	416.0558	10.66**	2.6373	654.1514	5.44*
A_4	1	0.0770	−302.9301		0.0074	−93.6459	
A_5	1	0.3851	7,710.4650	3.84	0.0670	3,006.5130	

(Continued next page)

Table 5.—Continued.

	Degrees freedom	District sugar			Variety trial sugar		
		Mean square[1]	Regression coefficient	F value	Mean square[1]	Regression coefficient	F value
Years	1	0.2017	0.0243	2.02	5.8759	−0.1314	12.13**
No. days	1	0.2126	−0.0079	2.12	1.9837	0.0242	4.09
Model	8	0.5022		5.02**	2.2848		4.72*
Error	11	0.1001		R^2 = 0.78	0.4843		R^2 = 0.77
Maximum							
Total	19	0.2694	25.3475		1.2424	40.2531	
A_0	1	0.1378	−0.0169	1.03	3.0010	0.0791	7.82*
A_1	1	0.0125	0.2181		0.1311	0.7051	
A_2	1	0.4103	8.6510	3.08	0.0037	0.8171	
A_3	1	0.6451	283.2390	4.84*	3.8147	688.7678	9.92**
A_4	1	0.4254	−629.6449	3.19	0.1201	−334.6344	
A_5	1	0.1267	−3,098.5630		1.1756	9,440.6010	3.06
Years	1	0.1452	−0.0200	1.08	5.1502	−0.1191	13.39**
No. days	1	0.1156	−0.0057		2.4087	0.0261	6.26*
Model	8	0.4566		3.42*	2.4217		6.30**
Error	11	0.1332		R^2 = 0.71	0.3847		R^2 = 0.82
Minimum							
Total	19	0.2694	20.7465		1.2424	16.4377	
A_0	1	0.0978	−0.0194	1.32	0.2375	0.0302	
A_1	1	0.0123	0.2451		0.0682	0.5780	
A_2	1	0.0125	−2.2749		0.0478	5.0371	
A_3	1	1.2589	497.4677	17.01**	1.5250	547.5226	2.93
A_4	1	0.1583	477.2237	2.14	0.8642	1,114.8860	1.66
A_5	1	0.6180	−14,499.6500	8.35*	2.5369	−29,378.1600	4.86*
Years	1	0.3244	−0.0349	4.39	7.0824	−0.1632	13.57**
No. days	1	0.1520	−0.0068	2.05	2.0978	0.0251	4.02
Model	8	0.5380		7.27**	2.2333		4.28*
Error	11	0.0740		R^2 = 0.84	0.5217		R^2 = 0.76

*Significant at 5%.

**Significant at 1%.

[1]Single degree of freedom mean square is that which would not have been accounted for by regression, if the variable had been omitted.

distribution coefficients added to the significance of the models for prediction, but not to the temperature distribution effects on yields (Table 5).

The effect of 1° rise above average temperature on district yields was close to the expected, except for the West Jordan site (Fig. 4A, B, C, D). At West Jordan, the delta curve was almost opposite to the Nampa and Nyssa delta curves, except for the minimum temperature measurement (Fig. 4D). This measure has R^2 values of 0.34 for West Jordan, 0.61 for Nampa, and 0.61 for Nyssa, the latter two being significant at the 1% level. At Nampa, the significance of the A_4 term in the model is hard to interpret, whereas at Nyssa, two terms of the model (A_O, the total temperature, and A_4) were significant. They tended to show that total temperatures throughout the season were the important factors on yield, whereas the distribution of temperature was not very significant.

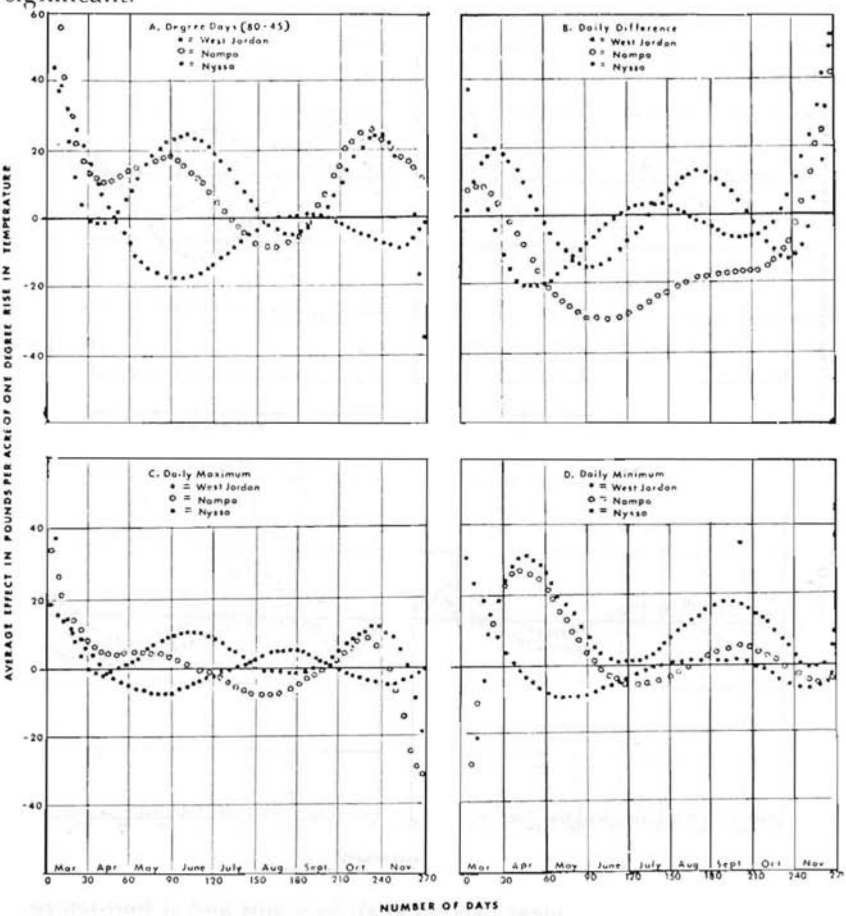

Figure 4.—District yield at all sites and four temperature measurements.

The delta curves for district sugar percentage gave the most significant R^2 values and were very consistent between sites, regardless of measure used (Fig. 5A, B, C, D). The Nampa delta curves were significant at the 1% point with the degree-day (80-45) and daily-minimum measurement and at the 5% point with the daily difference and daily maximum. R^2 values ranged from 0.85 to 0.71 (Table 5). The individual terms that were also highly significant were A_2, A_3, and A_5 for the degree-day (80-45) measure and for the daily-difference measure. A_3 and A_5 were significant for the daily-minimum temperature (Table 5). At West Jordan, it was at the 5% point for degree-day (80-45) and daily-difference measurements. The statistical significance was not as high at the other two sites.

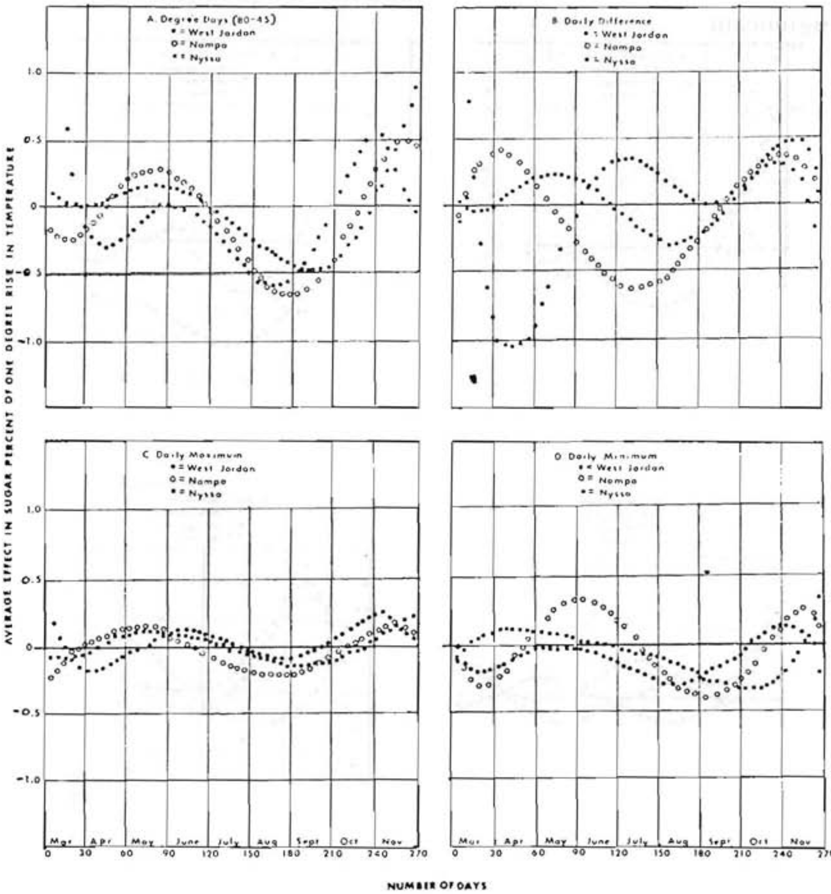

Figure 5.—District sugar percent at all locations and at four temperature measurements. Scale = percent × 10_2.

The district sugar percentage delta curves showed an increase of sugar percentage at the first of the season until mid-June for 1° increase in the average temperature measurement. They showed a decrease until the latter part of August and then an increase at the end of the season. These curves may not fit our postulation, but the significance of the models shows that fertility and soil condition were at the right level for a unit increase in the average fall temperature to increase sugar. The effect of a 1° rise in the temperature measurements is probably confounded by the curvilinear relationships and multicollinearity of the independent terms in the models (22, 23, 26).

Summary and Conclusions

In spite of some over-adjustment of district yield at West Jordan, the weather-index method would help separate yield trends caused by technology and weather. Several test sites within the districts are needed to obtain more critical indices.

The degree-days, daily-maximum, and daily-average measurements gave essentially the same results. The daily-minimum temperature had more effect on either yield of beet roots or sugar percentage than any of the other measurements.

The daily-difference measure, a function of daily maximum and minimum temperatures, needs some form of transformation, in order to obtain a better fit to actual yield curves. Results show that this measurement does have promise as a temperature measure on field crops.

Orthogonal polynomial distribution coefficients of 54 five-day periods for each year were used for 20 and 25 years to determine the effect of a unit increase in temperature-above-average on sugarbeet root yields and sugar percentage. Results showed that sugar percentage depended more significantly on temperature distribution than on root yield. Both methods need study of longer times and sites with and without irrigation for critical results.

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