Effects of Weather Variables on the Yields of Sugar Beets Grown in an Irrigated Rotation for Fifty Years

S. DUBETZ and M. OOSTERVELD[1]

Received for publication August 26, 1976

Introduction

Forecasting of crop yields can be useful for optimizing management of a commodity and for providing a lead time to make necessary adjustments. Several workers have studied the relationships between sugar beet yields and various climatic factors. Kel'chevskaya (6)[2] found that yields of sugar beets depend primarily on heat and moisture sufficiency during the vegetative period. Because southern Alberta is semiarid, all sugar beets are grown under irrigation, and hence moisture insufficiency would not be expected to be a major factor. Swift and Cleland (10) found that sugar beet yields were closely related to mean annual temperature but that there was less association with annual precipitation. Brummer (2) reported that temperature was the most important climatic factor that affected sugar beet yields. Scott *et al.* (8) found that beet yields closely correlated with the amount of solar energy intercepted by the leaf canopy.

Relatively long-term yield and weather data are required to establish meaningful relationships that could be useful for prediction in a particular area. A rotational experiment at the Lethbridge Research Station (lat. 49°42'N, long. 112°47'W) has included sugar beets in the cropping sequence since 1923 and thus provides half a century of such data. This paper presents the yield-weather relationships for sugar beets in southern Alberta and establishes predictions that may be useful to the industry.

Materials and Methods

A 10-year rotation, designated as Rotation "U," was established on irrigated land at the Lethbridge Research Station in 1910. The details of the rotational experiment were described by Dubetz (3). Sugar beets, one of the five crops grown in the rotation, were substituted for potatoes in 1923 and have been grown since. Half of the beet plot receives no fertilizer and the other half receives 100 lb/acre ammonium phosphate (11-48-0). Sugar beet yield data from the unfertilized plots were compiled from 1923 to 1974, and from the fertilized plots from 1933 to 1974.

---

[1]Soil Scientists, Research Station, Agriculture Canada, Lethbridge, Alberta, Canada T1J 4B1.

[2]Numbers in parentheses refer to literature cited.

Weather data have been recorded at the Station since 1902. The relationship between yield and various climatic variables was studied to see which variables constrain yields the most in this region. The independent variables studied were:

(a) Time (advancing years);
(b) Mean daily temperature (monthly and seasonal);
(c) Total degree days (base 42°F or 6°C) from mean planting date to mean harvest date;
(d) Mean daily hours of bright sunshine from May 1 to August 31;
(e) Total precipitation for May and June;
(f) Total precipitation 7 days before and 7 days after planting;
(g) Planting date;
(h) Number of frost-free days;
(i) Number of days with temperatures above 28°F or -2.2°C.

Multiple regression analyses of sugar beet yields between these variables were performed. The forward selection procedure was used to insert the independent variables one at a time into the regression equation. A 't-test' was performed for the variable most recently entered to indicate whether that variable had accounted for a significant amount of the variation over that removed by the previous variables in the regression.

To forecast yields several years in advance, additional calculations between yield and time were performed. First, the time trend was analyzed, using the linear and curvilinear regression methods, with time as the independent variable. After the trend factors were accounted for, a detailed time-series analysis was performed, using the method of Jenkins and Watts (5). The homogeneity of the variance with time was tested, by decades, using Bartlett's test (9). Then, the serial correlations and variance spectrum were computed (5), to establish whether there was any cycling in the yield data. Finally, a complete statistical forecasting model was assembled that gave the mean yields and the probabilities associated with a range of yields.

Results and Discussion

A summary of some of the long-term (1902-1975) weather data for southern Alberta appears in Table 1.

The multiple stepwise regression analysis of the data showed that temperature and time were the only factors that explained significant amounts of the variability in yield. The other climatic factors did not account for a significant amount of the residual variability. However, the number of hours of bright sunshine and temperature was significantly correlated ($r = 0.48$).

The regression of annual yields on advancing years (time) is shown in Figure 1. The regression coefficients and their levels of significance for the unfertilized and fertilized plots were 0.12 ton/acre/year ($P < 0.01$) and 0.10 ton/acre/year ($P < 0.025$), respectively. Because these trends were

Table 1.—Summary of weather data (1902-1975 mean) for Lethbridge, Alberta.

Month	Precipitation (in.)	Mean temperature[1] (°F)	Sunshine[2] (hr)
January	0.75	15.5	97.5
February	0.74	19.6	123.1
March	0.93	28.0	164.6
April	1.28	41.4	206.5
May	2.15	50.9	259.0
June	3.01	58.5	278.0
July	1.65	64.5	344.0
August	1.49	62.5	301.9
September	1.60	53.4	210.7
October	0.90	44.5	171.0
November	0.74	30.7	112.7
December	0.76	21.5	93.5
Total	16.00		2,362.4
Mean		40.9	

[1]The number of frost-free days and crop days (above 28°F) was 117 and 140.
[2]67-year average.

significant, the regression line with time was used as the basis for further analysis.

Bartlett's test (9) indicated no significant differences among the variances computed by decades; hence, further computations based on a homogeneous variance were valid. Serial correlation and spectral analysis indicated that there was some minor cycling in the variance. However, none of the cycles explained enough of the variance to be useful for forecasting. Deviations were not significantly skewed from the trend line.

It was decided from the preceding analyses to base forecasts on a projection of the regression line and to assign probabilities to a range of yields

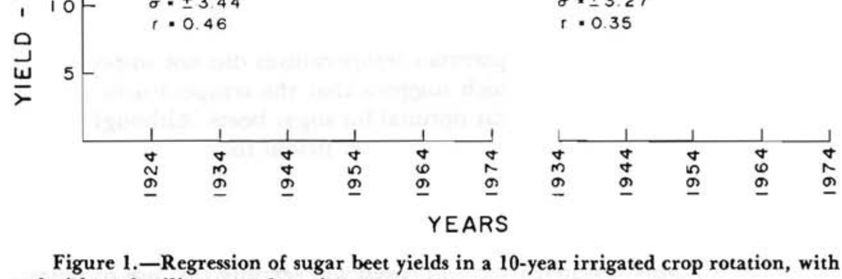

Figure 1.—Regression of sugar beet yields in a 10-year irrigated crop rotation, with and without fertilizer, on advancing years.

based on the normal distribution. The equation used for forecasting yields was:

$$Y = a + b \times year + \sigma \times \epsilon$$

where Y = yield in tons per acre that corresponds to a specific year; a = intercept; b = slope; year = calendar year; σ = standard deviation of the regression line; and ϵ = a standardized variate with a mean of 0 and a standard deviation of 1.

The equation was used to predict the yield for 1975 at various probability levels, and these are shown in Table 2.

The best forecast yields for 1975, using this equation, were 19.67 and 21.84 tons/acre for the unfertilized and fertilized plots in this rotation. The actual yields were 19.26 and 22.30 tons/acre, respectively, from the two plots. The above predictions were calculated without adjustment for any of the weather parameters. The calculated regression coefficients on temperature after the time trend was removed for the unfertilized and fertilized plots were 0.72 ($P < 0.025$) and 1.02 ($P < 0.005$) ton/acre/°F.

Table 2.—The probability that a given yield would not be equaled or exceeded in 1975.

Probability level (%)	Yield (tons/acre)		Expression
	Unfertilized	Fertilized	
90	24.14	26.09	Y (year) + 1.30σ
75	22.01	24.06	Y (year) + 0.68σ
50	19.67	21.84	Y (year)
25	17.33	19.62	Y (year) - 0.68σ
10	15.20	17.59	Y (year) - 1.30σ

An attempt to predict the mean daily temperature for a growing season from the mean daily temperatures of previous months (October-December, October-March, and October-May) proved unsuccessful because there was no dependence. The earliest that an improved forecast using temperature data from previous months can be made is after the crop is planted. The yield equations and standard deviations that were calculated by months after the crop was planted are shown in Table 3.

Incorporation of May or May plus June temperature data into the prediction equation after the crop was planted resulted in a significant reduction in the magnitude of the standard deviation of the forecast. Addition of July, August, and September temperatures did not improve the yield forecasts significantly, which suggests that the temperatures during these months in this area are near optimal for sugar beets. Although it was not statistically significant, the regression coefficient for the July temperature variable was negative. This suggests that perhaps the mean July temperature might be slightly high for optimal production.

The significant and positive regression coefficient of 0.1 ton/acre/year probably resulted from improved soil fertility (3), use of better adapted varieties, and improved management that occurred with time.

Table 3.—Yield equations and standard deviations (σ) calculated for various times.

Forecast date	Plot	Yield equation (tons/acre)	σ (tons/acre)
Before planting	Unfertilized	Y = -211.40 + 0.117 x year	3.44
	Fertilized	Y = -173.20 + 0.099 x year	3.27
June 1	Unfertilized	Y = -251.70 + 0.126 x year + 0.448 TMay	3.24
	Fertilized	Y = -240.61 + 0.118 x year + 0.597 TMay	2.85
July 1	Unfertilized	Y = -246.30 + 0.114 x year + 0.426 TMay + 0.322 TJune	3.16
	Fertilized	Y = -211.60 + 0.091 x year + 0.545 TMay + 0.424 TJune	2.65

These results agree with those of others (2, 5, 6, 9), who found that temperature was the most important climatic factor affecting sugar beet yields. Swift and Cleland (9) used mean temperatures of several months that preceded the planting date in their forecast of yields. However, we found no discernible dependence of growing season temperatures on temperatures of months that preceded the month of planting. After the crop was planted, incorporation of May or May plus June temperatures into the prediction equation reduced the size of the standard deviation of the forecast. The standard deviation would probably be further reduced if an average yield for several sites is to be predicted (6).

Because rainfall was not significantly related with yield, irrigation as practiced in this rotation apparently provided adequate moisture for sugar beets. Yields were also unaffected by the amount of precipitation that occurred immediately before and after planting. This may be explained in part by the fact that fall irrigation was usually practiced, the soil has a relatively fine texture, and the rate of seeding was usually sufficiently high to ensure a good stand.

The average planting date of sugar beets on this rotation was April 29 ± 11 days, and yields were not significantly affected by this variable. Anderson *et al.* (1) reported that sugar beet yields at Lethbridge were not significantly affected when the crop was planted between April 20 and May 10.

Summary

An equation for predicting sugar beet yields based on regression analysis of 50 years of yield data from one site in southern Alberta is presented. Under irrigation, temperature was found to be the only climatic variable that significantly affected sugar beet yields. Temperatures during a growing season were not dependent on those of previous months. Incorporation of May and June temperatures of the current year into the equation reduced the size of the standard deviation of the forecast. The precision of the prediction would probably be further improved if data from additional sites were incorporated.

Literature Cited

(1) ANDERSON, D. T., S. DUBETZ, and G. C. RUSSELL. 1958. Studies on transplanting sugar beets in southern Alberta. Proc. Am. Soc. Sugar Beet Technol. 10: 150-155.

(2) BRUMMER, V. 1961. On the relations between sugar beet yields and certain climatic factors in Finland. A statistical study and some cultivation technique applications [in Finnish]. Suom. Maataloust. Seur. Julk. 98: 1-180.

(3) DUBETZ, S. 1954. The fertility balance in a ten-year sugar beet rotation after forty-two years of cropping. Proc. Am. Soc. Sugar Beet Technol. 8: 81-85.

(4) HILL, K. W. 1951. Effects of forty years of cropping under irrigation. Sci. Agr. 31: 349-357.

(5) JENKINS, G. M. and D. G. WATTS. 1968. Spectral analysis and its application. Holden-Day, San Francisco, Calif. 525 pp.

(6) KEL'CHEVSKAYA, L. S. 1965. Complex estimate of the heat and moisture sufficiency of the vegetative period of sugar beets. Treatises Cent. Forecasting Inst. 1965(140): 97-104. (Transl. from Russian.)

(7) KRUMBIEGEL, DIETMAR. 1972. The effect of meteorological conditions on the level and stability of crop yields [German, English summary]. Arch. Acker-Pflanzenbau Bodenkd. 16: 771-777.

(8) SCOTT, R. K., S. D. ENGLISH, D. W. WOOD, and M. H. UNSWORTH. 1973. The yield of sugar beet in relation to weather and length of growing season. J. Agric. Sci. 81: 339-347.

(9) STEEL, R. G. D. and J. H. TORRIE. 1960. Principles and procedures of statistics. McGraw-Hill Book Company, Inc., Toronto. 481 pp.

(10) SWIFT, EDWARD L. and FRANK A. CLELAND. 1946. The effect of climate on sugar beet yields in western Montana. Proc. Am. Soc. Sugar Beet Technol. 4: 135-140.