Relationship of Climate and Sucrose Content of Sugarbeet Roots

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ABSTRACT

The sucrose content of sugarbeet (Beta vulgaris L.) roots measured on a fresh weight basis varies widely from year to year in an area and between areas over a period of time. The objective of this study was to determine the effect of variations in climate on sucrose content of sugarbeet roots.

Weather factors, average minimum and maximum temperatures and precipitation for the months of May through October as well as date of the first killing frost, were evaluated for their effect on sucrose content during a ten year period from 1970 through 1979 in eight areas of the Western Great Plains. August minimum temperatures and date of first -4.4°C temperature in the fall were the most important factors affecting differences in sucrose content between years in an area. September minimum temperatures and precipitation as well as October temperatures and precipitation also affect sucrose content. The best combination of factors for all areas--August minimum temperatures, date of first -4.4° C, September minimum temperature, and October precipitation--accounted for 67 to 94% of the yearly variation in sucrose content in the eight areas.

Minimum August temperatures were highly correlated with differences in average sucrose contents between areas (r = 0.93). The differences in sucrose content between areas are established by September 1 and remain constant until harvest in mid-October. The other factors affecting yearly differences in sucrose content had little effect on differences between the ten year average sugar contents of the eight areas.

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INTRODUCTION

Sugarbeets (Beta vulgaris L.) grown in the Great Plains of the United States are harvested in October when sucrose content is highest before beets are frozen in the ground. The sucrose content of sugarbeet roots expressed on a fresh weight basis increases in an almost linear manner during the growing season (2, 11, 17). The percent dry matter also increases with maturity (2) so that the sucrose percent of the root dry matter increases most during June and July with slower increases during August, September, and October (11, 19). Thus, the rapid increase in percent sucrose (fresh weight) measured late in the growing season is a function of both accumulation of sucrose and reduction in water content. Unless otherwise designated, sucrose content in this paper is expressed on a fresh weight basis.

Studies conducted in pots under controlled conditions (4, 12, 14, 15, 16) showed that temperatures late in the season were responsible for the rapid increase in sucrose content of the sugar-beet roots during that time. Low day temperatures were associated with higher sucrose contents (12), however, night temperatures may be more important than day temperatures in producing high sucrose contents (14, 16). Sucrose percent decreased in a linear manner from 4° C to 30° C night temperatures (14). Beets grown under constant temperatures had higher sucrose concentrations at low temperatures, 17° C, than at higher temperatures, 24 and 31° C (10). Bergen (2), on the other hand, showed no relationship between low temperatures late in the growing season and sucrose content in beets grown in Alberta, Canada.

Available soil nitrogen has a major effect on the sucrose content of sugarbeets at harvest (1, 18). A nitrogen deficiency four to six weeks prior to harvest resulted in higher sucrose concentrations at harvest than with ample nitrogen (4, 13, 14), however, low night temperatures improved sucrose content under both ample and depleted nitrogen conditions. Sugarbeet growers attempt to manage nitrogen so that it is depleted several weeks prior to harvest. Irrigation is also stopped two or three weeks prior to harvest, so the water content of the root decreases a resulting increase in sucrose content. The decreasing water content of the root may account for part of the rapid increase in sucrose content during September and October.

Final sucrose content is also affected by the date of the first killing frost. Sucrose accumulation often ceases after the first temperature below -4 to -5°C even though leaves continue to have a normal appearance (personal observations). Peto (7, 8) reported a strong relationship between date of first -3.3° C or less temperatures and sucrose content in beets grown in British Columbia. A severe freeze which defoliates plants may cause a reduction in sugar content.

The sucrose content at harvest is, no doubt, influenced by climatic as well as cultural practices. The objectives of this study were to identify climatic factors associated with a year to year variability in sucrose content and those associated with variability in sucrose content between different areas of the Western Great Plains.

METHODS AND MATERIALS

The sucrose contents of harvested sugarbeets grown in areas given in Table 1 were taken from records of the Great Western Sugar Company for a ten year period from 1970 through 1979. The sucrose contents expressed on a fresh weight basis were determined on washed and top tared beets (5). One 10 to 12 kg sample was analyzed for every 15 to 20 metric tons of sugarbeet roots harvested. Preharvest samples were taken from three-meter sections of row selected at random from every 36 ha of sugarbeets during the last week of August. The weather data was taken from Climatological Data (6) for a centrally located station in each area. The weather data included average minimum temperature, average maximum temperature, and total precipitation for the months of May through October for each year from 1970 through 1979. Date of the first -4.4°C in the fall was also recorded.

The data were analyzed with simple correlation and multiple linear regression analysis (9).

Table 1. Central locations and sucrose contents of sugarbeet roots grown in eight areas--1970 to 1979.

Area[a]	Latitude N		Longitude W		Altitude	Sucrose Contents[b]	
						Preharvest[c]	Harvest[d]
	°	'	°	'	m	------% Fresh Wt.-----	
Goodland, KS	39	22	101	42	1113	11.51±0.71	15.32±0.84
Holyoke, CO	40	35	102	18	1138	12.50±0.54	16.50±0.77
Sterling, CO	40	37	103	12	1201	11.74±0.67	15.79±0.65
Ft. Collins, CO	40	35	105	5	1526	12.87±0.82	16.75±0.83
Mitchell, NE	41	57	103	41	1244	12.27±0.46	16.55±0.65
Alliance, NE	42	8	102	57	1226	12.55±0.45	16.81±0.47
Huntley, MT	45	55	108	15	912	13.11±0.73	16.86±0.61
Lovell, WY	45	50	108	24	1170	13.01±0.79	17.16±0.73

[a]Location of weather station in area.

[b]Data expressed as mean ± standard deviation.

[c]September 1.

[d]October.

RESULTS AND DISCUSSION

The sucrose content of sugarbeets grown in the Western Great Plains differs widely in an area from year to year and between areas over a period of time (Table 1). The ten year average sucrose contents at harvest ranged from 15.32% at Goodland to 17.16% at Lovell with a range of sucrose contents between. The standard deviations show the yearly variability in sugar content of an area. The differences in sucrose contents between areas are established by September 1, correlation (r) between preharvest and harvest sucrose contents = 0.95. The average increase in percent sucrose from September 1 to harvest in October in quite constant between areas, 3.75 to 4.28 change in percent sucrose. The differences in sucrose contents between areas appear to be caused by factors exerting their influence prior to September 1. The strong association of latitude and altitude with sucrose content (multiple R = 0.90) gives evidence that climatic factors have a significant effect on sucrose content (multiple correlation of latitudes and altitude with August minimum temperatures = 0.97).

The simple correlations of temperature factors, average monthly maximum and minimum temperatures, with sucrose content in each area for the 10 year period are given in Table 2. May,

Table 2. Coefficient correlation (r) of temperature parameters with harvest sucrose content of sugarbeets.

Location	Temperature Parameters												
	May		June		July		August		September		October		Date First
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.	-4.4°C
	Correlation (r)												
Goodland	-0.01	-0.32	-0.07	-0.01	-0.02	-0.25	-0.18	-0.40	-0.44	-0.79**	0.38	0.51	0.80**
Holyoke	0.14	0.09	-0.34	0.08	0.08	-0.28	-0.36	-0.47	0.28	-0.25	0.49	0.45	0.62
Sterling	-0.06	-0.23	-0.04	-0.25	-0.25	-0.23	-0.38	-0.54	-0.41	-0.40	0.22	0.53	0.80**
Ft. Collins	0.28	-0.02	-0.02	-0.15	0.17	-0.04	-0.36	-0.76*	0.18	-0.27	0.56	0.69*	0.89**
Mitchell	-0.29	-0.09	0.09	0.21	-0.13	-0.23	-0.42	-0.55	-0.19	-0.28	0.46	0.63	0.74*
Alliance	-0.31	-0.11	-0.27	-0.47	-0.07	-0.24	-0.40	-0.59	-0.18	-0.64*	0.46	0.38	0.22
Huntley	-0.59	-0.61	0.01	-0.47	0.52	0.45	-0.71*	-0.57	0.51	-0.16	0.64*	0.16	0.20
Lovell	-0.24	-0.36	0.07	0.39	0.53	0.41	-0.84**	-0.61	0.64*	0.05	0.78**	0.50	0.28
Mean	-0.14	-0.21	-0.07	-0.05	0.10	-0.05	-0.46	-0.56	0.05	-0.34	0.50	0.48	0.57

*,** Correlation coefficient significant at 0.05 and 0.01 levels of probability, respectively.

June, and July temperatures had no consistent effect upon final sucrose content. August temperatures were negatively correlated with yearly variations in sucrose content at all locations. August minimum temperatures for the most part had better correlations with sucrose content that August maximum temperatures. These data suggest that lower than average August temperatures encourage sucrose accumulation. September minimum temperatures were, likewise, negatively associated with sugar content with exception of Huntley and Lovell where they had minimal effect. The positive correlation of September maximum temperatures with sucrose content at Huntley and Lovell suggests that warm September days in these northern areas may encourage sucrose accumulation. October temperatures were positively correlated with sucrose content at all locations; warm temperatures in October encouraged sugar accumulation.

The date of the first -4.4° C was positively correlated with sucrose content at all locations. The date of the first -4.4° C had less effect on sucrose content in the northern, high sugar areas, than other areas because sugar had often reached optimal levels before the killing frost.

Precipitation during September and October had a negative effect on sucrose content in all areas. Irrigation masks the effect of precipitation during the remainder of the growing season. The weather factors with average correlation coefficients better than ± 0.30 were used in multiple regression analysis to determine the best combination of factors to explain yearly variations in sugar content in each area. Factors include date of first -4.4° C, August minimum temperatures, October minimum and maximum temperatures, September minimum temperatures, and September and October precipitation in order of importance.

Date of first -4.4° C, minimum August temperatures, and maximum October temperatures had the highest simple correlation with sucrose content. Multiple correlations of combinations of these factors with sucrose content in each area is given in Table 4. Two weather parameter equations with August minimum temperatures and date of first -4.4° C gave the best multiple correlation values with R being significant in accounting for

Table 3. Coefficient correlation (r) of average montly precipitation with harvest sucrose content of sugarbeets.

	Precipitation Parameter					
Location	May ppt	June ppt	July ppt	August ppt	September ppt	October ppt
	Correlation (r)					
Goodland	−0.10	−0.09	0.73*	−0.45	−0.25	−0.28
Holyoke	−0.48	0.74*	−0.01	−0.11	−0.41	−0.22
Sterling	−0.43	−0.03	−0.46	0.38	−0.12	−0 18
Ft. Collins	−0.21	0.33	−0.15	0.12	−0.62	−0.40
Mitchell	−0.08	0.10	0.21	0.50	−0.32	−0.60
Alliance	−0.11	0.05	−0.46	0.13	−0.07	−0.43
Huntley	0.15	0.10	0.31	0.25	−0.44	−0.09
Lovell	−0.46	0.74*	0.77**	−0.01	−0.33	−0.20
Mean	−0.22	0.24	0.12	0.10	−0.32	−0.30

*,** Correlation coefficient significant at 0.05 and 0.01 levels of probability, respectively.

yearly variation in seven of eight areas. Combinations of August minimum temperatures and date of first −4.4° C gave significant correlations in only three areas each. Much variability in sucrose content is not accounted for with only two factors and so multiple regression analysis was carried out using four weather parameters (Table 5).

The best combination of factors—August minimum temperatures, date of first 4.4°C, September minimum temperatures, and

Table 4. Multiple coefficient of correlation (R) between two weather variables and sucrose content.

	Weather Parameters		
Area	August Min. Temp. Date First −4.4°C	August Min. Temp. October Max. Temp.	October Max. Temp. Date First −4.4°C
	Coefficient of Multiple Correlation (R)		
Goodland	0.79*	0.54	0.81*
Holyoke	0.58	0.52	0.63
Sterling	0.73*	0.54	0.72
Ft. Collins	0.94**	0.77*	0.93**
Mitchell	0.75*	0.57	0.64
Alliance	0.76*	0.66	0.62
Huntley	0.73*	0.79*	0.67
Lovell	0.73*	0.81*	0.79*
Mean	0.75	0.65	0.73

*,** Multiple correlation coefficient (R) significant at 0.05 and 0.01 levels of probability, respectively.

Table 5. Multiple coefficient of correlation (R) between four weather parameters and sucrose content.

	Weather Parameters			
	August Min. Temp. Date First -4.4°C September Min. Temp. October Max. Temp.	August Min. Temp. Date First -4.4°C September Min. Temp. October Precipitation	August Min. Temp. Date First -4.4°C September Precipitation October Precipitation	August Min. Temp. Date First -4.4°C September Precipitation October Max. Temp.
	Coefficient of Multiple Correlation (R)			
Goodland	0.94[a]*	0.92*	0.92*	0.89
Holyoke	0.66	0.92*	0.93*	0.96[a]**
Sterling	0.78	0.82	0.91[a]*	0.85
Ft. Collins	0.94*	0.95**	0.97**	0.97**
Mitchell	0.78	0.93[a]*	0.85	0.86
Alliance	0.88	0.97[a]**	0.84	0.82
Huntley	0.85	0.85	0.86	0.90[a]*
Lovell	0.93*	0.92*	0.81	0.90*
Mean	0.85	0.91	0.89	0.89

[a]Best combination of factors for area. The best combination of factors for Ft. Collins included August Min., Date of First -4.4°C, September precipitation, and October Min. (R = 0.99**). The best combination of factors for Lovell was August Min., Date First -4.4°C, September Max., and October Max. (R = 0.98**).

*,**Significant at 0.05 and 0.01 levels of probability, respectively.

October precipitation--gave significant correlations with sucrose content in six of the eight areas. These factors accounted for 67% of the yearly variability in sucrose content at Sterling and Huntley to over 94% of the variability at Alliance with an average of 83%. In some areas, September precipitation or September maximum temperatures gave slightly better correlations when substituted for September minimum temperatures. Multiple correlations using October maximum or minimum temperatures were better in some areas than October precipitation. The minimum and maximum temperatures for a given month were often positively correlated with each other while precipitation, especially during September and October, was negatively correlated with temperatures. These inter-relationships confounded the effects of average maximum, average minimum and precipitation effects in a given month.

The area averages for each parameter used in multiple correlation analysis are given in Table 6. The temperature parameters decreased with increasing latitude and altitude. The average date of the first -4.4° C also decreased with increasing latitude and altitude. During most years, the date of the first -4.4° C occurred about the same time in all areas when a major cold front passed through the whole Western Great Plains region. Occasionally, a weak front drops temperatures of the northern areas below -4.4° C without affecting the central areas. The yearly variability of temperature parameters was similar in the different areas, that is some areas did not have more extreme yearly weather fluctuations than others. The precipitation parameters had higher yearly fluctuations than temperature patterns.

Differences in August minimum temperatures between areas were highly correlated with differences in sucrose content between those areas (r = 0.93, Table 7). Low sugar contents occurred in areas with August minimum averaging above 14° C. The low sugar areas, Goodland and Sterling, had average sucrose contents (16.5%) only in years with August minimum temperatures of 13°C or less. The medium sucrose areas, Holyoke, Ft. Collins, and Mitchell, had low sucrose contents (<16%) in years when August minimums averaged over 14° C and high sucrose contents (> 17%) when August minimum temperatures were less than

Table 6. Mean and standard deviation of weather parameters related to sucrose content in eight areas.

	Weather Parameter							
	August	September			October			Date[a]
Area	Minimum Temp.	Minimum Temp.	Maximum Temp.	Precipitation	Maximum Temp.	Minimum Temp.	Precipitation	First −4.4°C
	°C	°C	°C	cm	°C	°C	cm	
Goodland	15.0±1.1[b]	9.1±1.0	25.0±2.4	3.7±4.3	18.9±2.3	2.7±1.3	1.7±1.2	52.6±9.6
Holyoke	13.1±1.2	7.8±1.3	25.4±2.1	3.2±2.6	19.6±1.7	1.8±1.8	1.5±1.0	50.4±8.6
Sterling	14.1±0.8	7.2±1.4	24.4±2.2	3.2±3.1	18.8±2.2	0.3±1.3	1.4±1.2	51.9±9.4
Ft. Collins	12.6±1.3	7.6±1.3	23.0±2.0	3.5±2.8	17.6±1.9	1.8±1.3	1.6±0.9	49.0±12.2
Mitchell	12.6±1.1	5.9±1.3	23.1±2.3	3.2±3.0	18.0±2.4	0.3±1.4	1.3±1.0	46.4±12.0
Alliance	12.3±0.9	5.8±1.3	23.1±2.3	4.1±4.0	17.1±2.4	0.0±0.9	2.2±1.9	37.5±6.9
Huntley	10.8±1.4	4.8±1.2	23.7±2.2	2.4±2.3	17.4±1.7	-0.5±0.7	4.3±2.1	44.8±11.8
Lovell	10.9±0.9	3.8±1.6	22.3±2.6	2.3±2.1	15.8±2.4	-1.6±1.4	1.7±1.3	43.9±13.9

[a] September 1 = 1.

[b] Mean ± Standard Deviation.

12° C. Correlation of September minimum temperatures with sucrose content (r = 0.80) was not as good as August minimums. The minimum temperatures at Huntley and Lovell may be colder than needed for optimal sucrose production in the latter part of September. Correlation of average August and September minimum temperatures with sucrose content in the eight areas was not as great as August minimum temperatures alone. On the other hand, the average number of nights with minimum temperature less less than 12.8° C was highly correlated (r = 0.96) with sucrose content in the eight areas.

Table 7. Relationship between average weather parameter and sucrose contents of eight sugarbeet growing areas.

Parameter	Correlation Coefficient
	------------r------------
Average August Minimum Temperature	-0.93***
Average September Minimum Temperature	-0.80*
Average September Maximum Temperature	-0.71*
Average October Minimum Temperature	-0.74*
Average October Maximum Temperature	-0.72*
Average August-September Minimum Temperature	-0.87**
No. Nights Minimum Temperature less than 12.8°C in August-September	0.96***
Date First -4.4°C	-0.72*
September Precipitation	-0.49
October Precipitation	0.29

*,**,*** Correlation Coefficient significant at 0.05, 0.01, and 0.001 probability levels, respectively.

October temperatures as well as date of first -4.4° C were negatively correlated with sucrose content between areas. These relationships do not explain differences in sucrose content between areas since they are opposite from those obtained with yearly variability in an area where higher than average October temperatures or later dates of first -4.4° C gave higher sucrose content. Precipitation in September and October had no significant effect on differences in sucrose content between areas.

CONCLUSIONS

Differences in sucrose content of sugarbeet roots occur between individual growers in a given area and year, between years in an area, and between areas over a period of time.

Differences in sucrose content between individual growers are caused primarily by available nitrogen (1, 18). Nitrogen available for sugarbeet usage is affected by residual nitrogen, rate of nitrogen application, as well as cultural practices such as date of planting and irrigation which affect nitrogen utilization. Hail significantly reduces sucrose content if defoliation of tops approached 100% (3). Hail is not recorded in Climatological Data and so was not investigated in this weather study.

Yearly differences in sucrose content in an area are caused primarily by average minimum August temperatures and date of first $-4.4^{\circ}C$ in the fall. Low August temperatures are associated with high sucrose contents. Sucrose formation normally stops with the first $-4.4^{\circ}C$ (7, 8, and personal observations). Photosynthetic or transport mechanisms are apparently damaged sufficiently at that temperature to stop sucrose accumulation even though leaves remain green. Lower temperatures, less than $-8^{\circ}C$, often kill the leaves resulting in a regrowth of leaves and petioles with a subsequent reduction in sucrose content. Date of the first $-4.4^{\circ}C$ has less effect on sucrose content in the northern, high sugar areas than in the central areas of the western great plains, no doubt because optimal sugar has already accumulated in beets of the northern area by that time. September minimum temperatures (lower temperatures = high sugar), October temperatures (high temperature = high sugar), and September and October precipitation (low precipitation = high sugar) can affect the sucrose content of harvested beets. Variation in September minimum temperatures are less important in the northern than the central areas as temperatures are always low enough in the northern areas during September for optimal sugar production. Warmer than average day temperatures may be beneficial in the northern areas in September and in all areas in October. Sucrose continues to accumulate until the first $-4.4^{\circ}C$.

Heavy precipitation during the latter part of September and October increases the water content of the root resulting in a lower sucrose percentage. Hail defoliating plants over a large portion of the area can significantly reduce the average sucrose content for the area.

August minimum temperature is the most important factor affecting differences in sucrose content between areas. Differences in sucrose content between areas is established by September 1. September minimum temperatures are negatively correlated with sucrose content (r = 0.80) but this may be caused by the strong correlation (r = 0.93) between August and September minimums. Temperature differences between areas, no doubt, have a direct effect on sucrose accumulation by affecting the physiology of the plant. Temperature differences between areas affect sucrose content indirectly through the nitrogen availability caused by different rates of nitrification, alternate crops grown, and cultural practices used. Date of first -4.4° C, September and October precipitation, and October temperatures contribute little to differences in sucrose content between areas.

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