A Comparison of Forced Ventilation and Natural Convection as Means of Cooling Sugarbeet Storage Piles in Several Geographic Locations *

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INTRODUCTION

Forced ventilation as a means of controlling the temperature in sugarbeet storage piles has been studied extensively, particularly in the 1940's and 1950's. Quamme (7) showed in a two-year study of short-term storage that sugar losses were reduced by 50% when beets were ventilated at the rate of approximately 10 cfm/ton. He concluded that not only were sugar losses reduced by ventilation, but also that spoilage of stored beets could be minimized if not entirely eliminated by ventilation. Orleans and Cotton (6) found that ventilating beet storage sheds in California greatly reduced sucrose losses and reduced the loss of purity even though the beets were in the storage bins for only 24 hours.

Further work of Orleans and Cotton (5), studying the ventilation of commercial piles in Montana, indicated that a reduction in sucrose loss of almost 50% could be realized by ventilating with 14 cfm/ton. Concurrent with a savings of sucrose was a retention of beet purity. Downie et al. (3), in a ventilation study at Rocky Ford, again showed that ventilation rates in the neighborhood of 10 cfm/ton could substantially reduce sucrose losses. They found similar results under short-term storage studies in Clarksburg, California. Recent work by Burke in Ireland (2), and extensive studies by the Great Western Sugar Company research group (1), have shown the additional advantages of ventilating sugarbeets in storage to minimize losses.

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However, the application of ventilation for cooling of sugarbeets on a commercial scale has not found wide acceptance. In many cases the conclusion has been that the sucrose saved did not justify the extra labor, capital investment and utility costs involved.

The lack of acceptance for forced ventilation cooling on a commercial scale is due to several factors--the most important of which is the price of sugar. When sugar prices are high, the cost-effectiveness of forced ventilation is good, but when prices are low, it is difficult to justify the capital investment required for ventilation. The second most important factor contributing to the lack of success has been inadequate equipment. Surplus Navy fans which have been used do not have the proper characteristics and capacities for existing duct systems. The result has been inadequate air flow, excessive power consumption and ineffective cooling.

Forced ventilation of sugarbeet storage piles should afford several advantages including more rapid cooling, reduction in the frequency of hot spots and thus lower sucrose losses. However, the benefits derived from forced air ventilation will vary by geographical area since the cooling capacity of the ventilation systems is dependent on the ambient cooling air available.

We have developed a successful computer simulation model of a sugarbeet storage pile (4) capable of evaluating the effectiveness of forced ventilation in various climates relative to free convection cooling. This paper compares free convection and forced ventilation cooling in various geographical areas throughout the United States and evaluates the relative benefits of developing low-respiring genotypes for long-term storage.

METHODS

Comparisons of forced ventilation and free convective cooling were made at the following locations: Moses Lake, Washington; Nampa, Idaho; Worland, Wyoming; Fort Collins, Colorado; Hereford, Texas; Moorhead, Minnesota and Saginaw, Michigan. These areas were selected to represent a broad range in climatic conditions during harvest and the early storage period.

The harvest period was divided into five four-day harvest increments at each location. The first increment represented a relatively early harvest for the location, and the remaining 20 days of harvest covered the normal harvest period in each of the geographic locations. Each harvest increment was then assumed to be stored for 50 days.

Temperature inputs to the model were daily maximum-minimum temperatures calculated as five-year averages and inputed as linear regression equations for the monthly periods involved. To demonstrate the importance of year-to-year variability in the minimum temperatures available for cooling, selected single year temperatures were also inputed as actual daily minimum and maximum temperatures.

Ventilation rates of 10, 20 and 30 cfm/ton were compared to free convection cooling. The ventilation fans were programmed to turn on whenever the following equation was satisfied:

$$\text{Fan-on temperature} = \frac{DB-WB}{2} + \text{avg. pile temperature}$$

DB = Dry bulb temperature

WB = Wet bulb temperature

Average relative humidities were used to demonstrate the WB for each location. This method of establishing the temperature for initiating ventilation fully utilizes the èvaporate cooling effects that occur near the ventilation ducts (4).

Respiration rates of two genotypes were determined during the first 12 days of storage by methods described previously (8). The roots of an inbred designated as 416 and the commercial cultivar, Great Western D2, were machine harvested and immediately placed into storage at three temperatures--35, 40 and 50°F. Respiration rates were monitored continuously for 12 days. The respiration data at each temperature were then fit to a polynomial equation. These equations were then utilized in the computer model as described previously (4).

RESULTS

The predicted sucrose losses under nonventilated conditions in the various geographic locations ranged from a high of 23.6 lbs in Saginaw to a low of 14 lbs in the Moorhead, Minnesota area (Table 1). The magnitude of loss at each location was directly related to the availability of cool night air. Those areas having sufficient cool night temperatures could adequately cool piles by free convection alone if the piles are free of trash. For example, the development of hot spots from dirty beets can be a significant problem in Moorhead, Minnesota even though sufficient cool night air is available (Wyse, personal observation). The savings due to forced ventilation were also correlated with the ambient cooling air available. In most cases 10 cfm/ton gave the greatest increment of sucrose saved over free convection cooling. An additional 10 or 20 cfm/ton gave additional savings of about 1 lb/10 cfm. In all cases, the greatest savings were realized by ventilating beets stored early in the campaign.

The geographic area showing the greatest potential for conservation of sucrose through ventilation was Saginaw, Michigan. Saginaw has marginal cooling air available for lowering pile temperatures and, thus showed the greatest savings of sucrose at the higher ventilation rates which maximize use of available cool air.

The use of the linear regression models to predict five-year average minimum-maximum temperatures at each location tended to eliminate the effects of widely fluctuating temperatures. For example, three- or four-day warm spells during the harvest period can greatly increase sucrose losses as a result of an inability to control pile temperature. Therefore, an additional comparison was made using actual daily maximum-minimum temperatures for a single year (Table 2). Years were selected to represent the normal swing in temperatures expected at each location. Note, for example, the cold period during the second harvest increment at Hereford in 1973 and the cor-

Table 1. Predicted sucrose losses with free convection cooling and estimated sucrose savings by ventilation at 10, 20, 30 cfm/ton during the first 50 days of storage at selected U.S. locations. Temperature inputs were from linear regression equations of five-year average daily max-min temperatures for each location. Each harvest period was divided into five four-day segments.

Location-Variety	Time Period[1/]	Free Convection Only	Sucrose Conserved by Ventilation 10 cfm/t	20 cfm/t	30 cfm/t
			lbs/ton/50 days		
Fort Collins	15-65	20.7	5.1	6.4	6.8
	19-69	18.9	4.3	5.5	5.8
	23-73	17.4	3.7	4.7	5.0
	27-77	16.1	3.2	4.0	4.3
	31-81	15.1	2.8	3.5	3.8
	Avg.	17.6	3.8	4.8	5.1
Hereford	32-82	19.6	3.7	4.9	5.2
	36-86	18.5	3.2	4.3	4.6
	40-90	17.6	2.9	3.8	4.1
	44-98	16.8	2.6	3.4	3.7
	48-98	16.2	2.4	3.2	3.4
	Avg.	17.7	2.9	3.9	4.2
Nampa	20-70	19.0	4.2	5.3	5.6
	24-74	18.0	3.9	4.9	5.2
	28-78	17.0	3.5	4.4	4.7
	32-82	16.2	3.3	4.1	4.4
	36-86	15.4	3.0	3.8	4.0
	Avg.	17.1	3.6	4.5	4.8
Moorhead	15-65	16.4	3.6	4.5	4.8
	19-69	15.0	3.0	3.8	4.1
	23-73	13.8	2.5	3.2	3.4
	27-77	12.8	2.0	2.6	2.8
	31-81	12.0	1.7	2.2	2.4
	Avg.	14.0	2.6	3.3	3.5
Moses Lake	20-70	18.1	4.2	5.3	5.6
	24-74	17.0	3.9	4.8	5.0
	28-78	16.1	3.6	4.4	4.6
	32-82	15.5	3.4	4.1	4.4
	36-86	14.7	3.1	3.7	4.0
	Avg.	16.3	3.7	4.5	4.7
Saginaw	15-65	27.5	9.1	11.0	11.4
	19-69	25.5	8.1	9.9	10.3
	23-73	23.7	7.3	8.9	9.3
	27-77	21.9	6.4	7.9	8.3
	31-81	19.4	5.2	6.5	6.8
	Avg.	23.6	7.2	8.8	9.2

1/ Days from October 1.

Table 1. (Continued)

Location-Variety	Time Period[1/]	Free Convection Only	Sucrose Conserved by Ventilation 10 cfm/t	20 cfm/t	30 cfm/t
			lbs/ton/50 days		
Worland	15-65	16.0	2.8	3.7	4.0
	19-68	15.0	2.4	3.2	3.5
	23-73	14.2	2.2	2.9	3.1
	27-77	13.5	1.3	1.9	2.1
	31-81	12.8	1.7	2.3	2.5
	Avg.	14.3	2.2	3.0	3.2

Table 2. Prediced sucrose losses with free convection cooling and estimated sucrose savings by forced ventilation at 10, 20, 30 cfm/ton during the first 50 days of storage at selected U.S. locations. Temperature inputs were daily max-min temperatures for a single year.

Location-Variety	Time Period[1/]	Free Convection Only	Sucrose Conserved by Ventilation 10 cfm/t	20 cfm/t	30 cfm/t
			lbs/ton/50 days		
Fort Collins 1974	15-65	20.8	3.8	4.9	5.1
	19-69	25.3	7.1	9.0	9.4
	23-73	19.5	3.7	5.2	5.5
	27-77	18.7	3.4	4.8	5.1
	31-81	14.1	1.0	1.5	1.6
	Avg.	19.7	3.8	5.1	5.4
Hereford 1973	32-82	24.6	4.8	6.8	7.3
	36-86	17.2	0.7	1.2	1.2
	40-90	17.8	1.5	2.1	2.2
	44-98	30.9	7.6	12.8	13.6
	48-98	19.7	3.0	4.6	5.0
	Avg.	22.0	3.5	5.4	5.9
Hereford 1972	32-82	13.7	1.0	1.4	1.5
	36-86	18.8	3.7	5.2	5.6
	40-90	14.9	1.9	2.7	2.9
	44-98	12.4	0.9	1.2	1.3
	48-98	12.0	0.8	1.1	1.2
	Avg.	14.4	1.7	2.4	2.6
Nampa 1976	20-70	16.5	2.2	3.0	3.2
	24-74	17.6	3.0	4.0	4.3
	28-78	16.7	2.7	3.6	3.8
	32-82	17.2	3.1	4.0	4.3
	36-86	16.2	2.6	3.6	3.9
	Avg.	16.8	2.7	3.6	3.9

1/ days from October 1.

Table 2. (Continued)

Location-Variety	Time Period1/	Free Convection Only	Sucrose Conserved by Ventilation		
			10 cfm/t	20 cfm/t	30 cfm/t
			lbs/ton/50 days		
Moorhead 1976	15-65	16.3	3.2	4.0	4.2
	19-69	17.4	3.8	5.1	5.4
	23-73	13.3	2.2	2.8	3.1
	27-77	12.5	1.8	2.3	2.5
	31-81	12.0	1.5	2.1	2.3
	Avg.	14.3	2.5	3.3	3.5
Moses Lake 1972	20-70	19.0	4.1	5.3	5.6
	24-74	17.1	3.6	4.5	4.7
	28-78	14.8	2.7	3.3	3.4
	32-82	14.0	2.2	2.6	2.7
	36-86	15.1	2.7	3.3	3.5
	Avg.	16.0	3.1	3.8	4.0
Saginaw 1971	15-65	43.9	19.8	23.3	23.8
	19-69	--	24.1*	21.4*	21.4*
	23-73	--	24.4*	18.1*	17.5*
	27-77	--	20.2*	18.3*	17.6*
	31-81	27.0	8.0	10.9	11.6
	Avg.	--	--	--	--
Saginaw 1972	15-65	16.1	3.2	3.8	3.9
	19-69	16.0	3.4	3.9	4.0
	23-73	18.3	4.6	5.8	6.1
	27-77	15.4	3.0	3.6	3.7
	31-81	15.6	3.4	4.2	4.4
	Avg.	16.3	3.5	4.3	4.4
Worland 1974	15-65	16.2	1.6	2.3	2.4
	19-68	19.8	3.9	5.5	5.8
	23-73	14.7	2.0	2.6	2.8
	27-77	15.8	2.7	3.6	3.9
	31-81	14.0	2.3	3.0	3.2
	Avg.	16.1	2.5	3.4	3.6

* Actual predicted loss. Loss values for non-ventilated condition indicated loss of temperature control within the pile.

responding reduction in sucrose losses. However, a warm period occurred in the fourth incremental harvest, and pile temperatures could not be controlled, resulting a substantial increase in losses. In 1972, in Hereford, a very cool fall, losses were significantly lower and the benefits of ventilation were marginal. However, in 1973, the substantial amount of sucrose saved due to the ventilation of the fourth increment represented a significant insurance factor.

A similar example is shown for Saginaw in 1971. Because of a mild fall, the model predicts that cooling pile temperatures could not be controlled by free convection. However, with just 10 cfm/ton, losses were cut in half from 43.9 lbs/ton, representing a savings of approximately 20 lbs of sucrose/ton. In all cases when a pile could not be controlled by free convection cooling, it could be controlled with 10 cfm/ton, although losses were still high. However, the fall of 1972 in Saginaw was much cooler, and the effects of forced ventilation were minimal. The data indicate that in some locations forced ventilation cooling may only be profitable in infrequent years, and an analysis of the weather patterns would be a logical extension of the data presented.

The sucrose savings shown in Tables 1 and 2 are minimal savings resulting from temperature control of respiration only. The tables do not show the additional benefits of rapid cooling on reduced storage rots or on the elimination of hot spot patterns, both of which cause tremendous losses. Therefore, these data represent minimal losses and give only a relative comparison of geographical locations.

The selection of genotypes for low storage respiration rates has been studied for many years. Recently Wyse et al. (8) showed that storage respiration rates were genetically controlled and that selection for low respiration was feasible. However, the benefits of storing a low-respiring variety have not been evaluated.

The patterns of respiration for the two genotypes are shown in Figure 1. The respiration rates of 10°C were very high initially but declined to an equilibrium value after about 12 days. The reduction in respiration rate was not as apparent at 2 and 5°C as at 10°C but the genotypes still required 10-12 days to reach equilibrium. When the equilibrium-respiration rates are averaged over all three temperatures, the inbred 416 respired at a rate 20% higher than the commercial hybrid, D2. Thus the data input into the model represents a difference in respiration rate between two genotypes of 20%.

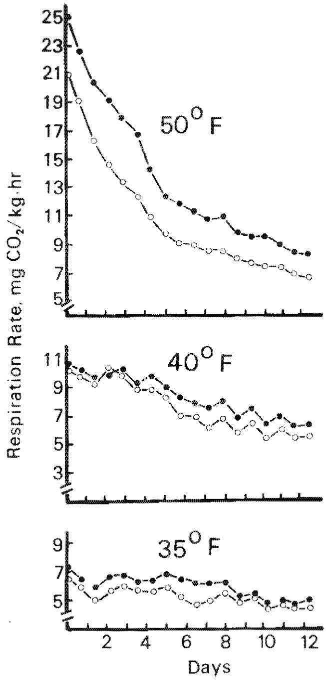

Figure 1. Respiration rates of two genotypes (Inbred (●) 416, hybrid (○) - D2) during 12 days immediately after harvest at 35, 40, and 50°F.

Table 3 compares sucrose losses of a high-and low-respiring variety at various geographic locations and storage ventilation conditions. The most significant effect of a low-respiriring variety is at Saginaw, Michigan where storage temperatures are warmer than those at any other locations. These results indicate only marginal benefit of developing a low-respiring variety. However, these data pertain only to the initial 50 days of storage and do not reflect the potential benefits of a variety with high storage rot resistance.

DISCUSSION

The data indicate that locations having variable or mild fall harvest temperatures may derive considerable benefit from forced ventilation cooling of sugarbeet storage piles. The greatest apparent benefit would be in Saginaw, Michigan. The capital investment could be reduced and the problems involved in installing a ventilation system minimized by ventilating only

Table 3. Comparison of ventilation and varietal respiration on sucrose conservation during the initial 50 days of storage in seven sugarbeet growing areas. Temperature inputs were five-year average daily max and min temperatures.

	Sucrose Conserved			
	Ventilation Rate, cfm/ton			
	0	10	20	30
	lbs/ton/50 days			
Fargo - HR[2/]	--(14.0)[1/]	2.6	3.3	3.5
- LR	1.4	3.6	4.2	4.2
Moses Lake - HR	--(16.3)	3.7	4.5	4.7
- LR	2.0	5.2	5.7	5.5
Hereford - HR	--(17.7)	2.9	3.9	4.2
LR	2.5	5.3	5.9	6.0
Ft. Collins - HR	--(17.6)	3.8	4.8	5.1
LR	2.6	5.8	6.4	6.3
Nampa - HR	--(17.1)	3.6	4.5	4.8
- LR	2.3	5.6	5.5	6.3
Worland - HR	--(14.3)	2.2	3.0	3.2
- LR	1.4	3.6	4.1	4.3
Saginaw - HR	--(23.6)	7.2	8.8	9.2
	7.8	7.3	10.2	10.5

1/ Numbers in parentheses represent predicted loss of sucrose during first 50 days of storage without ventilation.

2/ HR - high respiring variety LR - low respiring variety

those beets harvested and stored in the early part of the harvest season. For example, ventilation at 20 cfm/ton during the first 20 days of storage for the intitial increments of beets placed in storage, would rapidly cool the pile by taking full advantage of limited cooling air available. Later stored roots would require only about 10 cfm/ton or no ventilation at all. Such a program would minimize the capital investment involved (Figure 2).

The second advantage of storage pile ventilation is the insurance factor. During years with mild fall temperatures, forced air ventilation would provide a significant insurance factor for cooling the piles and minimizing losses.

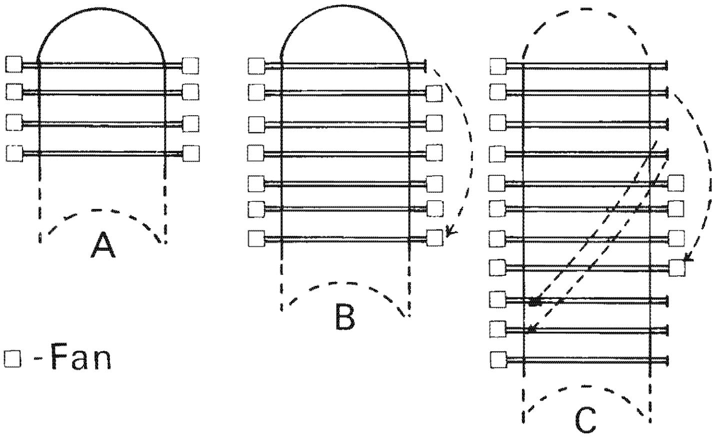

Figure 2. Proposed ventilation system to maximize ventilation rates during the early portion of the storage period using a minimum number of fans. A) The first roots placed into storage are ventilated with a fan at each end of the duct giving a total capacity of approximately 20 cfm/ton. B) As the early stored roots are cooled sufficiently, one fan is removed and used on freshly piled roots. C) Later cool night temperatures allow either single fans or free convection to adequately control pile temperatures.

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