1-2005

Aeration Strategies and Fan Cost Comparisons for Wheat in Mid-South Production Regions

Thomas C. Bridges
University of Kentucky, tom.bridges2@uky.edu

Michael D. Montross
University of Kentucky, michael.montross@uky.edu

Samuel G. McNeill
University of Kentucky, sam.mcneill@uky.edu

Aeration Strategies and Fan Cost Comparisons for Wheat in Mid-South Production Regions

Notes/Citation Information
Published in *Applied Engineering in Agriculture*, v. 21, issue 1, p. 115-124.

Digital Object Identifier (DOI)
https://doi.org/10.13031/2013.17903

AERATION STRATEGIES AND FAN COST COMPARISONS FOR WHEAT IN MID-SOUTH PRODUCTION REGIONS

T. C. Bridges, M. D. Montross, S. G. McNeill

ABSTRACT. *Numerous factors influence the sizing of aeration fans for summer−harvested crops. Thirty years of weather data for Lexington, Kentucky, were analyzed and the cost of aeration was compared for two axial fans (afan1, afan2) and one centrifugal fan (cfan1). Aeration costs were defined as the sum of the following components: the cost of owning the fan, the cost of electricity for operating the fan, a cost for wheat shrinkage during aeration, and a cost for dry matter loss (DML). The fans were selected to deliver airflow rates of approximately one, two, and three times the recommended aeration rate of 0.11 m^3/min/t (0.1 cfm/bu). Aeration fan investment costs ranged from \$709 (afan1) to \$1739 (cfan1). Aeration costs for each fan were compared for four initial grain temperatures: 21.1°C, 23.9°C, 26.7°C, and 29.4°C (70°F, 75°F, 80°F, and 85°F); four harvest dates: 1 June, 15 June, 1 July, and 15 July; and two aeration temperature windows (0 to 15°C and 0 to 17°C). Generally, the total aeration cost increased with initial grain temperature, decreased with later harvest dates, and was not significantly affected by aeration temperature window. When the total cost of aerating the wheat was considered, the results showed that the most expensive fan (cfan1) was not appreciably more costly than the least expensive (afan1). It was also found that using fans with airflow rates above the minimum recommendation were successful in reducing the amount of wheat shrinkage and dry matter loss, which should provide the producer with a larger volume of better quality grain at market.*

Keywords. *Wheat, Aeration, Simulation, Cost, Shrink.*

Grain stored for long periods of time is generally aerated to maintain the overall quality and reduce the risk of storage losses due to insects and mold growth. Typically it is recommended that producers maintain the temperature of the stored grain to within ±5.5°C (10°F) of the average monthly temperature (depending on location), but not to exceed 15°C (59°F) in the warmer months or less than 0°C (32°F) during the winter. This recommendation generally works well to maintain grain quality in the Midwestern United States but has proven somewhat difficult to implement. It has been suggested (Navrarro and Noyes, 2002) that the use of a fixed number of cycles to cool the grain would be more appropriate. However, this procedure may not be practical with grains such as winter wheat, which are often placed into storage at elevated temperatures due to the timing of harvest. For example, in the mid−south region of the United States (Missouri, Kentucky, Virginia), corn and wheat are often harvested in the 20°C to 30°C (68°F to 86°F) temperature range and ambient conditions during harvest time are not sufficient to cool the grain. This places the grain in storage at temperatures where it is susceptible to deterioration and storage losses from mold growth and insects.

Due to the higher harvest temperatures, a major consideration when aerating grain in the mid−south region of the United States is the availability of the desired weather conditions to allow rapid cooling below 15°C (59°F). It is desirable to maintain the stored grain at or below the recommended 15°C to sufficiently prevent insect and mold development (Burgess and Burrell, 1964). Assuming that weather conditions are favorable, several weeks may be necessary to cool the grain using a fan that supplies the recommended airflow rate of 0.11 m^3/min/t (0.1 cfm/bu). In addition to the time requirement, the warmer harvest temperatures combined with the high ambient relative humidities in the mid−south region present additional problems for the producer in cooling and maintaining proper storage conditions.

The ambient weather conditions during wheat harvest in the mid−south United States pose numerous concerns for producers when selecting aeration equipment in this area. Airflow requirements are based on research from the Midwestern United States and may need to be higher in warmer and more humid climates. The risks and costs of increasing the airflow rate have not been well quantified. The objective of this study was to compare various aeration fans with respect to total aeration cost using historical weather data for a given mid−south location and demonstrate for mid−south producers a procedure for selecting aeration fans for their wheat storage systems.

BACKGROUND

Computer simulation has been a popular tool for researchers when investigating the dynamics of grain drying and

Article was submitted for review in December 2003; approved for publication by the Food & Process Engineering Institute Division of ASAE in September 2004.This article is published with the approval of the Director of the Kentucky Agricultural Experiment Station and designated Paper No. 03−05−138.

The authors are **Thomas C. Bridges, ASAE Member Engineer,** Research Specialist, **Michael D. Montross, ASAE Member Engineer,** Assistant Professor, and **Samuel G. McNeill, ASAE Member Engineer,** Extension Professor, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, Kentucky. **Corresponding author:** Tom Bridges, 128 C. E. Barnhart Building, University of Kentucky, Lexington, KY 40456−0276; phone: 859−257−3000, ext. 209; fax: 859−257−5671; e−mail: tbridges@bae.uky.edu.

storage systems, especially where ambient weather conditions need to be considered. Montross and Maier (2000a) used computer simulation to examine the performance of various high−temperature drying systems with and without the use of dryeration for various locations in the Midwest. The above authors (Montross and Maier, 2000b) also used experimental results to examine the reconditioning (rewetting) of corn and soybeans with aeration and to validate a computer model for prediction of aeration strategies in Des Moines, Iowa, and Indianapolis, Indiana.

Grain aeration has also been subjected to various studies in the literature. Early efforts involving aeration investigated corn, but in recent years several investigations have considered stored wheat. Harner and Hagstrum (1990) investigated high airflow rates for cooling wheat during the summer. These authors determined that an airflow rate of 1.7 m^3/min/t (1.5 cfm/bu) would allow Kansas's producers to cool wheat by an average of 6°C (11°F) with approximately 9 h of fan operation. This had the potential to reduce insect population growth by 80 to 97%.

Reed and Harner (1998a) studied aeration fan controllers to determine their usefulness for insect control in hard red winter wheat in Kansas and found them to cool the grain faster than manual operation of fans using standard recommendations. Reed and Harner (1998b) also determined that insect populations and grain damage were significantly reduced when aeration fan controllers were used to cool the grain shortly after harvest. Further, Sinicio and Muir (1998) presented allowable storage times and determined various control strategies for aerating wheat for different locations in Brazil.

Casada and Alghannam (1999) investigated aerating over−dry wheat in the Northwest United States. Large temperature differences between the air and grain caused the grain to absorb moisture. However, condensation on cool grain under high humidity conditions occurred only briefly during tests. Large additions of moisture could create unsafe storage conditions quickly, less than 100 h.

Mani et al. (2001) compared different models for predicting insect populations in wheat for weather conditions in Winnipeg, Canada, and Topeka, Kansas, and showed larger insect populations in wheat in the warmer climate. Arthur and Flinn (2000) considered different aeration strategies and simulated their impact on the rusty grain beetle in hard red winter wheat using weather data from locations in Texas, Oklahoma, Kansas, eastern New Mexico, and Colorado. It was determined that insect populations would decrease in the areas where there were sufficient hours available for cooling the grain to recommended temperatures.

There is a minimal amount of published research concerning the aeration strategies for stored wheat in the mid−south region of the United States. As Arthur and Flinn (2000) demonstrated, there were fewer hours available for cooling the stored grain in the southern regions of their study, especially in the late spring, summer and early fall periods when mold growth and insect populations are most difficult to control. Recently, Montross et al. (2003) used 30 yrs of weather data at various locations in the eastern United States and presented contour lines for available fan run times when the ambient temperatures were between 0 to 15°C (32°F to 59°F) and 0 to 17°C (32°F to 62.6°F). For Evansville, Indiana, ambient temperatures were within the 0 to 17°C window approximately 11% of the time for the month of June and less than 4% of the time in July. The percentages shown for Evansville are indicative of the insufficient cooling potential available for mid−south grain producers when conditioning their grain for proper storage. The lack of ambient temperatures to cool the wheat is especially critical in the face of warmer harvest temperatures and raises questions for the wheat producer in the mid−south as to what type of aeration equipment to use and what strategies will be most advantageous. Aeration fan controllers have great capabilities, but if few cooling periods exist then sophisticated equipment will not solve the problem.

PROCEDURE

FAN SELECTION

One potential solution for the lack of sufficiently cool temperatures to properly aerate stored wheat during June and July would be for mid−southern grain producers to increase the airflow rate beyond the recommended minimum value of 0.11 m^3/min/t (0.1 cfm/bu). The estimated fan runtime required to move a temperature front completely through a bin of grain is approximately 150 h at an airflow rate of 0.11 m^3/min/t (GEAPS, 1989). The above estimate is based on high humidity conditions where evaporative cooling effects would be negligible and would vary depending on seasonal ambient conditions. For example, predicted cooling times ranged from 100 (Epperly, 1989) to 225 h (Armitage et al., 1991) for an airflow rate of 0.11m/min/t. For a more exact determination of aeration times for specific situations the reader is referred to the heat balance equations presented by Brooker et al (1992). In the mid−south region, Montross et al. (2003) has shown that weather conditions limit the effectiveness of aeration especially using the recommended airflow rate. If the producer were to select a fan that doubled the minimum recommended airflow rate, this would reduce the required time to cool a bin by approximately 50% and be more effective when cooler temperatures prevail.

However, increasing the airflow rate for aeration requires a larger fan with an increased investment cost. This raises questions for the wheat producer, i.e. will a more expensive fan be worth the investment in terms of the end product (grain quality). There are several cost factors that should be considered when choosing an aeration fan. They include the investment cost of the fan, the electricity cost for fan operation to condition the grain, the amount of moisture shrinkage in the grain bin due to the ambient weather conditions, and deterioration of the quality of the grain (dry matter loss). Ideally the producer would like to minimize the amount of shrinkage and dry matter loss, which should aid in maximizing the quality of the wheat and result in a larger quantity of marketable grain.

Simulations were conducted to examine the yearly aeration costs for wheat and determine how these are affected by the seasonal variation in weather. Thirty years of hourly weather data (1961 to 1990) for the mid−southern location of Lexington, Kentucky, was used assuming a grain bin with a diameter of 9.14 m (30 ft) and a grain height of 9.14 m (30 ft) and initially filled with wheat at 13.0% moisture content (wb). Three aeration fans were chosen for cost comparisons in this study and the specifics for each fan are listed in table 1. Two of the selected fans are axial type (designated afan1 and afan2) and the third is an in−line centrifugal (cfan1). These fans are from a representative manufacturer's brand and were selected such that the airflow rate that each delivered (table 1) for the desired bin (table 2) was approximately one, two, and three times the recommended minimum value of 0.11 m^3/min/t (0.1 cfm/bu). Airflow rates for each fan were determined using the performance curve of the fan and the WINFANS computer program (Hansen et al., 1996). This program contains Shedd's data for wheat (*ASAE Standards*, 1994) and the airflow rates were determined using a Shedd's curve multiplier of 1.3. Fan investment costs shown in table 1 are list prices obtained at the National Farm Machinery Show in February 2003 and show a significant rise in cost if the producer chooses to increase the airflow rate for aeration. Annual costs for each fan (table 1) are based on straight−line depreciation, 10% rate of return, 2% for taxes and insurance, 10% salvage value and a 7−yr fan economic life. Due to the current economic environment, interest rates for loans on farm equipment are currently in the 5% to 6% range. However, loan rates have been much higher in the past and are poised to be so in the future. Thus, a 10% rate of return was chosen for this analysis as representative of the long term.

AERATION ANALYSIS

The aeration and storage computer model developed and validated at Purdue University (Maier, 1992; Zink 1998; Montross and Maier, 2000a) was used to conduct the simulated aeration runs. The Purdue model determines dry matter loss for wheat based on relationships presented by Fraser and Muir (1981). Table 3 presents the initial simulation variables and the ranges considered for this study. A total of 32 simulations were performed for the 30−yr period for each of three fan and bin combinations. Four initial grain temperatures (table 3) were used: 21.1°C, 23.9°C, 26.7°C, and 29.4°C (70°F, 75°F, 80°F, and 85°F). The harvested wheat was assumed to enter the bin at the initial grain temperature. Four harvest dates were considered: 1 June, 15 June, 1 July, and 15 July. These dates were chosen to encompass most of the harvest period for wheat in the mid−south United States. The two aeration temperature windows (table 3) were used to determine the times that the aeration fan would run to condition the grain. Humidity controls were not considered in this study and the fans were run when the ambient temperature was within the specified temperature window. The aeration−storage model terminated when the average bin temperature was $\leq$15°C (59°F). Upon completion of each yearly simulation, the computer model returned the date at which the target temperature was reached, the hours of run time required by the fan, the average moisture content of the bin and the average dry matter loss of the wheat that occurred from the starting date.

Table 1. Aeration fan information including size, type, cost, and capacity for the various fans selected for this study.

Fan Type and Name		Fan Size kW (hp)	List Price $	Annual Cost[a] $	Airflow[b] m^3/min/t (cfm/bu)	
axial	afan1	1.12 (1.5)	709	137.95	0.145	(0.13)
axial	afan2	3.73 (5.0)	1231	239.52	0.252	(0.227)
cent.	cfan1	7.45 (10.0)	1739	338.36	0.388	(0.348)

[a] Annual cost is based on straight−line depreciation, 10% interest rate, 2% for taxes and insurance, 10% salvage value, and a 7−yr fan life.
[b] Airflow values are for wheat in 9.14−m (30−ft) bin with a grain depth of 9.14 m (30 ft).

Table 2. Initial bin, grain and economic conditions for the simulated aeration analysis in this study.

Bin	
Diameter	9.14 m (30 ft)
Height	9.14 m (30 ft)
Capacity	461.7 t (16964 bu)
Grain	
Wheat	
Initial moisture	13.0 % wb
Value	110.23 $/t (3.00 $/bu)
Economic	
Bin value	50893.8 $
Electricity cost	0.06 $/kWh
Fan life	7.0 yr
Interest rate	10.0%
Taxes and insurance	2.0%

Table 3. Initial temperatures for wheat entering the bin, harvest dates, and aeration windows used in this study.

Initial Wheat Temperatures		Harvest Dates
21.1°C (70.0°F)		June 1 (day of year 152)
23.9°C (75.0°F)		June 15 (day of year 166)
26.7°C (80.0°F)		July 1 (day of year 182)
29.4°C (85.0°F)		July 15 (day of year 196)
Aeration Temperature Windows		
0 to 15°C	0 to 17°C	
(32°F to 59°F)	(32°F to 62.5°F)	

ECONOMIC ANALYSIS

Producers frequently are concerned with the additional cost of a larger aeration fan when building or modifying their grain storage. For this analysis, the cost of aeration for each year was determined and averaged over the 30−yr simulation period. The cost of aeration was defined as the sum of the annual cost of owning the aeration fan, the electrical cost for the cooling hours necessary to reach the target temperature, a cost for grain shrinkage due to the aeration of the grain, and a cost for dry matter loss in the bin during the aeration period.

The annual cost associated with owning each fan is listed in table 1. Other economic assumptions used in the analysis are presented in table 2. The wheat was assumed to have an initial value of $110.23/t ($3.00/bu) and initial moisture content of 13.0% w.b. with no damage or mold discounts on the starting date. Electrical costs for fan operation each year were determined using the product of power rating of the fan, the hours of operation and the cost for electricity (table 2). It was assumed that the fan motor was 75% efficient.

Some drying will take place during the aeration process, which produces a shrinkage that reduces the marketable grain mass. The economic loss due to shrinkage was calculated based on the mass of grain placed into storage minus the weight of grain after aeration using the average bin moisture returned by the simulation model. The cost due to shrinkage was calculated by subtracting the difference in mass, dividing by the standard bulk density of 772 kg/m^3 (60 lb/bu), and multiplying by the initial wheat value of $110.23/t ($3.00/bu). In addition to the shrinkage cost due to moisture loss, a small percentage of dry matter loss generally occurs when the grain is stored. To reflect the additional loss in saleable volume of the bin due to wheat spoilage, it was assumed for each simulated year that the producer would lose a percentage of the initial bin value (table 2) equal to the average dry matter loss predicted by the simulation model from the harvest date.

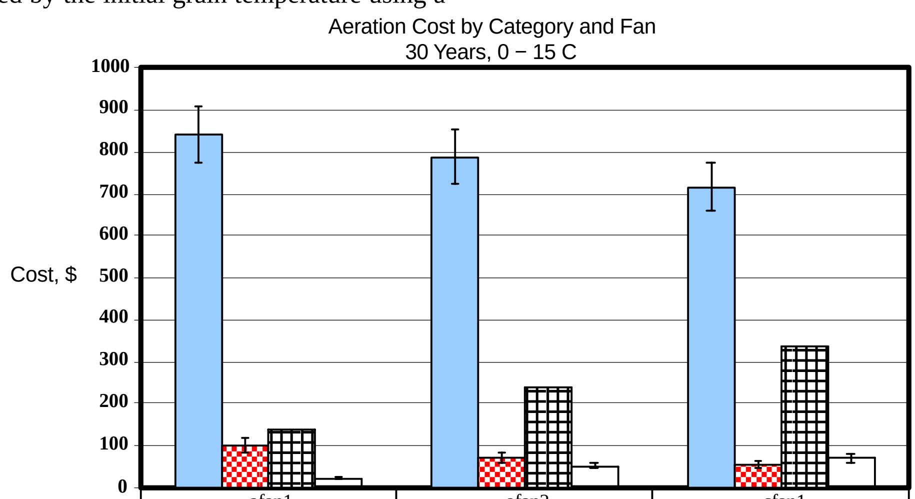
RESULTS

Four component expenditures were identified in this analysis as comprising the total yearly cost of the aeration process. These component costs were: the fixed or annual cost of owning the aeration fan (table 1); the cost for electricity based on the hours to cool the grain determined by the simulation model and the cost of electricity (table 2); the cost assigned for grain shrinkage caused by any over drying of the wheat from the initial moisture content (13% w.b.); and a charge based on any quality loss due to grain spoilage (DML). The cost of the four aeration components by fan type averaged over 30 yrs for the four starting dates and four initial grain temperatures in this study using a 0 to 15°C (32°F to 59°F) temperature window is presented in figure 1. The data shows that the average cost components associated with shrinkage and dry matter loss decreased as the fan size increased while the cost components for owning the fan and electricity use increased with the larger fans. Grain shrinkage was identified as the largest component cost [based on a value of 110.23 $/t (3.00 $/bu)]. Electricity and DML proved to be the least significant of the component costs (fig. 1). The dry matter losses for the 30−yr study were small generally ranging from a maximum of 0.5% to a minimum of 0.05%. The sum of the component costs (fig. 1) was approximately the same for all three fans ranging from $1101 to $1179.

TOTAL AERATION COSTS VERSUS INITIAL GRAIN TEMPERATURE

The 30−yr total average aeration cost for the three fans in this study as affected by the initial grain temperature using a harvest date of 15 June is compared in figure 2. The costs are shown in $/t (cents per bushel) and the temperature window for controlling fan operation was 0 to 15˚C (32˚F to 59˚F). Figure 2 shows that the aeration costs are relatively small per unit volume (the overall range is 2.3 to 2.8 $/t [6.3 to 7.7 cents/bu]) and become larger for each fan as the initial grain temperature increases. For a given fan, the increase in the total aeration cost as the initial grain temperature was elevated was a result of an increase in DML and grain shrinkage with fan electrical runtime cost remaining relatively constant. For the 30−yr average, the least expensive fan was afan1, having the lowest aeration costs for all temperatures (fig. 2) and the centrifugal fan (cfan1) was the most expensive. The costs for the second axial fan (afan2) were between those shown for afan1 and cfan2. However, the increase in aeration cost for a given temperature was generally small from the least to most expensive fan. For an initial grain temperature of 21.1˚C (70˚F) the aeration costs ranged from 2.3 to 2.5 $/t (6.3 to 6.7 cents/bu) while for 29.4˚C (85˚F) the range was 2.6 to 2.8 $/t (7.1 to 7.7 cents/bu). The average costs in figure 2 illustrate that while fans afan2 and cfan1 required a significant increase in initial investment, when the total cost of aeration was considered, the overall cost increase to the producer was small.

The data in figure 3 presents average total aeration cost for the same temperature ranges and harvest date used in the figure 2 examples, but specifying a 0 to 17°C (32°F to 62.5°F) temperature window for aeration fan control. The effect of temperature and the trend lines for the fan costs in figure 3 are similar to those shown in figure 2. The overall cost range for the example in figure 3 was slightly smaller than figure 2, 2.3 to 2.8 $/t [6.2 to 7.6 cents/bu]. The small axial fan (afan1) was again the least expensive with the centrifugal fan being the most expensive. The aeration cost ranges (from the least to most expensive fan) for a given temperature were again small; for 21.1°C (70°F) the costs ranged from 2.3 to 2.5 $/t (6.2 to 6.9 cents/bu) while for 29.4°C (85°F) the range was



	afan1	afan2	cfan1
shrink	839	789	716
dml	102	71	55
fan	138	240	338
electric	22	53	70

Fan Type

Figure 1. The 30−yr average values and standard deviation bars for the aeration cost components of shrinkage, dry matter loss, owning the fan and electricity use by fan type for Lexington, Kentucky, weather data, four starting dates, four initial grain temperatures and a 0 to 15°C temperature window.

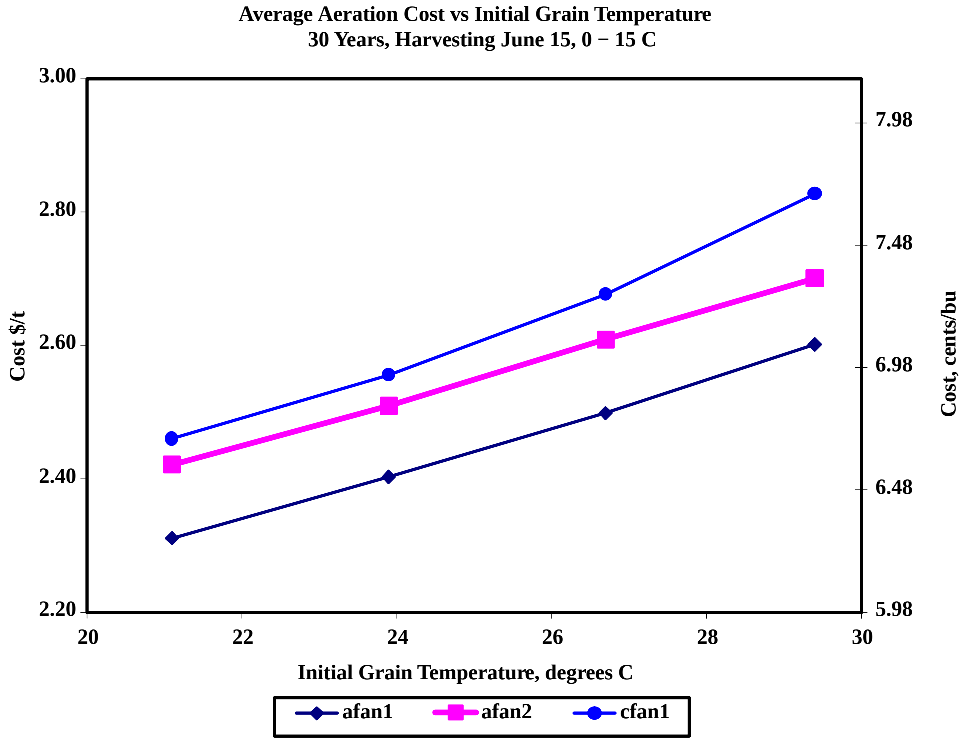


Figure 2. Average aeration costs in $/t and cents/bu vs. initial grain temperature for the three fans in this study using 30 yrs of weather for Lexington, Kentucky, a 15 June harvest date and an aeration temperature window of 0 to 15°C.

2.5 to 2.8 $/t (6.9 to 7.6 cents/bu). On average, the data in figure 3 suggest that increasing the upper temperature limit for operating the fan had little effect on aeration costs for the range of temperatures in this study.

Total Aeration Costs Versus Harvest Date

The effect of harvest date on the 30−yr average total cost for aerating wheat for the three fans in this study is presented in figure 4. For this comparison the initial grain temperature was set to 26.7°C (80°F) and a temperature window of 0 to 15°C (32°F to 59°F) was used for operating the fan. Generally the data in figure 4 showed that the average cost of aerating wheat decreased as the harvest date became later in the year. The latter harvest dates in this study occurred when there was a greater probability of time when ambient conditions were within the temperature window. The average costs in

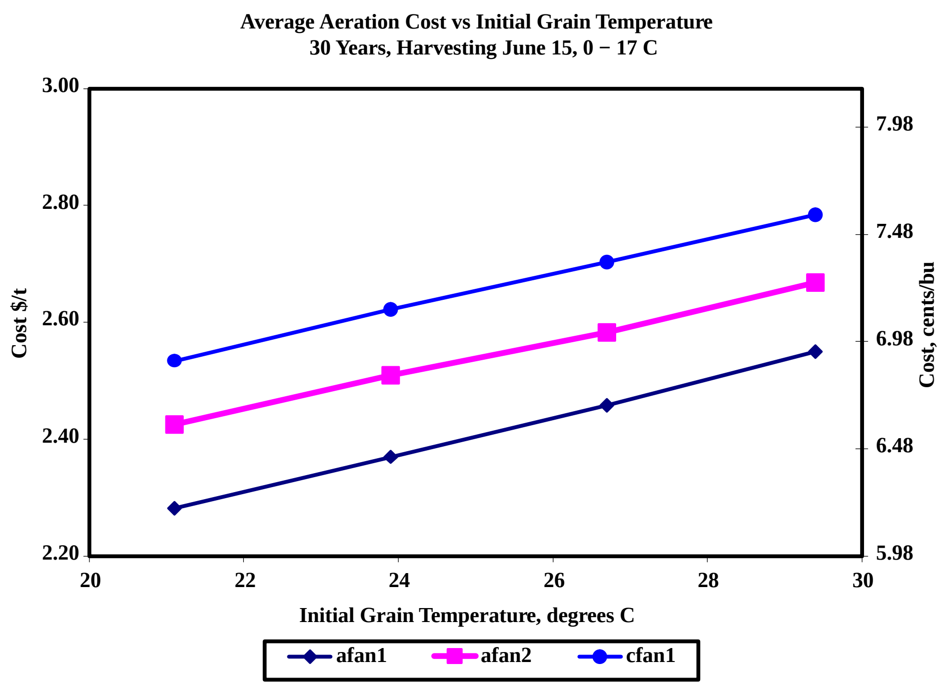


Figure 3. Average aeration costs in $/t and cents/bu vs. initial grain temperature for the three fans in this study using 30 yrs of weather for Lexington, Kentucky, a 15 June harvest date and an aeration temperature window of 0 to 17°C.

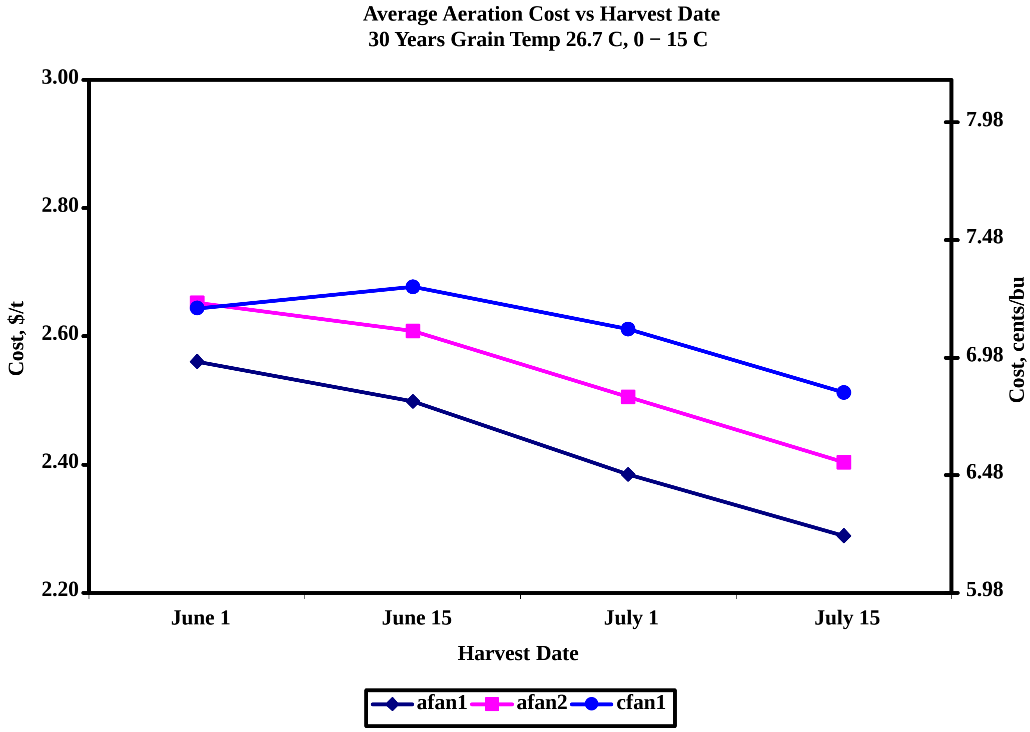


Figure 4. Average aeration costs in $/t and cents/bu vs. harvest date for the three fans in this study using 30 yrs of weather for Lexington, Kentucky, an initial grain temperature of 26.7˚C (80.0˚F) and an aeration temperature window of 0 to 15°C.

figure 4 ranged from 2.7 to 2.3 $/t (7.3 to 6.2 cents/bu) as the harvest date moved from 1 June to 15 July. The small axial fan (afan1) was again shown to be the least costly of the three while the centrifugal fan (cfan1) proved to have the highest average aeration costs except for the June 1 harvest date. For the 1 June date, the average aeration cost ranged from 2.5 to 2.6 $/t (7.0 to 7.2 cents/bu) while for latest date (15 July) resulted in costs between 2.3 to 2.5 $/t (6.2 to 6.8 cents/bu). The cost data in figure 4 would indicate that when practical, that later dates for harvesting the wheat would be preferable, especially when harvest temperatures are warmer.

The effect of using a larger temperature window [0 to 17°C (32°F to 62.5°F)] for fan control is shown on the average total aeration cost (fig. 5) under the same conditions shown in the figure 4. Generally the data in figure 5 resulted in slightly higher costs and the trends with harvest date were slightly less than shown in figure 4. The average aeration costs in figure 5 decreased from 2.7 to 2.3 $/t (7.4 to 6.3 cents/bu) as the harvest date moved forward from 1 June to 15 July. Cost differences between the least and most expensive fans were again small. For the 1 June date, the average aeration cost ranged from 2.5 to 2.6 $/t (6.7 to 7.1 cents/bu) while for the 15 July date the cost range was slightly larger [2.3 to 2.6 $/t (6.3 to 7.2 cents/bu)]. The data in figure 5 indicated that increasing the temperature window by 2°C for operating the fan did little to lower the average cost of aeration.

Shrinkage Cost

The effect of initial grain temperature on the 30−yr average shrinkage cost as a percentage of the total aeration cost for the three fans in this study is shown in figure 6. Harvest was begun on 15 June using an aeration window of 0 to 15°C (32°F to 59°F) and the results showed an increase in the percentage of wheat shrinkage, as the initial grain temperature was elevated. This effect is similar to the effects of temperature shown on the total aeration cost in figure 2 and was not surprising as the shrinkage cost was the largest component of the total aeration cost (fig. 1). However, the interesting fact illustrated by figure 6 was that the centrifugal fan (cfan1), which supplied the highest airflow rate and required the largest investment cost, was lowest of the three fans in terms of shrinkage cost. The shrinkage cost for cfan1 ranged from approximately 59% to 63% of the total cost as the initial grain temperature increased. The least expensive axial fan (afan1) was identified to have the largest average shrinkage cost ranging from approximately 74% to 76% of the total aeration cost. The values in figure 6 indicate that on average, an aeration fan that delivers approximately three times the suggested minimum of 0.11 m^3/min/t (0.1 cfm/bu) could contribute substantially in reducing the amount of grain shrinkage during the aeration process.

The influence of fan size (afan1 and cfan1) on grain shrinkage is better demonstrated in figure 7, which compares the yearly shrinkage cost ($/t) for each fan from 1961 through 1990 at Lexington, Kentucky with a harvest date of 15 June and an initial grain temperature of 26.7°C (80°F). The data in figure 7 further illustrated a definite advantage of using fans with higher airflow rates when aerating wheat. The yearly shrinkage costs for cfan1 (fig. 7) were lower for all but 6 years of the 30−yr analysis. For those 6 years where cfan1 had higher cost, the difference between the two fans was less than $30 for the entire bin except for 1971.

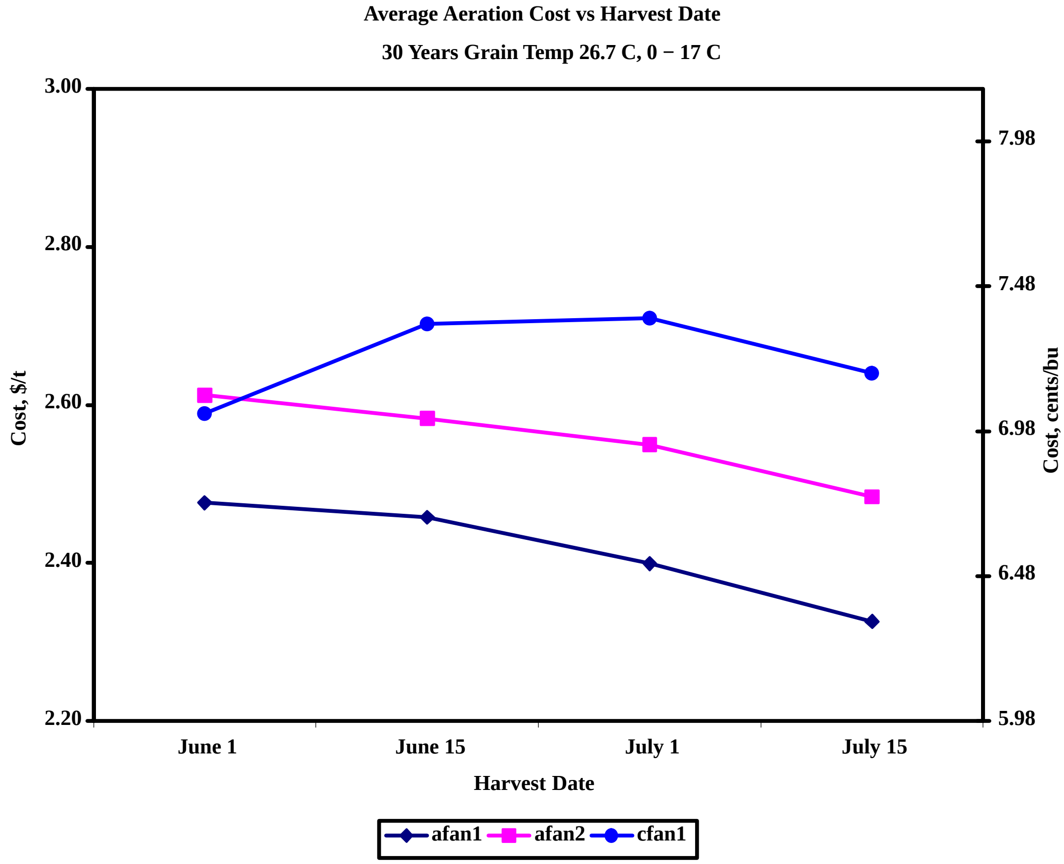


Figure 5. Average aeration costs in $/t and cents/bu vs. harvest date for the three fans in this study using 30 yrs of weather for Lexington, Kentucky, an initial grain temperature of 26.7˚C (80.0˚F) and an aeration temperature window of 0 to 17°C.

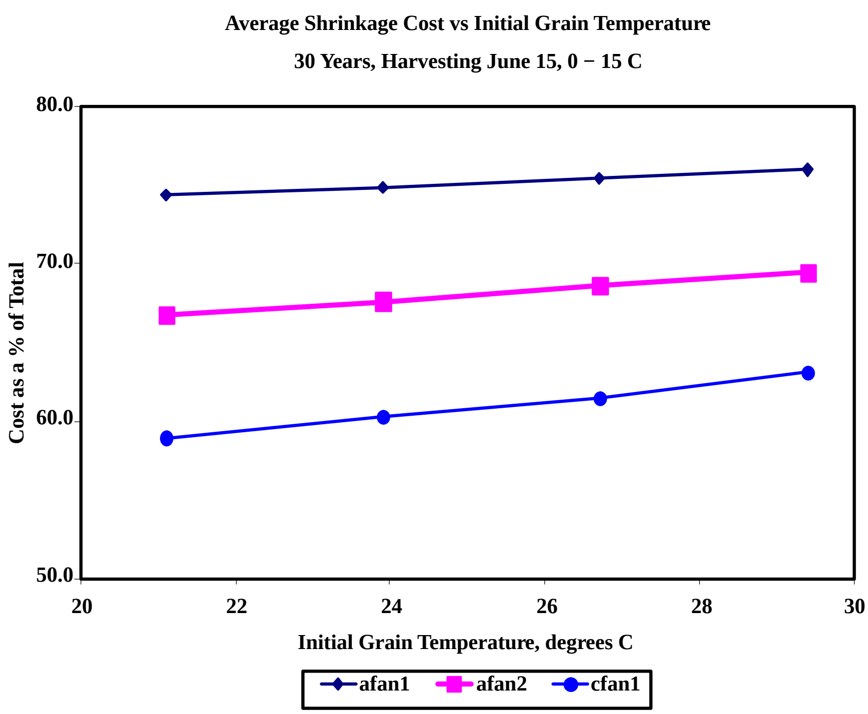


Figure 6. The average cost of the wheat shrinkage as a percent of the total aeration cost for the three fans in this study using 30 yrs of weather for Lexington, Kentucky, a 15 June harvest date and an aeration temperature window of 0 to 15°C.

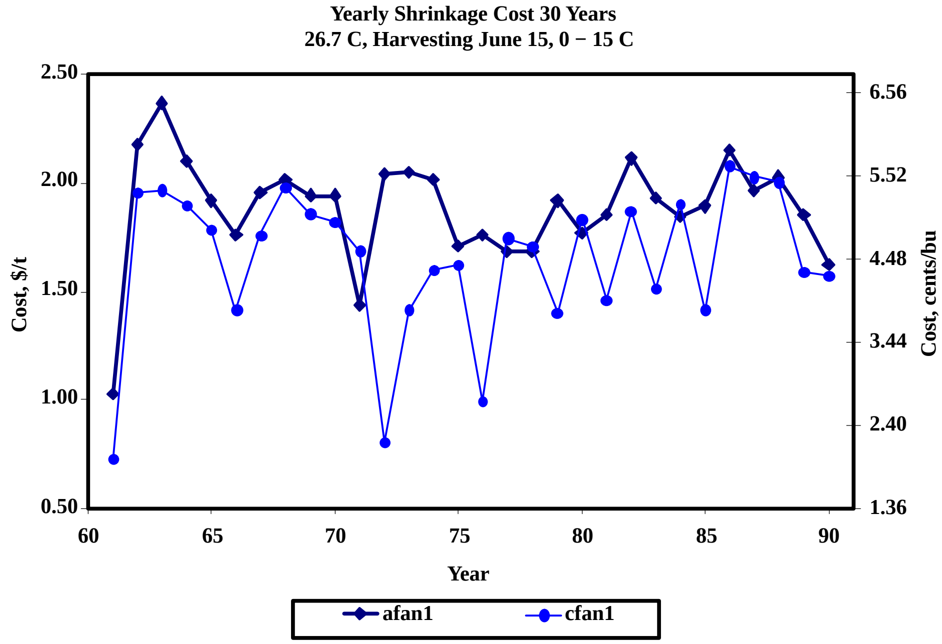


Figure 7. The yearly shrinkage cost ($/t) of wheat due to aeration for the fans afan1 and cfan1 in this study using 30 yrs of Lexington, Kentucky weather beginning harvest on 15 June, with an initial grain temperature of 26.7°C (80°F) and an aeration window of 0 to 15°C.

Dry Matter Loss (DML)

The effect of initial grain temperature on the average 30−yr component cost due to dry matter loss (DML) as a percentage of the total aeration cost for fans afan1, afan2 and cfan1 is shown in figure 8. The example in figure 8 uses the same harvest parameters as the example in figure 6 and showed a slight decrease in the cost with each fan as the temperature of the wheat increased. The cost in figure 8 was based on the amount of dry matter loss that occurred during the time required to cool the grain to 15°C and the initial value of the bin of wheat (table 2). While the DML costs are smaller, the results are similar to those shown for the cost of the shrinkage (fig. 6) with respect to fan. The DML cost for afan1 in figure 8 was about 10.5% of the total and this cost was reduced to 5% for cfan1. These results indicate that selecting an aeration fan that delivered airflow rates above the suggested minimum value would be beneficial in minimizing dry matter loss.

To further illustrate the point, data in figure 9 shows a comparison of the yearly DML cost for fans afan1 and cfan1 from 1961 through 1990 at Lexington, Kentucky. As with the shrinkage cost example, figure 9 had a harvest date of 15 June and assumed an initial grain temperature of 26.7°C (80°F). Figure 9 shows that the DML costs for cfan1 were lower than those for afan1 for all years of the 30−yr analysis.

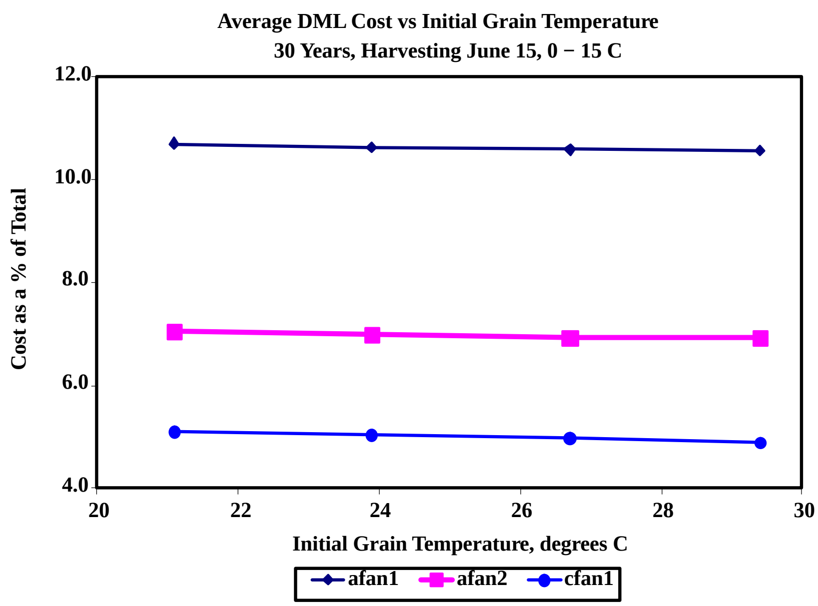


Figure 8. The average cost of the dry matter loss (DML) of wheat as a percent of the total aeration cost for the three fans in this study using 30 yrs of weather for Lexington, Kentucky, a 15 June harvest date and an aeration temperature window of 0 to 15°C.

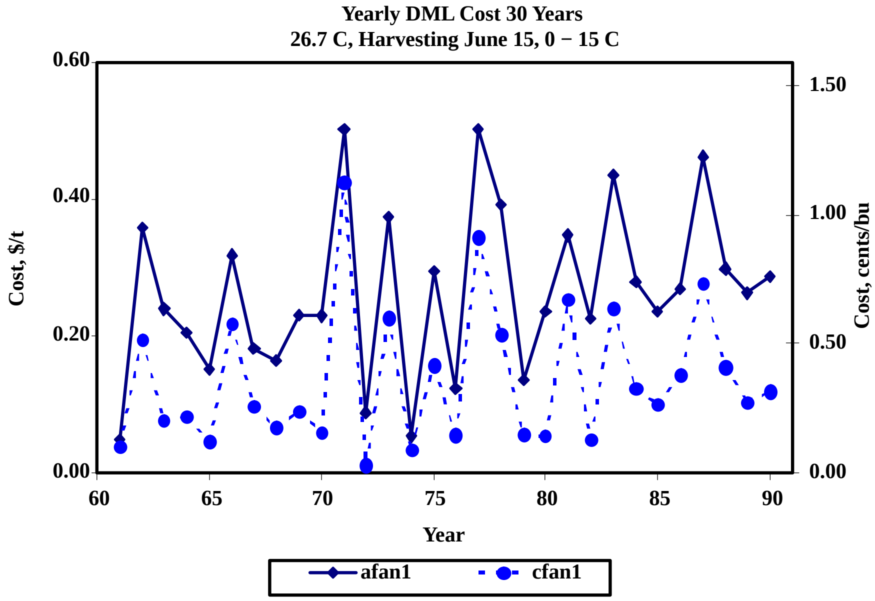


Figure 9. The yearly cost ($/t) of dry matter loss (DML) due to aeration for the fans afan1 and cfan1 in this study for 30 yrs of Lexington, Kentucky weather beginning harvest on 15 June, with an initial grain temperature of 26.7˚C (80˚F) and an aeration window of 0 to 15°C.

Discussion

In the mid−south region of the United States where winter wheat is harvested at warmer temperatures during the months of June and July, there is often a lack of sufficient weather conditions to cool the wheat to acceptable storage temperatures. To offset the lack of cooler weather, one alternative for wheat producers is to purchase a larger, more expensive aeration fan, thus decreasing the time required to move a cooling front through the grain mass when sufficient ambient air conditions are present. Considering the investment cost range for the fans investigated in this study ($709 to $1739), purchasing a larger fan may represent a significant increase in investment for the producer, depending on the number of fans required. However for the fans considered in this study, the results for the 30−yr average show that while the larger fans are more expensive, when all cost factors of the aeration process are considered the costs are not appreciably higher. For the scope of variables in this study, the average difference in total aeration cost between the least and most expensive fans ranged approximately from 0.20 to 0.26 $/t (0.54 to 0.71 cents/bu). This small cost difference should provide incentive for producers to consider choosing larger fans that provide increased airflow rates.

The decision for a producer to purchase a larger fan may be influenced by several factors. The analysis in this study considered list prices for the aeration fans. Grain equipment is often discounted and a reduced purchase price for a fan capable of delivering a higher airflow rate would make the larger fan a more attractive choice. Another consideration when purchasing equipment is the producer's individual tax bracket, which could offset some of the increased investment for a larger fan. Grain prices at market would be another factor. This analysis assumed a wheat value of $110.23/t ($3.00/bu) for the fan comparisons. A significant increase in market value of the wheat would make the shrinkage and DML costs in this analysis higher and accentuate the need for increased aeration capacity. The bottom line is that when possible, mid−south wheat producers should consider purchasing larger aeration fans because in most years, there is an insufficient amount of ambient conditions during harvest to cool the grain to desired temperatures levels for safe storage. Larger airflow rates would also allow for additional opportunities for automatic aeration controllers to minimize grain shrinkage and DML.

Summary

This study compared wheat aeration costs for two axial and one centrifugal aeration fans using 30 yrs of weather for the mid−south location Lexington, Kentucky. For the fan and bin combinations shown in this study, the three fans delivered approximately one, two and three times the recommended aeration airflow rate of 0.11 m^3/min/t (0.1 cfm/bu). Initial grain temperature, harvest date and aeration temperature window were varied to determine how each factor affected the costs for each fan. Generally for each fan, the aeration cost increased with higher temperatures and decreased as harvest occurred later in the year. Using a larger aeration temperature window did not significantly decrease the cost of aeration. The total aeration cost generally was smaller for the least expensive axial fan and increased slightly on a per volume basis as the more expensive fans were considered. However, it was shown that as the airflow rate increased, the amount of shrinkage and dry matter loss (DML) in the aeration process decreased. This decrease in shrinkage and DML is significant in two respects; first, the reductions in shrinkage and DML aid in offsetting the increased cost for larger fans and second, less shrinkage and DML should increase the volume and quality of the wheat at market time.

REFERENCES

Armitage, D. M., D. R. Wilkin, and P. M. Cogan. 1991. The cost and effectiveness of aeration in the British climate. *Proc. 5th Int. Working Conf. on Stored Prod. Prot.*, eds. F. Fleurat−Lessard and P. Ducom. 1925−1933. Wallingford, Oxfordshire, UK: CABI Publishing.

ASAE Standards. 1994. D272.2 Resistance to airflow of grains, seeds, other agricultural products, and perforated metal sheets. St. Joseph, Mich.: ASAE.

Arthur, F. H., and P. W. Flinn. 2000. Aeration management for stored hard red winter wheat: simulated impact on rusty grain beetle (coleoptera: cucujidae) populations. *J. of Economic Entomology* 93(4): 1364−1372.

Brooker, D. B., F. W. Bakker−Arkema, and C. W. Hall. 1992. *Drying and Storage of Grains and Oilseeds*, Chapter 14. New York: Van Nostrand Reinhold.

Burgess, H. D., and N. J. Burrell. 1964. Cooling bulk grain in the British climate to control storage insects and improve keeping quality. *J. of Scientific Food and Agriculture* 15(1): 32−50.

Casada, M. E., and A. Alghannam. Aerating over−dry grain in the Northwest. *Transactions of the ASAE* 42(6): 1777−1784.

Epperly, D. R. 1989. Effects of airflow rates on cooling time and temperature distribution in aerated wheat. Unpublished PhD diss. Stillwater, Okla.: Oklahoma State University.

Fraser, B. M., and W. E. Muir. 1981. Airflow requirements predicted for drying grain with ambient and solar−heated air in Canada. *Transactions of the ASAE* 24(1): 208−210.

GEAPS. 1989. Control aeration costs while maintaining grain quality. *Grain* 9(10): 4.

Hansen, D. J., W. F. Wilcke, and R. V. Morey. 1996. WINFANS:A computer program for selecting crop drying fans and determining airflow. Biosystems and Agricultural Engineering Department. University of Minnesota Extension Service St. Paul, Minn.

Harner, J. P., and D. W. Hagstrum. 1990. Utilizing high airflow rates for aerating wheat. *Applied Engineering in Agriculture* 6(3): 315−321.

Maier, D. E. 1992. The chilled aeration and storage of cereal grains. Unpub. PhD thesis. East Lansing, Mich.: Michigan State University.

Mani, S., P. W. Flinn, W. E. Muir, D. S. Jayas, and N. D. G. White. 2001. Two models of grain temperatures and insect populations in stored wheat. *Transactions of the ASAE* 44(3): 655−660.

Montross, M. D., and D. E. Maier. 2000a. Simulated performance of conventional high−temperature drying, dryeration and combination drying of shelled corn with automatic conditioning. *Transactions of the ASAE* 43(3): 691−699.

Montross, M. D., and D. E. Maier. 2000b. Reconditioning corn and soybeans to optimal processing moisture contents. *Applied Engineering in Agriculture* 16(5): 527−535.

Montross, M. D., S. G. McNeill, and T. C. Bridges. 2003. Seasonal aeration rates for the eastern United States based on long−term weather patterns. *Applied Engineering in Agriculture* 20(5): 665−669.

Navarro, S., and R. E. Noyes. 2002. *The Mechanics and Physics of Modern Grain Aeration*, Ch 7, ed. S. Navarro and R. Noyes, 315−412. Boca Raton, Fla.: CRC Press.

Reed, C., and J. Harner III. 1998a. Cooling of stored wheat in multiple or single cycles using automation aeration controllers. *Applied Engineering in Agriculture* 14(5): 497−500.

Reed, C., and J. Harner III. 1998b. Thermostatically controlled aeration for insect control in stored hard red winter wheat. *Applied Engineering in Agriculture* 14(5): 501−505.

Sinicio, R., and W. E. Muir. 1998. Aeration strategies for preventing spoilage of wheat stored in tropical and subtropical climates. *Applied Engineering in Agriculture* 14(5): 517−527.

Zink, D. J. 1998. Optimization of popcorn conditioning and storage strategies. Unpublished M.S. thesis. W. Lafayette, Ind.: Purdue University.