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Seasonal Aeration Rates for the Eastern United States Based on Long-Term Weather Patterns

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

Abstract. *Most aeration fans are sized to produce a minimum airflow rate of 0.1 m^3/min/t (0.1 cfm/bu) in on−farm grain storage structures. At this airflow rate a significant amount of time is required to move a cooling front completely through a bin. The desired grain temperature and prevailing weather conditions will have a significant effect on required fan size. Thirty years of weather data were analyzed for the eastern United States to determine the amount of time available in temperature windows between 0 to 15 °C and 0 to 17 °C. Contour maps were generated with ArcMap 8.3 for the percentage of each month within the given temperature windows. A substantial amount of time (over 4% of the month) is available within temperature limits of 0 and 17 °C between September and April. This indicates that airflow rates of at least 0.6 m^3/min/t (0.5 cfm/bu) would be more adequate to completely move an aeration front through a bin for summer harvested grain in Southern regions of the United States. However, during July and August only the northern half of the United States would have a sufficient amount of time available for cooling grain below 17 °C using an airflow rate of 0.1 m^3/min/t (0.1 cfm/bu). The maps generated provide a starting point for sizing aeration fans in the eastern United States.*

Keywords. *Stored product, Temperature, Fan, Control.*

Grain that is stored for long periods of time is generally aerated to maintain product quality and reduce the risk of storage losses due to insects and mold growth. A general recommendation is that the temperature of the stored grain should be kept within ±5.5°C of the average monthly temperature, but not to exceed 15°C in the warmer months or less than 0°C during the winter (Navarro and Noyes, 2001). This recommendation generally works well to maintain grain quality in the Midwestern United States but may not be practical with grains such as winter wheat, which are often placed into storage at warmer temperatures due to the timing of harvest. In addition, ambient temperatures during the late summer (August and September) corn and milo harvest in the mid−South are generally considerably greater than temperatures in the Midwest. For example, in the mid−south region of the United States, corn and wheat may often be harvested in the 20°C to 30°C temperature range and the high ambient temperatures and relative humidities in this region often prevent grain from being cooled to desirable storage temperatures.

Another 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 to prevent insect and mold development. The recommended minimum airflow rate for most on−farm aeration systems is generally 0.1 m^3/min/t (0.1 cfm/bu). Assuming that weather conditions are favorable, several days may be required to cool the grain.

The time required to move a temperature front through a grain bin is primarily a function of airflow rate (fan size). Weather conditions dictate the appropriate airflow rate and aeration strategies for producers in different regions of the country. The amount of time required for cooling grain is a function of the airflow rate, air temperature and relative humidity of the air. If drying occurs during aeration, evaporative cooling effects will significantly reduce the amount of time required to cool a bin. A wide range in the amount of time required to cool a bin using calculated and experimental conditions have been determined and reported in the literature (Navarro and Noyes, 2001). The greatest amount of time required for cooling a bin was given by Armitage et al. (1991) and the lowest amount of time required was given by Epperly (1989) and Miller (1965).

At an airflow rate of 0.1 m^3/min/t (0.1 cfm/bu), the predicted cooling time ranged from 100 (Epperly, 1989) to 225 h (Armitage et al., 1991). Using an airflow rate of 0.2 m^3/min/t (0.2 cfm/bu) the predicted cooling time ranged from 50 (Epperly, 1989) to 115 h (Armitage et al., 1991). An approximation of the time (in hours) required to move a temperature front through a grain bin is 16.5 divided by the airflow rate in m^3/min/t (15 divided by the airflow rate in cfm/bu) (GEAPS, 1989). This estimated time is based on an assumption of high humidity conditions where evaporative cooling effects would be negligible. Although there is considerable variation in the predicted amount of time required to cool a bin, rough estimates can be developed that would assist in sizing aeration fans. Summer aeration of wheat would typically occur at night under high humidity conditions, when evaporative cooling effects would be minimal.

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Literature Review

Computer simulation is a popular research tool that has long been used to investigate the dynamics of grain drying and storage systems, especially where historical weather data is available. Grain aeration has been the subject of numerous studies in the literature. Early efforts involving aeration used corn as the grain of choice, but in recent years several investigations have considered stored wheat. Harner and Hagstrum (1990) investigated high airflow rates for cooling wheat during the summer. They determined that an airflow rate of 1.7 m^3/min/t (1.5 cfm/bu) would allow Kansas producers to cool wheat by an average of 6°C with approximately 9 h of fan operation. This airflow rate had the potential to reduce insect population growth by 80% to 97%.

Arthur et al. (1998) used recorded weather data from 11 southern states to determine the optimum activation temperature for cooling corn after harvest during September and October. Aeration using temperature limits of 15.6°C or 18.3°C with an airflow rate of 0.1 m^3/min/t (0.1 cfm/bu) resulted in the lowest predicted maize weevil population.

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 beginning shortly after harvest.

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, Manitoba, Canada, and Topeka, Kansas, and showed larger insect population 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 has not been much published research concerning the aeration of stored wheat in the mid−south region of the United States. As Arthur and Flinn (2000) showed, 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. This raises questions for the wheat producer in the mid−south as to what type of aeration equipment to use and what strategies would be most advantageous. Aeration fan controllers have great capabilities, but if few cooling periods exist, then sophisticated equipment will not solve the problem.

In the mid−south region, weather conditions limit the effectiveness of aeration with low airflow rates. To cool grain during the months between June and September, a producer may be required to consider aeration fans that will supply a higher airflow rate than the traditionally recommended 0.1 m^3/min/t. If the producer were to select a fan that doubled the airflow rate, this fan would reduce the required time to cool a bin by 50%, but would increase the fan horsepower by a factor of approximately 4. Higher airflow rates could be readily achievable by limiting the eave height (or grain depth) or increasing fan horsepower. Higher airflow rates may be beneficial to producers in certain circumstances, such as cooling grain during July and August to limit insect development (Harner and Hagstrum, 1990).

The objectives of this article were to determine the amount of time available during summer and fall that would be available for aerating grain and generate data that could be used to develop recommendations for the minimum airflow rate required for different locations in the eastern United States.

Methods

When wheat is harvested at warm temperatures (20°C to 30°C), the grain is generally cooled to 15°C as weather conditions permit, to reduce the risk of insect damage and mold growth. One consideration is the amount of time required to cool the grain and the availability of ambient conditions suitable for reducing the temperature. The necessary ambient conditions will vary by location and time of the year. Hourly weather data from the National Climatic Data Center (1993) between the years of 1961 and 1990 were used for the weather analysis. A total of 143 weather stations were utilized to generate maps of available runtime. The available runtime in the eastern grain production area of the United States were analyzed between temperatures of 0°C and below a temperature of 15, 16, 17, and 18°C, respectively. No limits were applied to the relative humidity or equilibrium moisture content.

To move a temperature front completely through a bin of grain, the estimated time required to run the fan would be 150 h [approximately 20.5% of the time available in an average month (30.4 days)] at an airflow rate of 0.1 m^3/min/t (GEAPS, 1989). The amount of time estimated using the equation from GEAPS would produce a worst−case estimate of the time required to cool a bin. The time required is based on a high humidity condition that would limit evaporative cooling and would result in a conservative estimate of the time required to cool a bin. This value should be sufficient as a design value due to the safety factor built into the assumption. However, the weather conditions during summer and early fall would probably have high humidity conditions. As a result, the GEAPS rule of thumb is used to estimate cooling times.

A custom program using Visual Basic 6.0 (Microsoft Corporation, Redmond, Wash.) was written to calculate the 30−year average time available per month with specified temperature limits. The 30−year average percent fan runtime for each month was then imported into ArcMap 8.3 (ESRI, Redlands, Calif.). Ordinary Kriging was used to generate contours at intervals of 1.0, 2.1, 2.8, 4.2, 8.3, 20.8, and 41.7% of the month that would correlate to an approximate airflow rate of 2.2, 1.1, 0.8, 0.6, 0.3, 0.1, and 0.06 m^3/min/t (2.0, 1.0, 0.75, 0.5, 0.25, 0.1, and 0.05 cfm/bu).

Results and Discussion

The average and standard deviation of the available time each month with temperature windows below 15, 16, 17, and 18°C in Minneapolis, Evansville, Wichita, and New Orleans are shown in figure 1. Approximately 11.2% of the month of August is below 15°C in Minneapolis, and approximately 4.0% of the month is below 15°C in Evansville. This data indicates the importance of considering airflow rate and temperature limits for aeration recommendations in southern regions of the United States. Increasing the temperature window from 15°C to 17°C doubled the amount of time available for fan operation in Evansville. This indicated that the airflow rate required to move a temperature front completely through a bin with a temperature limit of 15°C would be approximately 0.6 m^3/min/t, however 0.3 m^3/min/t would be required with a temperature limit of 17°C. The appropriate temperature limit and fan size will allow producers to minimize their risk in aerating stored grain. The standard deviation of the runtime indicates that there is substantial variability in the amount of time available at each location in figure 1 and was true for all locations analyzed. Increasing the temperature range increased the standard deviation at each location. The variability would be less of a problem when a large amount of time was available for fan operation because slightly larger fans could be specified that would not be as significantly affected by seasonal weather patterns as small fans.

Figures 2 through 7 show the contour lines of percent available runtime with temperature limits between 0 and 15°C and 0 and 17°C in the months between April and September. During April (fig. 2), two−thirds of the United States had more than 41.7% of the month available for fan

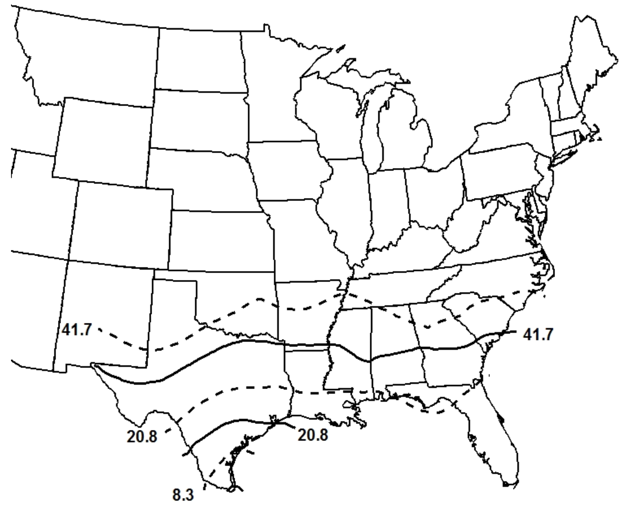

Figure 2. Contour lines of percent available runtime with a temperature window of 0 to 15°C (− − −) and 0 to 17°C (—) during the month of April. (Numbers on the left side of the graph correspond to a temperature window of 0 to 15°C and numbers on the right side correspond to a temperature window of 0 to 17°C).

operation when the temperature limits were between 0 and 17°C. Data from figure 2 indicated that an airflow rate of 0.06 m^3/min/t (0.05 cfm/bu) would be adequate to cool the bin to a temperature below 17°C in most of the eastern United States.

By May (fig. 3) the southern United States has relatively little time below 17°C. Above Oklahoma, Arkansas, Tennessee, and North Carolina, more than 20% of the month is below 17°C and an airflow rate of 0.1 m^3/min/t (0.1 cfm/bu) would be adequate for ambient aeration cooling.

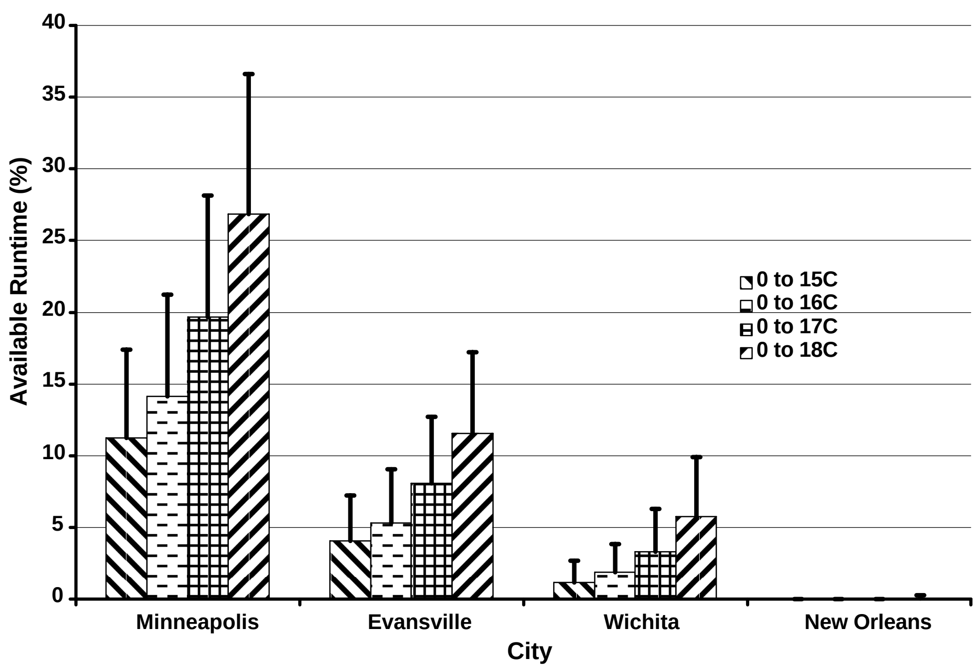

Figure 1. Average available runtime and standard deviation during the month of August with temperature limits between 0 and 15°C, 0 and 16°C, 0 and 17°C, and 0 and 18°C and no relative humidity limits in Minneapolis, Minnesota; Evansville, Indiana; Wichita, Kansas and New Orleans, Louisiana.

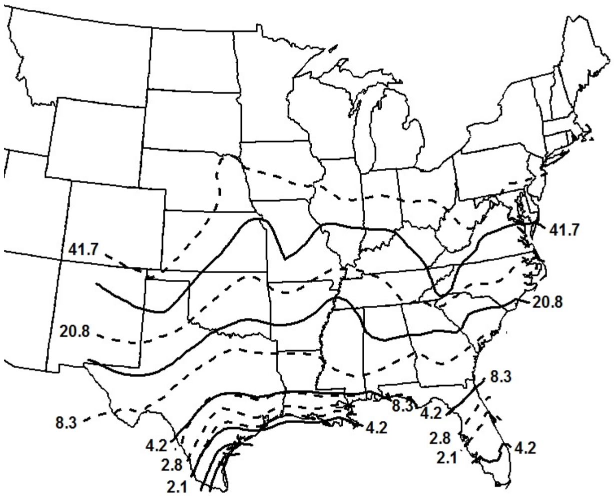

Figure 3. Contour lines of percent available runtime with a temperature window of 0 to 15°C (– – – –) and 0 to 17°C (—) during the month of May. (Numbers on the left side of the graph correspond to a temperature window of 0 to 15°C and numbers on the right side correspond to a temperature window of 0 to 17°C).

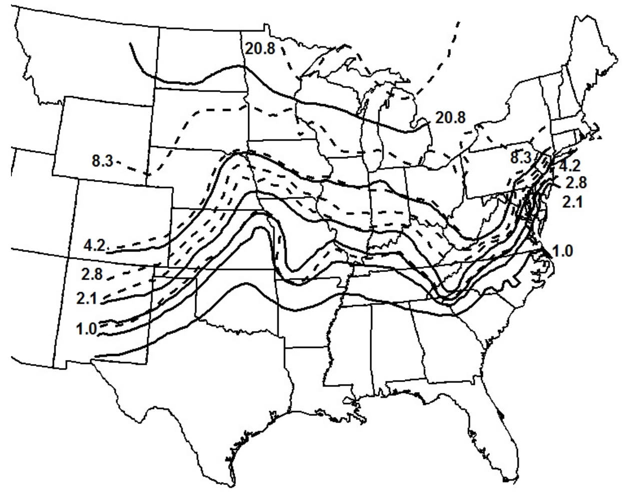

Figure 5. Contour lines of percent available runtime with a temperature window of 0 to 15°C (– – – –) and 0 to 17°C (—) during the month of July. (Numbers on the left side of the graph correspond to a temperature window of 0 to 15°C and numbers on the right side correspond to a temperature window of 0 to 17°C).

Figure 4 shows the contour lines for June. In Minneapolis, Minnesota, the percentage of time below 15°C and 17°C was approximately 20% and 27%, respectively. The changes in contour values are very large in some regions of the map and reading exact numbers from the contour map is subjective. However, for Evansville, Indiana, the time below 15°C and 17°C was 6% and 10%, respectively. This amount of time would indicate that an airflow rate of approximately 0.1 m^3/min/t (0.1 cfm/bu) would be sufficient in Minneapolis to reduce the grain temperatures to between 15°C and 17°C but 0.28 m^3/min/t (0.25 cfm/bu) would be required in Evansville. Wichita, Kansas, has similar temperatures to Evansville, Indiana, and would require approximately the same airflow. However, New Orleans, Louisiana, has less than 1% of the month available for fan operation with ambient temperature limits.

During July (fig. 5), there is little time available for ambient aeration cooling in the southern third of the United States. Evansville, Indiana, has 1.5% and 3.4% of the month of July available for fan operation if the temperature limits were set to 15°C and 17°C, respectively. This amount of time would require airflow rates between 0.8 and 2.2 m^3/min/t (0.75 and 2.0 cfm/bu) to achieve average grain temperatures of 15°C and 17°C, respectively. This grain temperature could prove advantageous to producers trying to minimize insect development after harvest. Data from Harner and Hagstrum (1990) indicated that airflow rates as high as 1.6 m^3/min/t

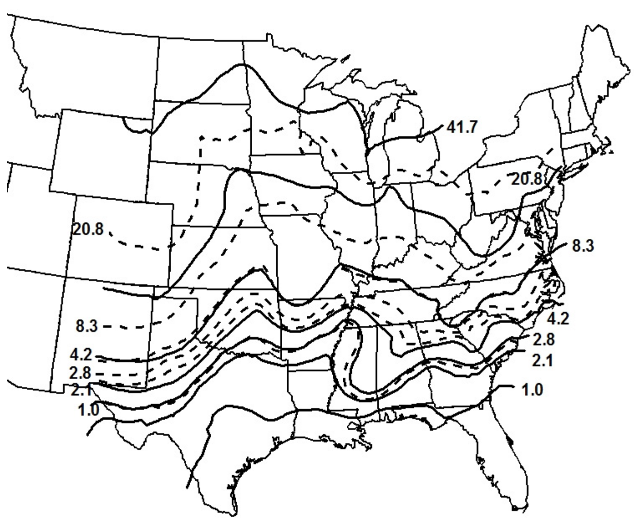

Figure 4. Contour lines of percent available runtime with a temperature window of 0 to 15°C (– – – –) and 0 to 17°C (—) during the month of June. (Numbers on the left side of the graph correspond to a temperature window of 0 to 15°C and numbers on the right side correspond to a temperature window of 0 to 17°C).

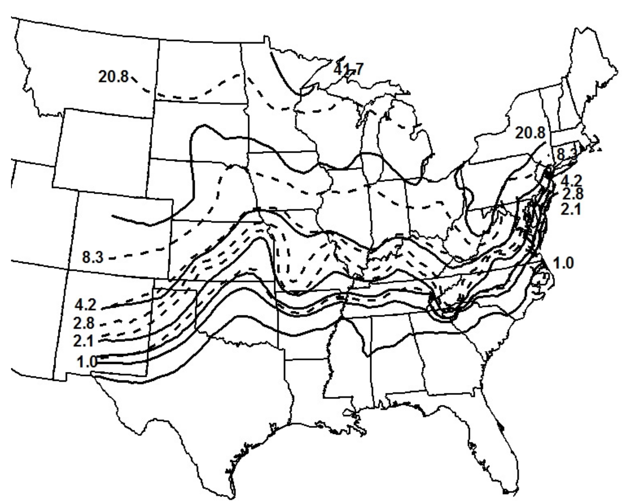

Figure 6. Contour lines of percent available runtime with a temperature window of 0 to 15°C (– – – –) and 0 to 17°C (—) during the month of August. (Numbers on the left side of the graph correspond to a temperature window of 0 to 15°C and numbers on the right side correspond to a temperature window of 0 to 17°C).

(1.5 cfm/bu) would be beneficial to producers in limiting insect development in Kansas. In contrast, Minneapolis has over 8% and 15% of the month of July available for fan operation with temperature limits of 15°C and 17°C, respectively. Available weather 8% of the month indicated that airflow rates as low as 0.1 m^3/min/t (0.1 cfm/bu) would be sufficient to cool wheat to approximately 17°C. Increasing the temperature window in warm climates would affect the amount of available runtime, although this was not considered.

Figure 7 shows the percentage of September available for fan operation with temperature limits below 15°C and 17°C. An airflow rate of 0.1 m^3/min/t (0.1 cfm/bu) would be sufficient to cool grain in the fall for the majority of the eastern United States. The majority of the eastern United States had more than 20% of the time in September with temperatures below 15°C or 17°C.

Conclusions

The contour maps generated provide a starting reference point for sizing aeration fans and temperature limits within the eastern United States. The plots were based on 30 years of historical weather data and indicate the potential benefits of changing airflow rates and temperature limits. Using conservative estimates of the time required to cool summer harvested grain, an approximate airflow rate can be determined.

During July and August, only the northern half of the United States would have a sufficient amount of time available for cooling grain below 17°C using an airflow rate of 0.1 m^3/min/t (0.1 cfm/bu). However, most of the mid−South of the United States would have sufficient time available to cool wheat during July and August if the airflow rates were between 0.8 and 2.2 m^3/min/t (0.75 and 2.0 crfm/bu). A substantial amount of time (over 4% of the month) which correlates to an airflow rate of 0.6 m^3/min/t (0.5 cfm/bu) is available within temperature limits of 0 and 17°C in the months between September and April, including much of the southern United States.

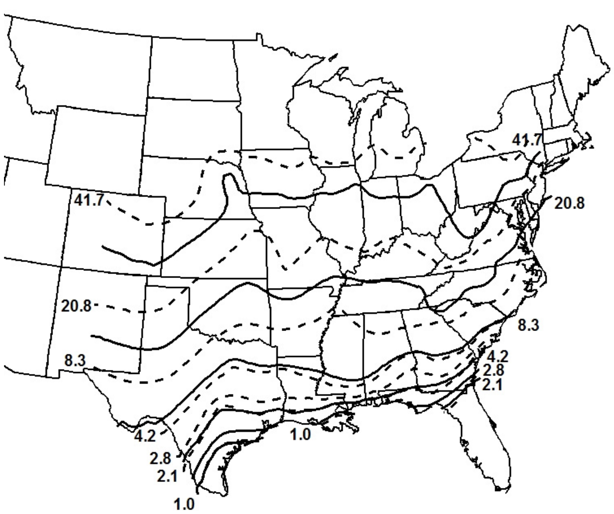

Figure 7. Contour lines of percent available runtime with a temperature window of 0 to 15°C (− − − −) and 0 to 17°C (—) during the month of September. (Numbers on the left side of the graph correspond to a temperature window of 0 to 15°C and numbers on the right side correspond to a temperature window of 0 to 17°C).

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