HISTORICAL WEATHER DATA AND PREDICTED AERATION COOLING PERIODS FOR STORED RICE IN ARKANSAS

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ABSTRACT. *Historical weather data were used to partition Arkansas into southern, central, and northern zones, based on the number of hours that ambient air temperatures were below 15°C in September and October between 1990-1999. Data from one site from each zone were analyzed to predict how quickly rice could be cooled in early autumn to 15°C, the lower limit of development for most stored-product insects, using airflow rates of 0.08, 0.4, and 0.8 m^3/min/m^3 (0.1, 0.5, and 1.0 cubic feet per minute, CFM, per bushel), and different initial storage dates. The durations required for cooling decreased as the airflow rate increased, and fewer cooling days were required with later initial storage dates. Predicted durations required to cool rice to 15°C, using the lowest airflow rate of 0.08 m^3/min/m^3, ranged from 15 to 35 days, 6 to 20 days, and 5 to 18 days, in the weather stations chosen to represent the southern, central, and northern zones, respectively, depending on the initial storage date. Increasing the airflow from 0.08 to 0.4 m^3/min/m^3 yielded a predicted decrease in cooling durations of about 3 to 7 days. Increasing the airflow rate from 0.4 to 0.8 m^3/min/m^3 gave only a one- or two-day decrease in predicted cooling durations to reach 15°C. Cooling durations were also determined for the same three airflow rates for a second cooling cycle, beginning 1 November and cooling to 7.2°C. Results of these studies show that temperatures during autumn could be used to cool stored rice in Arkansas using low-volume aeration.*

Keywords. Stored rice, Aeration, Cooling, Insects.

Aeration for insect management in stored grain can be defined as using low airflow rates of ambient air to cool a bulk grain mass. When used in this manner aeration is considered grain temperature management, not moisture content control. Typical airflow rates recommended for stored wheat are 0.08 m^3/min/m^3 (0.1 ft^3/min/bu, 0.1 CFM/bu) or less (Foster and Tuite, 1982; Noyes et al. 1992; Reed and Arthur, 2000). Grain drying utilizes higher airflow rates to remove moisture instead of heat, and these systems often involve the use of heated air (Reed and Arthur, 2000). Controlled aeration for specified durations using defined temperature setpoint thresholds have been tested in field studies of stored wheat (Reed and Harner, 1998ab). Results of model simulation studies show the potential for the expanded use of aeration in management programs for stored wheat (Flinn et al., 1997; Arthur and Flinn, 2000).

Aeration for fall crops is often used for two cooling cycles, one for early autumn and one for late autumn. The first cycle cools the grain mass to 15°C (60°F), which is the lower limit of development for most stored-grain insects (Fields, 1992), the second cools to 7.2°C (45°C). However, these optimal temperatures can be varied depending on the specific needs of the crop or the region. Aeration seldom kills insects, especially in the southern United States where winters are comparatively mild. Instead, aeration limits insect development by lowering the temperature of the grain mass.

Historical weather data can be used to predict hours of temperature accumulation below defined temperature thresholds. At 0.08 m^3/min/m^3, 120 h below a specified temperature are required to cool a grain mass to that temperature. As the airflow rate increases, the time required to cool the bin proportionally decreases; at 0.8m^3/min/m^3 only 12 h are needed to cool a grain bin to a desired temperature (McCune et al., 1963; Noyes et al., 1992). Noyes et al. (1992) also contains a table giving the hours required to push a cooling front through a grain mass at different airflow rates. Previous model simulation studies have shown the potential benefits for aeration management for corn stored in the southern and northern United States (Arthur et al., 1998, 2001), and the concepts could be expanded to other systems.

Another method for utilizing historical weather data for aeration management is to combine bin-cooling models with insect population models, as has been done for development of the maize weevil, *Sitophilus zeamais* (L.) on corn (Maier et al., 1996), and the rusty grain beetle, *Cryptolestes ferrugineous* (Stephens) on wheat (Flinn et al., 1997). Currently these methods are complex and require hourly weather data for engineering models for precise and accurate bin-cooling models. Similarly, the insect population models are based on developmental time for individual life stages (Throne, 1994), and are usually relevant to a single insect species applied to a particular commodity. Currently no data are available for development of the lesser grain borer, *Rhyzopertha dominica* (Fauvel) or the rice weevil, *Sitophilus oryzae* (L) on stored rough rice.

Article was submitted for review in March 2004; approved for publication by the Food & Process Engineering Institute Division of ASAE in June 2005.

This article reports the results of research only. No recommendations are implicit or implied by either the University of Arkansas or the U. S. Department of Agriculture.

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Rice harvest and storage in Arkansas occurs primarily in September and October. Specific storage dates vary with location, and weather data can be used to estimate the durations required to reach target grain temperatures in different regions within Arkansas. The objectives of this study were to: 1) determine appropriate climatic zones within Arkansas having similar potential for cooling rice, 2) predict durations needed to cool rice stored in each zone first to 15°C, then to 7.2°C, and 3) determine effects of airflow rate and binning date on durations needed for cooling.

Materials and Methods

Historical weather data were obtained for 1990-1999 from EarthInfo (Boulder, Colo.). Data are available for approximately 90 stations in Arkansas, however, some stations were eliminated because of incomplete records during the selected 10-year period, or too much missing data during the months of September through December for an individual year during 1990-1999. Occasionally, temperature data for a date were missing, and values were interpolated from the adjacent dates. Also, some stations were so close together that near-duplicates were eliminated. After this reduction, data from 49 stations distributed throughout Arkansas were used.

For each station and year, the total hours below 15°C from 1 September to 31 October were calculated using a model written in QBASIC. The model calculates the number of hours each day that are below the specified temperature, based on daily low and high temperatures and sunrise and sunset times. Daily sunrise and sunset data for each weather site were obtained from the Web site of the U.S. Naval Observatory (http://aa.usno.navy.mil/data/docs).

A complete description of the QBASIC model has been previously published (Arthur and Johnson, 1995).

Data for each year for each station were calculated and the results for each of the 10 individual years were averaged using the Means Procedure of the Statistical Analysis System (SAS Institute, 2002). Contour maps were then created using Surfer software, then re-drawn using MapViewer software (Golden Software, Golden Colo.). Arkansas was partitioned into "climatic zones" based on the number of hours below 15°C from 1 September to 31 October. One city from each zone was selected for further analysis to determine how quickly rice stored in each site could be cooled with aeration using three airflow rates, 0.08, 0.4, and 0.8 m^3/min./m^3 (0.1, 0.5, and 1.0 cubic feet per minute, CFM, per bushel). These rates were chosen because the low rate of 0.08 m^3/min/m^3 is typically used for corn and wheat, while the highest rate of 0.8m^3/min/m^3 was used for aeration in stored rice because fans are usually sized for drying (Ranalli et al., 2002).

The beginning of the cooling period for a particular climatic zone was determined by selecting an initial (or beginning) storage date based on rice production data from the Arkansas Cooperative Extension Service. Cooling durations were determined based on this average date; however, calculations were also made for one and two weeks prior to and after the selected dates, to account for potential variation in any particular year. For the late autumn cooling to 7.2°C, the beginning date was chosen as 1 November for all selected sites because by that time autumn cooling had occurred at all sites.

Results and Discussion

The predicted number of hours in which ambient temperatures were below 15°C in Arkansas from 1 September to 31 October ranged from 367 ± 23 in the southeast to 669 ± 29 in the northwest. Initially, Arkansas was partitioned into four general areas or zones based on the hours below 15°C (fig.1), zone 1, < 400 h; zone 2, 400-480 h; zone 3, 481-560 h; zone 4, > 560 h. However, the Ozark mountain range comprised most of the northernmost zone 4, and since there is little rice grown in that region, this zone was eliminated from further discussion. The three remaining zones (1, 2, and 3) were denoted as the southern, central, and northern zones for rice storage in Arkansas. Most of the rice grown in Arkansas is produced in the eastern portion of the state, and although 49 weather stations were used to generate the general climatic map, only the hours below 15°C in those cities or weather station locations from counties that produced at least 45,454,545 kg (or one million hundred weights) of rice, based on crop statistics for 2001 and 2002 reported by the Arkansas Agricultural Statistical Service, are listed for each zone (table 1, fig. 2). The central zone comprises the major rice-producing and storage regions of Arkansas. Temperatures throughout this region are fairly homogeneous, with little north to south variation in predicted accumulated hours below 15°C, and much of the variation in temperature was from factors other than a north-south temperature gradient.

The cities of Eudora, Stuttgart, and Corning were selected to represent the southern, central and northern zones (fig. 2, numbers 1, 8, and 16, respectively), and the average initial or beginning dates that rice would be stored at each site were chosen as 15, 22, and 29 September, respectively. The predicted durations required for cooling decreased as the airflow rate increased, and fewer days between initial storage and the rice temperature reaching 15°C were required with later initial storage dates. At Eudora, the predicted durations required to cool rice to 15°C, using airflow rates of 0.08, 0.4, and 0.8 m^3/min/m^3 ranged from 15 to 35 days, 6 to 20 days, and 5 to 18 days, respectively, depending on the initial storage date (table 2). The highest rate of 0.8 m^3/min/m^3 decreased the predicted cooling durations by as much as two days at any given initial storage date because at airflow rates of 0.8 and 0.4 m^3/min/m^3, 12 and 24 h, respectively, are needed to cool the grain mass to a specified temperature. Similar results occurred in the simulations for Stuttgart and

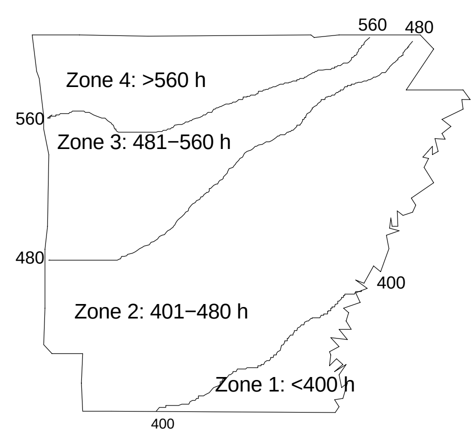

Figure 1. Delineation of generalized climate zones in Arkansas based on the indicated number of hours in which the ambient temperature was below 15°C from 1 September to 31 October.

Table 1. **Average number of hours (± SEM) in which the ambient temperature was below 15°C (60°F) from 1 September to 31 October in each year from 1990-1999, at selected weather sites from counties in Arkansas that produced at least 45,454,545 kg (one million cwt, or 100 lb) of rice in 2001 and 2002.[a]**

Zone 1	1.	Eudora	367 ± 23
	2.	Dumas	377 ± 20
	3.	Dermott	399 ± 20
Zone 2	4.	Helena	401 ± 23
	5.	Pine Bluff	402 ± 24
	6.	Warren	424 ± 20
	7.	DesArc	427 ± 20
	8.	Stuttgart	427 ± 20
	9.	Blytheville	430 ± 23
	10	Paragould	438 ± 19
	11	Batesville	455 ± 24
	12	West Memphis	456 ± 29
	13	Wynne	477 ± 14
	14	Clarendon	478 ± 27
	15	Sheridan	480 ± 24
Zone 3	16	Corning	518 ± 30
	17	Pocahontas	550 ± 19

[a] Approximate locations of each site are shown on figure 2.

Table 2. Theoretical number of calendar days (mean ± SEM of values for each year from 1991-2000) required to cool stored rice to 15°C in Eudora, Stuttgart, and Corning, Arkansas, using airflow rates of 0.08, 0.4, and 0.8m^3/min/m^3,beginning at the indicated initial storage dates.

Initial Storage Date	0.08m^3/min/m^3	0.4m^3/min/m^3	0.8m^3/min/m^3
Eudora			
1 September	35 ± 2	20 ± 2	18 ± 2
8 September	28 ± 2	13 ± 2	11 ± 2
15 September	22 ± 2	9 ± 2	7 ± 2
22 September	15 ± 2	5 ± 1	4 ± 1
29 September	15 ± 1	5 ± 1	4 ± 1
Stuttgart			
8 September	26 ± 2	13 ± 2	6 ± 2
15 September	20 ± 2	8 ± 2	6 ± 2
22 September	16 ± 1	6 ± 2	4 ± 1
29 September	14 ± 1	4 ± 1	3 ±" 1
6 October	11 ± 1	4 ± 1	2 ± 1
Corning			
15 September	16 ± 2	7 ± 2	5 ± 2
22 September	14 ± 1	4 ± 1	2 ± 1
29 September	12 ± 1	4 ± 1	3 ± 1
6 October	10 ± 1	3 ± 1	2 ± 1
13 October	11 ± 2	2 ± 1	2 ± 1

Corning. A larger incremental increase in required cooling durations was evident when using 0.4 compared to 0.08 m^3/min/m^3, especially at the earlier storage dates (usually 7 to 14 days earlier). However, even his one- or two-day gain in cooling durations may be advantageous, because it would give the storage manager more control and reduce dependence on the weather pattern.

The results of this analysis show that temperatures in Arkansas during September and October will allow cooling to 15°C, the threshold level of development for stored-product beetles. Insect development is directly related to temperature, and most stored-product beetles require about 6 weeks (42 days) to develop from eggs to the adult stage at 27°C (Hagstrum and Milliken, 1988). Therefore, aeration at 0.08 m^3/min/m^3 should cool stored rice to 15°C in time to suppress adult emergence in stored rice throughout most of Arkansas. Even with the earliest initial storage date chosen for Eudora, and the extreme situation where beetles would infest the bins the day rice was stored and immediately lay eggs, cooling was accomplished in 35 days at 0.08 m^3/min/m^3. However, even though the bulk of the bin is cooled, the surface and peripheral areas will still respond to fluctuations in ambient temperature.

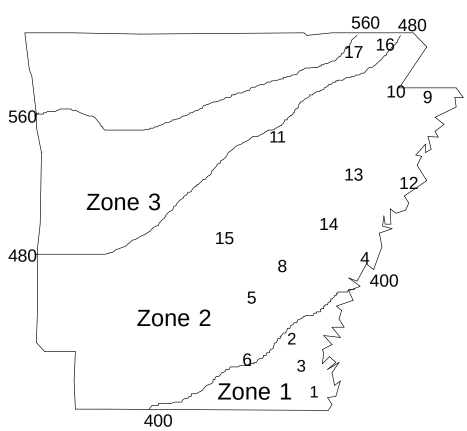

Figure 2. Approximate locations of weather stations listed in table 1. The contours indicate the number of hours in which the ambient temperature was below 15°C from 1 September to 31 October (fig. 1)

Once cooling occurs, there is a potential danger of re-warming during extended warm periods. In a field study in which rice stored in Arkansas was aerated at a rate of 1.3 m^3/min/t generated quick temperature drops, but some re-warming occurred after the cooling cycle was completed (Ranalli et al., 2002). Potential re-warming could possibly be alleviated by using a fan controller that allowed for intermittent maintenance aeration, regardless of the airflow rate. Aeration costs can sometimes increase with the higher airflow rates, even though the fans run for shorter time periods as temperatures increase (Reed and Arthur, 2000), but these costs must be balanced with the power requirements for a particular system and the flexibility gained by utilizing higher rates.

For the second cooling cycle, cooling durations were simulated with 1 November as the starting date and 7.2°C as targeted temperature. There was less variation compared to temperatures at the time of the first aeration cycle, and predicted temperatures were more uniform among the three sites. Predicted results for this second cycle showed that faster cooling may be more advantageous, especially in the southern zone, because of the decreased time required to complete the cooling cycle. As the airflow rate increased from to 0.04 to 0.08 m^3/min/m^3, the predicted durations required for cooling ranged from 43 to 23 days at Eudora, 39 to 16 days at Stuttgart, and 34 to 13 days at Corning (table 3). Increasing the airflow rate to 0.8 m^3/min/m^3 produced a 3- to 5-day decrease in cooling duration, and as with the first cycle, higher airflow rates would give managers and operators more flexibility and less dependence on temperature. This second aeration cycle would be used to minimize temperature variation within the grain mass and could limit problems associated with differential grain temperatures, as well as managing temperature for insect population suppression.

Table 3. Simulated durations (mean ± SEM of values for each year from 1991-2000) required to cool stored rice to 7.2°C in Eudora, Stuttgart, and Corning, Arkansas, using three different airflow rates.[a]

City	$0.08 m^3/min/m^3$	$0.40 m^3/min/m^3$	$0.8 m^3/min/m^3$
Eudora	46 ± 2	23 ± 2	18 ± 2
Stuttgart	39 ± 2	16 ± 2	13 ± 2
Corning	18 ± 3	15 ± 2	10 ± 2

[a] Simulations began on 1 November for all sites.

CONCLUSIONS

- Autumn temperatures throughout Arkansas are below the thresholds that can support insect populations and could be used to cool stored rice and help suppress insect population development.
- Cooling could be accomplished with different airflow rates. If the storage bins are already equipped with fans that deliver airflow rates of 0.8 $m^3/min/m^3$ commonly used for drying, these fans could be utilized for delivering controlled aeration. If drying is completed in separate systems, storage bins with fans that deliver 0.08 to 0.48 $m^3/min/m^3$ could be used for aeration with low-volume ambient air, assuming adequate power supply.
- Rice is sensitive to changes in relative humidity, which can cause fissuring and reduce head rice yield. This can be mitigated by installing upper limits on aeration controllers to limit aeration during periods of high relative humidity.
- Aeration could be combined with other management strategies, such as the use of reduced-risk insecticides to manage specific insect pest species, and reduce reliance on fumigation as an insect control strategy.

ACKNOWLEDGMENTS

The authors thank the Arkansas Rice Research and Promotion Board for partial funding of this study, and C. Burks and T. Wilson for reviewing the manuscript prior to journal submission.

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