FEASIBILITY OF AUTOMATIC AERATION FOR INSECT PEST MANAGEMENT FOR RICE STORED IN EAST TEXAS

F. H. Arthur, Y. Yang, L. T. Wilson, T. J. Siebenmorgen

ABSTRACT. *Aeration using automatic controllers was compared with manually-activated aeration (manual aeration) in bins of farm-stored rice in Nome, Texas, from 17 September 2002 through the end of the year. Manual aeration was defined as the farm owner manually activating the fans in mid-October, while automatic aeration employed activation temperatures of 23.9 °C, 15.6 °C, and 7.2 °C for three discreet cooling cycles. Population development of* Rhyzopertha dominica *(F.), the lesser grain borer, and* Sitophilus oryzae *(L.), the rice weevil, was assessed by confining 20 adults of each species with 150 g of rough rice in separate cages placed at 6 different locations in the top of the rice mass. Total heat units at temperatures above 15 °C were 150 to 300 degree days (DD) lower in bins with automatic aeration compared to manual aeration. Temperatures from 17 September through mid-October were 8 °C to 10 °C less in bins with automatic aeration than in with manual aeration, and 3 °C to 6 °C less during the remainder of the year. The number of adult* R. dominica *in the cages from bins with manual aeration were 45.4 ± 13.1, 114.5 ± 17.7, and 223.0 ± 24.8 after 5, 10, and 15 weeks, respectively, while populations in cages from bins with automatic aeration were significantly less ($P < 0.05$); 0.8 ± 0.3, 24.5 ± 4.5, and 21.7 ± 2.7 after 5, 10, and 15 weeks, respectively. There was no statistical difference ($P \geq 0.05$) in the number of adult* S. oryzae *collected in cages from bins with manual versus controlled aeration after 5 weeks (11.7 ± 8.1 and 0.3 ± 0.3, respectively), 10 weeks (14.7 ± 7.1 and 18.0 ± 9.6, respectively), and 15 weeks (39.0 ± 21.2 and 10.5 ± 5.6, respectively). However, the variation in the data set could have masked the apparent differences in the two aeration strategies.*

Keywords. Aeration, Stored rice, Rhyzopertha dominica*,* Sitophilus oryzae*.*

Rice is an important agricultural crop in the coastal region of eastern Texas, with a total economic value estimated at more than $700 million, which includes the value-added milling industry (Anderson et al., 2005). Rice is the ninth largest economic crop in the state, even though it is grown in a comparatively small region. Usually two crops are produced, a main crop and a ratoon crop, which is a second cutting of the main crop. Average dates of 50% harvest of the main crop ranged from 6 to 23 August from 1999 to 2005 (Stansel and Morace, 2006). When this crop is loaded into bins for storage, the temperature of the rough rice inside the bin is generally in the range of 22°C to 35°C, which is optimal for the growth and development of stored-grain insects (Howe, 1965; Fields, 1992).

Two of the primary insect pests of all stored grains, including rough rice, are *Rhyzopertha dominica* (F.), the lesser grain borer, and *Sitophilus oryzae* (L.), the rice weevil. The female *R. dominica* lays an egg on the exterior of the kernel, and the neonate larva bores inside the kernel and completes development. The female *S. oryzae* oviposits directly into the kernel. Immature stages of both species complete development to the adult stage inside the kernel, and then bore out of the kernel, thereby creating a large exit hole. The kernel is then classified as an insect-damaged kernel (IDK) for grading purposes. This grade deterioration is in addition to the feeding damage caused by the developing larva.

One important component of integrated pest management (IPM) strategies for stored wheat is the use of aeration with low-volume ambient air to cool bin temperatures to 15°C, which is the lower limit of development for most stored-grain insects (Fields, 1992). Wheat is a summer crop in the southern and central plains states in the United States, and some researchers have recommended initiating aeration management in early autumn when temperatures begin to cool (Noyes et al., 1992). However, modeling simulation studies and field research show the benefits of an initial cooling cycle to lower temperatures from the mid-30s°C to about 23°C, followed by a cooling cycle of 15°C when outside ambient temperatures are consistently below this threshold (Arthur and Flinn, 2000; Arthur and Casada, 2005).

These aeration cooling cycles are accomplished through the use of controlled aeration systems that operate when temperatures decrease below specified thresholds. These systems are generally more effective than manually-operated systems for controlling *R. dominica* and *S. oryzae* in wheat (Reed and Harner, 1998ab) and in rough rice stored in

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Arkansas (Ranali et al., 2002). However, temperatures at the time of rice harvest and during storage are much higher in eastern Texas than in Arkansas, and with the earlier harvest in Texas, conditions are more extreme and could limit the use of aeration. In addition, there are no published data regarding the effectiveness of controlled aeration on rice stored in eastern Texas. Therefore, the objectives of the present study were to: 1) compare manual versus controlled aeration to limit population growth of *R. dominica* and *S. oryzae* at a field site, 2) monitor temperatures in bins with manual and controlled aeration to characterize cooling patterns and relate these cooling patterns to insect development.

Materials and Methods

A field study was initiated with a private cooperator in Nome, Texas, which is located approximately 19 km west of Beaumont, Texas. Four rice storage bins 7.4 m high × 5.8 m diameter (24 ×19 ft), identified as numbers 7, 8, 9, and 10 and filled with rough rice to heights of 4.9, 4.6, 5.0, and 5.8 m, respectively, were used for the test. All bins were equipped with aeration systems, and the calculated or targeted airflow rates were set at approximately 0.013 $m^3/s/m^3$ (1.0 CFM/bushel), a typical airflow rate for stored rice as cited by previous workers (Ranali et al., 2002). Two aeration strategies were evaluated; manually-activated (hereby termed manual) and automatic aeration. In manual aeration, the fans were activated by the farm owner in mid-October and ran continuously for approximately two weeks, which is a typical management strategy for on-farm stored rice in Eastern Texas. A second manual cycle was initiated in mid-November, in which the fans were again turned on by the farm owner, and the fans ran continually for about two weeks before they were shut down. In the automatic aeration strategy, controllers were wired into the bins, as reported in the earlier cited literature (Ranali et al., 2002), and set to activate when ambient temperatures fell below 23.9°C. After this cooling cycle was completed, the next activation temperature was set at 15.6°C, upon completion of this cooling cycle the final activation temperature was set at 7.2°C. Manual aeration was employed on bins number 7 and 8, while the aeration controllers were installed on bins number 9 and 10.

The study was initiated on 18 September 2002, and the bins had been filled to the previously listed depths about 6 weeks prior. The grain peak produced through the loading process had been removed manually using shovels to level the grain mass in each bin. Temperature and relative humidity recording sensors (HOBO, Onset Computers, Bourne, Mass.), were placed on the top surface of the rice mass in each bin, and three temperature cables were inserted into the rice at the north, south, and center positions at approximately 1 m from the top surface, and a fourth cable was inserted into the center position at a depth of 2 m. The cables at the north and south positions were about 2 m from the sides of the bin walls. Upon completion of the installation process the HOBOs were activated to record continuously at 1-h intervals.

Insect cages were constructed of PVC fittings as described in Ranali et al. (2002). Briefly, these cages comprised threaded PVC couplings that were 15 cm in length and 3.8 cm diameter, with 0.0185-cm mesh screens glued inside the open caps which covered each end. These screens allowed air movement but prevented insect escape from the cage. The bottoms of each of the 48 cages were capped, and 150 g of Cocodrie cultivar long-grain rough rice was loaded into each cage. Twenty mixed-sex 1- to 2-week-old *R. dominica* were placed in 24 cages and twenty 1- to 2-week-old *S. oryzae* adults were placed into the remaining 24 cages. After the insects were placed into the cages the tops were screwed onto the threads and the cages were sealed.

Three sets of four cages, each set consisting of two cages of each of the two insect species, were placed at an approximate depth of 0.5 m from the grain surface in the center of the grain mass, also as described in Ranali et al. (2002). One set of cages was removed after 5 weeks, another set after 10 weeks, and the final set after 15 weeks. When the cages were removed from the bins, the rice was passed through a #12 sieve, and live and dead adults were collected and their numbers tabulated. The rice from each cage was then incubated at approximately 27°C and 60% relative humidity for an additional six weeks to record adult emergence from any immature stages present in the kernels upon removal from the bins.

Samples of rice were taken for moisture content analysis on 20 September, 23 October, and 5 December of 2002 and 1 February of 2003 by taking a composite sample of about 100 g from the top 1 m at each of the north, south, and center positions in each of the four bins. For each sample, 100 whole kernels were analyzed for MC using a Model C2R800E Individual Kernel Moisture Meter (Shisouka Seiki Co., Shisouka, Japan). Data were combined for the two bins with manual aeration and the two bins with automatic aeration, and the samples from each position were pooled as sub-replicates.

Data for temperature within the bins with manual versus automatic aeration were summarized using the MEANS Procedure of the Statistical Analysis System (SAS Institute, 2002) to obtain daily values, which were plotted using Sigma-Plot Software (SPSS Inc., Chicago, Ill.). Data for insect populations were analyzed using the General Linear Models (GLM) Procedure and the *t*-test Procedure to determine significant differences in insect populations in the embedded cages at 5, 10, and 15 weeks after the cages were placed into the bins. Data for insect populations were also plotted using Sigma-Plot.

Results

In the bins with automated aeration at an initial threshold of 23.9°C, the temperature was reduced by about 10°C within a week at all sensor positions (fig. 1, A-D). There was another slight reduction in temperature from about 23°C to 20°C in mid-October, and a further reduction to 15°C in mid-November. In contrast, temperatures in the bins with manual aeration remained above 30°C until the aeration fans were activated in mid-October. The temperatures then stabilized at 23°C to 27°C until mid-November, depending on the specific sensor position. Temperatures were reduced when the fans were activated again in mid-November. Temperatures for bins with manual aeration remained well above the corresponding temperatures for bins with automatic aeration throughout the entire study. The cumulative heat units above development threshold

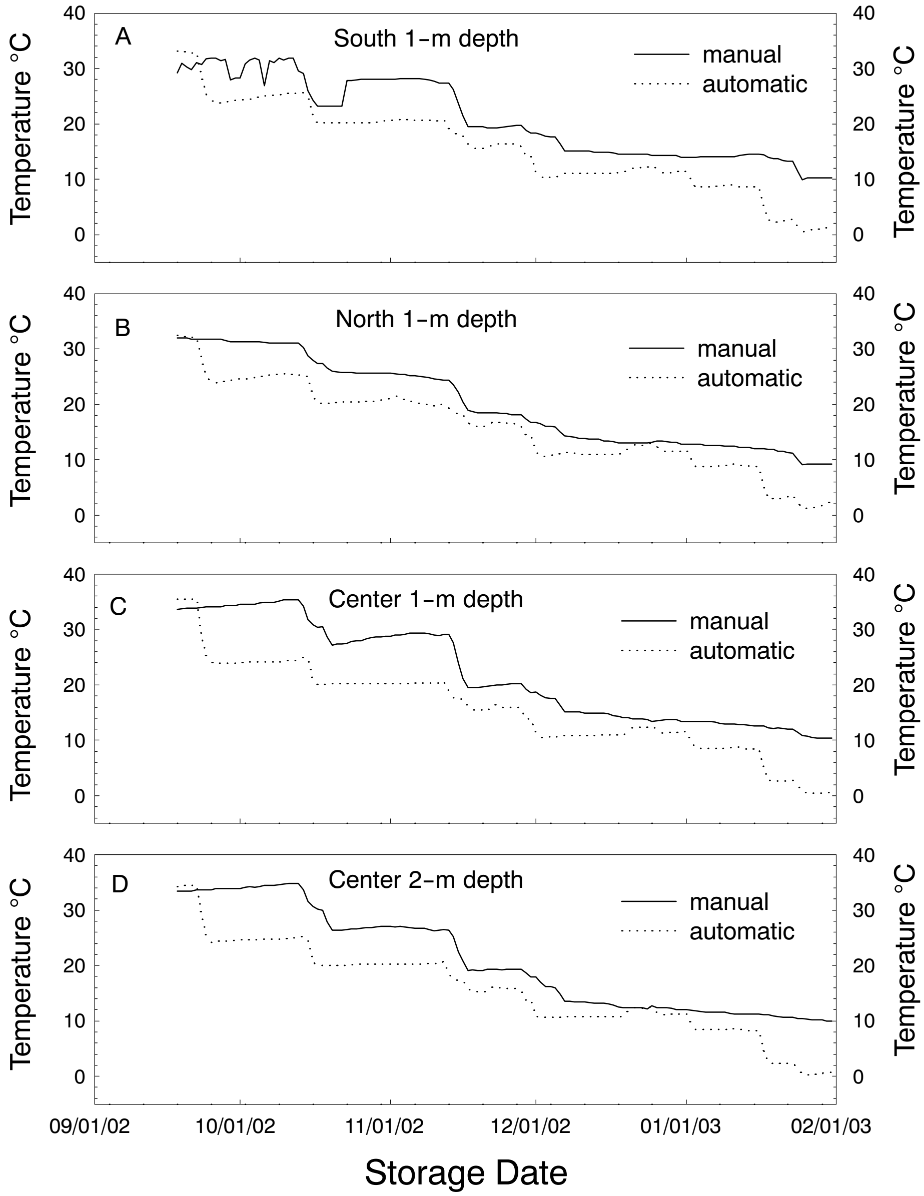

Figure 1A-D. Temperatures in rough rice storage bins with manual versus automatic aeration, at depths of 1 m at the north, south, and center positions in the bins, and 2 m in the center position.

temperature (15°C) were 300 to 650 degree-days higher for bins with manual aeration than for bins with automatic aeration (table 1). The average temperatures in the bins with automatic aeration were about 8°C to 10°C less than the temperatures in the bins with manual aeration after the first cooling cycle (table 2). During the remainder of the year, temperatures in bins with automatic aeration ranged from 3°C to 6°C less than corresponding temperatures in bins with manual aeration, depending on the period of observation and position of the temperature sensor in the bin (table 2).

This large difference in temperature had an effect on insect population development in the cages inserted into the top surface of the grain mass in each respective bin. Both of the main effects, aeration mode and sample date, and the interaction, were highly significant ($P < 0.01$) for emerged adult *R. dominica* ($F = 210.5$, d.f. = 1, 18; $F = 48.5$, d.f. = 2, 18; $F = 6.2$, d.f. = 2, 18; respectively). At each sample date, there were more emerged adults in the cages from bins with manual aeration compared to those in the cages from bins with automatic aeration (fig 2A). Average populations of adult *R. dominica* after 5, 10, and 15 weeks in cages from bins

Table 1. Heat units (degree days) above 15°C from weeks 0-5 cumulative, 0-10 cumulative, and 0-15 cumulative in bins with manual vs. automatic aeration.

Sensor Position	Aeration	Weeks 0-5	Weeks 0-10	Weeks 0-15
South 1 m	Manual	1070	1990	2556
	Automatic	920	1616	2025
North 1 m	Manual	1116	1958	2473
	Automatic	920	1620	2039
Center 1 m	Manual	1219	2165	2716
	Automatic	921	1608	2018
Center 2 m	Manual	1202	2090	2583
	Automatic	925	1606	2040

Table 2. Average temperatures (mean ± SE) and cumulative heat units for temperatures above 15°C at 1 m at the north, south, and center positions, and 2 m in the center positions, in bins with manual (Man.) and automatic (Auto.) aeration, upon completion of three cooling cycles.

		South 1 m	North 1 m	Center 1 m	Center 2 m
		9/24-10/15[a]			
Man.	Ave.	30.4 ±0.4	31.2 ±0.1	34.5 ±0.2	34.1 ±0.1
Auto.		24.5 ±0.2	24.7 ±0.2	24.1 ±0.2	24.5 ±0.2
Man.	Sum	670	686	759	749
Auto.		566	568	553	564
		10/17-11/13			
Man.	Ave.	26.9 ±0.4	25.1 ±0.1	25.7 ±0.2	26.9 ±0.2
Auto.		20.3 ±0.1	20.4 ±0.1	20.2 ±0.1	21.1 ±0.1
Man.	Sum	753	714	804	754
Auto.		570	571	566	564
		11/13-11/30			
Man.	Ave.	19.3 ±0.1	18.2 ±0.1	19.7 ±0.1	19.1 ±0.1
Auto.		15.8 ±0.2	16.1 ±0.2	15.6 ±0.2	15.1 ±0.2
Man.	Sum	270	255	276	255
Auto.		221	225	218	214

[a] Period in which temperatures were relatively stable upon completing of cooling cycles depicted in figure 1A-D.

with manual aeration were 45.4 ± 13.1, 114.5 ± 17.7, and 223.0 ± 23.8 compared to 0.8 ± 0.04, 24.5 ± 4.5, and 21.7 ± 2.7, respectively, in cages from bins with automatic aeration.

The samples taken at 5, 10, and 15 weeks were also incubated for six weeks at 25°C/60% r.h. to determine the number of adults emerging from any kernels which might have been infested at the time the cages were removed from the bins. Aeration strategy and sample date had no effect on adult emergence ($F = 1.2$, $df = 1{,}18$; $P = 0.29$; $F = 2.2$, $df = 2{,}18$; $P = 0.13$) but the interaction was significant ($F = 9.4$, $df = 2{,}18$; $P < 0.01$). At the first sampling period, more adult *R. dominica* emerged from rice that had been in the bins with manual aeration, but this was reversed for the cages removed at week 10 (fig. 2B). There was no difference in adult emergence at week 15 between manual versus automatic aeration.

In contrast to the data for adult *R. dominica*, neither main effects aeration mode or sample date were significant for emerged adult *S. oryzae* ($F = 0.04$, d.f. = 1,18, $P = 0.83$; $F = 2.4$, d.f. = 1,18, $P = 0.12$), however, the data for this species showed considerable variation (fig 3A.). In addition, there were numerically less *S. oryzae* in the cages compared to *R. dominica*. The analysis for adult emergence from the incubated samples likewise did not show significance for main effect aeration mode or sample date ($F = 1.0$, $df = 1{,}18$; $P = 0.34$; $F = 1.3$, $df = 2{,}18$; $P = 0.29$), and there were comparatively fewer adult *S. oryzae* in the incubated samples compared to *R. dominica* (fig. 3B). The data were transformed by square root in an attempt to normalize the variances, but analysis results were similar before and after the transformation.

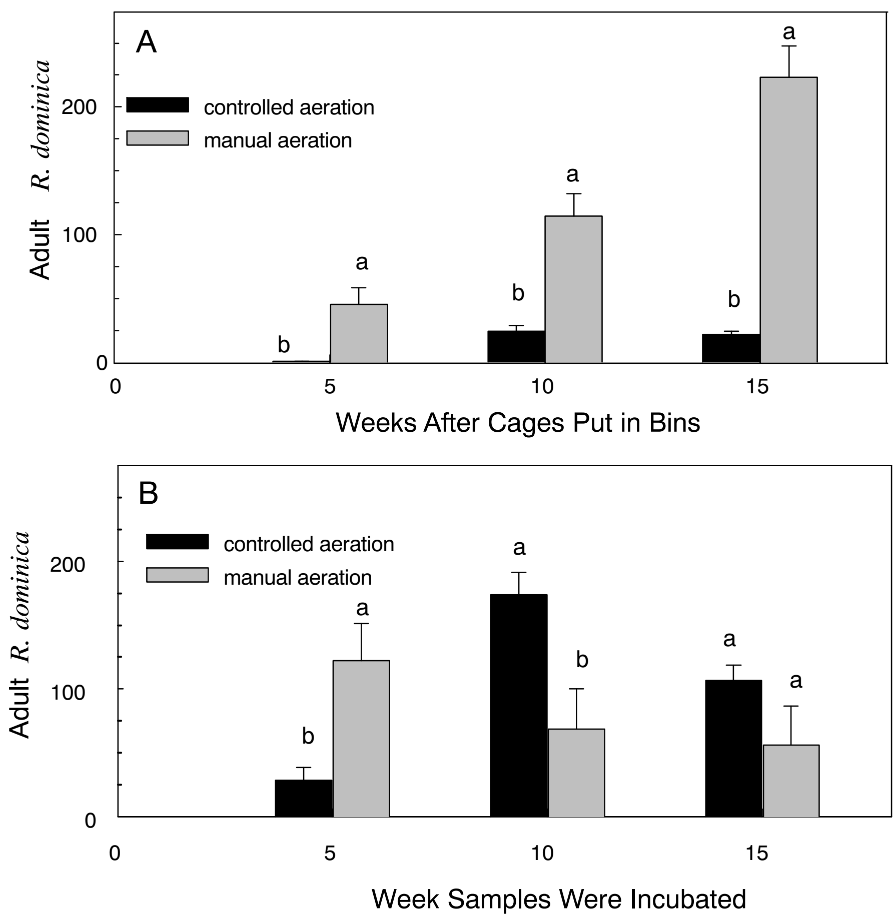

Figure 2. Number of adult *R. dominica* in 150 g of rice (mean ± SE), from an initial infestation of 20 mixed-sex adults, after 5, 10, and 15 weeks in confined cages of rough rice placed in bins with manual vs. automatic aeration (A); number of adults (mean ± SE) later emerging from rice removed after 5, 10, and 15 weeks, and incubated at 27°C (B). Means depicted with different letters are significantly different (P < 0.05, Proc t-test, SAS Institute).

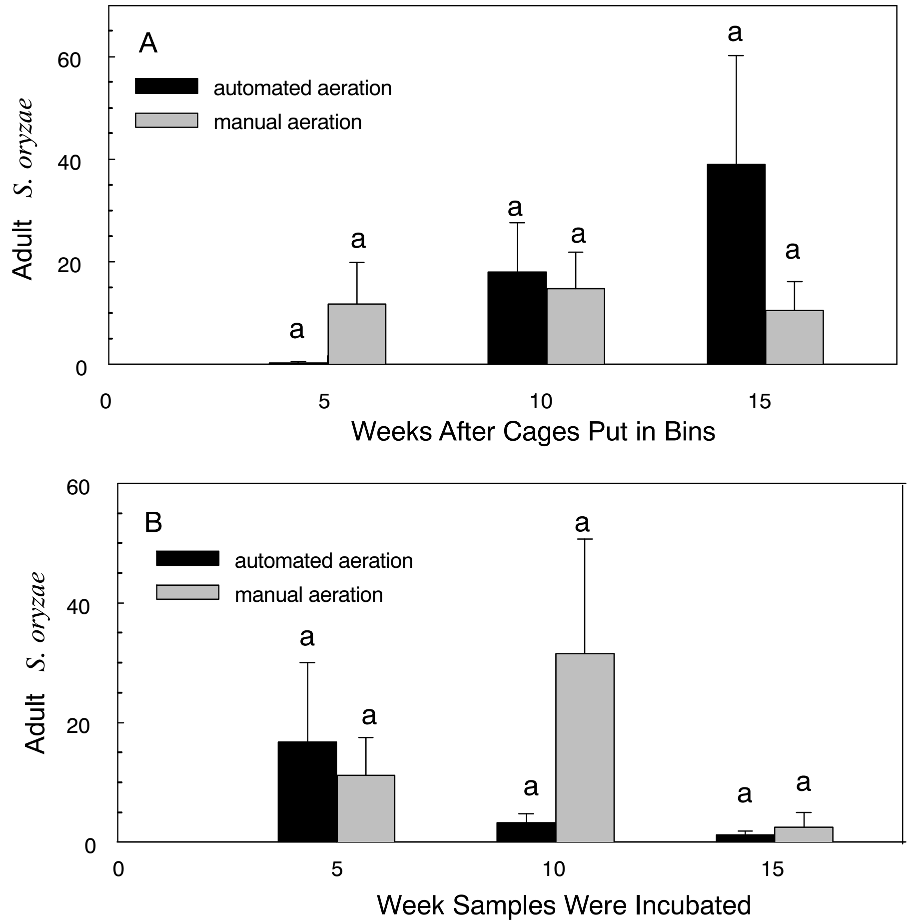

Figure 3. Number of adult *S. oryzae* in 150 g of rice (mean ± SE), from an initial infestation of 20 mixed-sex adults, after 5, 10, and 15 weeks in confined cages of rough rice placed in bins with manual vs. automatic aeration (A); number of adults (mean ± SE) later emerging from rice removed after 5, 10, and 15 weeks, and incubated at 27°C (B).

Aeration strategy (manual versus automatic) was significant in the resulting moisture content (MC) for rice ($F = 11.0$, $df = 1,40$; $P < 0.01$), but sample date and the interaction were not significant ($F = 1.5$, $df = 3,40$; $P = 0.24$; $F = 0.4$, $df = 3,40$; $P = 0.78$, respectively). The initial analysis for moisture content (MC) for rough rice from the bins with manual versus automatic aeration showed that the main effect aeration mode was significant ($F = 11.0$, $df = 1,40$; $P < 0.01$), but sample date or the interaction was not ($F = 1.5$, $df = 3,40$; $P = 0.24$; $F = 0.4$, $df = 3,40$; $P = 0.78$, respectively). When MC data for sample date were pooled by averaging across sample date, the MC was greater ($P < 0.01$) in rice samples from bins with manual aeration (11.7 ± 0.16%) compared with automatic aeration (10.7 ± 0.23%).

Discussion

The results show that early aeration during storage produced an immediate reduction in the temperature of the stored rice (fig. 1, A-D). Although we have no data to show what could have happened had manual aeration been initiated at the same time as automatic aeration, other studies with stored grains have shown that manual aeration is consistently initiated later than what can be accomplished through the use of automated controllers (Reed and Harner, 1998ab; Ranali et al, 2002). This could be extremely important for rough rice stored in eastern Texas, because the temperature of the rice will remain in the range for optimum insect development well into autumn. In contrast, temperatures in eastern Arkansas will already begin to decline in September such that initial cooling can be accomplished to reduce temperatures to 15°C (Arthur and Siebenmorgen, 2005).

The initial cooling produced an effect similar to that shown in Arthur and Casada (2005), where immediately reducing the temperature of stored wheat early in the summer in Kansas greatly reduced insect populations compared to waiting until temperatures approached the threshold of population development (15°C) in September. Simulation studies using corn stored in the southern United States, also show the benefits of this initial cooling to lower temperatures first to 23.9°C, followed by later cooling to 15°C (Arthur et al., 2001), on predicted populations of *Sitophlus zeamais* (Motschulsky), the maize weevil. Similar studies also document predicted population reductions of insects in stored wheat using an initial summer cooling cycle (Flinn et al., 1997; Arthur and Flinn, 2000).

The reduction in temperature through automatic aeration greatly reduced population growth and development of *R. dominica* (fig. 2A-B), but the effects were inconsistent for development of *S. oryzae* (fig. 3A-B). Optimal growth and development of most stored-product beetles occurs between 22°C and 32°C (Howe, 1965; Fields, 1992). Population growth of *R. dominica* in the confined cages was far greater than corresponding growth of *S. oryzae*, especially in the bins with manual aeration. One possible reason for the discrepancy for the two insect species is that previous studies have indicated that reproduction and fecundity of *R. dominica* is greater at 32°C than at 27°C (Vardeman et al., 2006; Chanbang et al., 2007), while the reverse is true for *S. oryzae* (Arthur, 2002; 2004). Population growth of *Sitophilus oryzae* is more limited by higher temperatures than for *R. dominica*, and in fact, a gradual cooling may actually promote growth of *S. oryzae* because temperatures will be in the favorable range for development. This is perhaps another advantage attached to automated cooling, especially where the cooling is linked to decreases in outside ambient temperatures, because it would normally quickly decrease temperatures through the zone favorable for development of *S. oryzae* to the threshold temperature of 15°C.

The effect of automatic aeration on insect population dynamics can be further explored using an interactive web-based modeling program available from the Texas A&M Beaumont website (http://beaumont.tamu.edu/ ricessweb). This web-based system represents an important step in the delivery of user-friendly applications (Wilson et al., 2004ab). It allows users to predict population dynamics of *R. dominica* and *S. oryzae* on rough rice stored in different geographic locations in the south-central United States, using available weather data or data input by users.

Conclusions

Our results show that automatic aeration reduced the temperature of stored rough rice more quickly than the cooling accomplished through manual aeration. This reduction in temperature clearly reduced populations of *R. dominica* in rough rice cooled through automatic aeration compared to populations in rice cooled by manual aeration. However, results were not as conclusive for population control *S. oryzae*, due in part to variation in the data. Actual numbers did give an indication of lower populations in rough rice cooled by automatic aeration. Overall the results showed that automatic aeration could potentially be used to manage rough rice in a warm climate such as southeastern Texas.

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