CONDITIONING PRACTICES AND THEIR EFFECTS ON INFESTATION AND QUALITY OF CORN STORED ON KANSAS FARMS

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ABSTRACT. *To determine the effects of various conditioning practices on grain quality in northeast Kansas, corn stored in farm bins of various sizes was sampled and field simulations were conducted in 3.6-m (12-ft) diameter bins. Grain quality deterioration, as evidenced by insect infestation and mold infection, was common in farm-stored corn when storage extended into the summer months. Inefficient conditioning practices were observed commonly in farm grain. Excessively long fan operation, combined with failure to remove peaks and accumulations of fine material in spoutlines before aeration often resulted in over-dried grain in lower and outer parts of the grain mass and unconditioned grain in the center. In the field simulation bins, caged adult insects did not survive the winter in grain cooled rapidly by forced air. However, adult sawtoothed grain beetles were found in March in cages placed in unaerated grain the previous fall, and adults of all species of test insects were present in cages left in the grain from binning until the following summer, regardless of whether the grain had been cooled by forced air.*
Keywords. *Grain storage, Grain conditioning, Grain deterioration.*

In the southern and western parts of the U.S. cornbelt, corn is harvested and stored at a wide range of temperatures and moisture contents. Grain temperature and moisture must be managed in order to protect the grain from deterioration by molds and insects. Producers typically dry grain harvested at greater than about 18 or 19% moisture content (w.b.) in a heated-air grain dryer before storage. Usually, additional air is passed through this grain after binning to remove heat and additional moisture. Corn harvested at less than this moisture often is placed directly into storage bins from the field and subjected to "natural-air", low-temperature drying. In natural-air drying, air is passed through the grain without the addition of heat except that supplied by the fan and motor. This is the most energy-efficient drying method, but subjects the grain to a greater risk of deterioration compared to other methods (Loewer et al., 1994). Many producers in Kansas, which may be typical of the warm, dry areas of the corn belt, seem to prefer this strategy.

Because of the high risk of deterioration by molds when grain is not dried immediately, much research has focused on the effects of airflow rates, temperature, moisture, and length of storage time on grain condition. Tuite et al. (1970) determined that continuously aerated corn (at 0.6 m^3/min/t, 0.5 cfm/bu) must contain no more than 21% moisture, and that if the conditioning by aeration does not dry the grain enough, spoilage by *Penicillium* molds may occur during subsequent storage, even if the grain temperature is very low. Hodges (1970) demonstrated that very rapid cooling was required for high-moisture corn, and that drying the grain to 20% moisture content allowed a much longer cooling time without spoilage. Steele et al. (1969) developed an equation to relate grain temperature, moisture content, and condition to the respiration rate of the grain mass, and hence, to the "safe" storage time before deterioration occurs.

Seitz et al. (1982a) reported that the type and amount of fungal inoculum significantly affected deterioration rates of corn at 22 to 27% moisture content at high temperature. A companion study (Seitz et al., 1982b) demonstrated the rates of respiration, heat production, and dry matter loss in bins of freshly harvested corn at 25% moisture and 22 to 38°C (72 to 100°F). The studies showed the potential for deterioration, dry matter loss, and toxin contamination from molds during storage when the moisture content and/or grain temperature was too high.

The creation of fine material during handling and its accumulation in the spoutline, e.g., the core of grain directly beneath the peak, are well described. Hall (1984) showed that corn having an initial fine material content of 4.4% had up to 27% in parts of the spoutline. Heating, accompanied by grain deterioration, is common in spoutlines (Meronuck, 1984). Though standard extension materials recommend cleaning or coring to remove peaks and spoutlines in order to make aeration more efficient, there are apparently no published data that quantify typical reductions in air velocities due to spoutlines.

Storage molds, especially *Aspergillus* species, often are associated with stored-grain insects and mites (Christensen and Meronuck, 1986). Stored corn can be infested by a variety of beetle and moth species (Arbogast and Throne,

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1997). Weevils of the genus *Sitophilus*, the lesser grain borer, *Rhyzopertha dominica* (Fab.), and the Angoumois grain moth, *Sitotroga cerella* (Olivier), are considered primary feeders because their larvae develop inside the corn kernel. The maize weevil, *Sitophilus zeamais* (Motschulsky), is one of the most abundant insect pests of corn stored in the U.S. (Barney et al., 1991). Secondary feeders often are found in cracked and broken corn, and in corn that has been damaged by a primary feeder. These include the red flour beetle, *Tribolium castaneum* (Herbst), the confused flour beetle, *Tribolium confusum* (DuVal), the sawtoothed grain beetle, *Oryzaephilus surinamenis* (L.), the rusty grain beetle, *Cryptolestes ferrugineus* (Stephens), and the Indianmeal moth, *Plodia interpunctella* (Hubner). Other beetles such as the hairy fungus beetle, *Typhea stercorea* (L.), and the foreign grain beetle, *Ahasveras advena* (Walt.), often are found in association with storage molds (primarily *Aspergillus* species) in corn with elevated moisture content (Christensen and Meronuck, 1986).

Few field studies have described typical grain storage practices and conditions on farms and the extent to which grain managers successfully dry and cool grain, control insects, and maintain grain condition. In a survey of Nebraska farms, Spitz (1980) found that grain in many bins exhibited “moisture condensation”. Many farmers told him they were too busy to aerate or did not realize the importance of aeration in maintaining grain quality. In Minnesota, 40 to 90% of grain samples taken from farm bins in the summer contained insects (Barak and Harein, 1981). They also reported that 25% of the corn lots in farm bins were not leveled, that grain cleaning was rare, and that temperature control was inconsistent. Storey et al. (1983) reported that most samples of farm-stored corn they examined contained one or more live insects. Rates of infested samples ranged from 71% of those from Illinois to 93% of those from Indiana. The average number of insects per 1000 g (2.2 lb) of infested corn sample was 26.

The series of studies reported here was undertaken to describe the typical conditions of fall crops stored on farms in northeast Kansas. Another objective was to document the effect of producer’s post-harvest conditioning and storage practices on the grain quality. Also, the use of simple, thermostat-based fan controllers to more accurately control aeration fans was investigated.

Materials and Methods

Field Trials

Field trials were established at nine farms in northeast Kansas during 1995-1996 and 1996-1997 to document storage conditions for on-farm corn and to compare controlled aeration with manual aeration. The bins were typical of farm storage in this area [5.4 to 7.2 m diameter (18 to 24 ft)], and contained 50 to 180 t (2,000 to 7,000 bu) of corn harvested in September, October, or November. At each site, a simple aeration controller consisting of a high-limit thermostat, a contact relay, a power switch, and an hour meter was placed on one bin, and an hour meter was placed on a companion bin. Typical fans were 45-cm (18-in.) diameter with 1.1-, 1.5-, or 2.3-kW (1.5-, 2-, or 3-hp) motors, though one farm had bins with 6.8-kW (9-hp) fan motors. All were axial fans. Roof vents were common but not universal in these farm bins, and stirring devices were rarely observed.

Grain samples were taken at depths of about 1, 2, and 3 m (3.3, 6.6, and 9.8 ft) below the grain surface, at approximately half the distance from the north and south walls to the center, and directly in the center. At each point, the probe was filled twice to obtain about 800 g (1.8 lb) of corn. Grain temperatures were recorded at the same locations. Lots were sampled at the same locations periodically throughout the fall, winter, and spring. Grain moisture content was determined by drying 15 g of whole corn for 72 h at 103°C (ASAE, 1994). Fine material content was determined by passing the sample over a 0.48-cm (12/64-in.) round-hole sieve. To identify species of fungi that had invaded the corn, kernels were plated on malt-salt-Tergitol agar (MS6T) as described by Sauer et al. (1982).

To develop a daily log of temperatures at different locations in the grain mass, temperature probes were monitored with computers and data acquisition equipment (DataLoggers Div., Onmidata Inc., Logan, Utah). One probe was placed just outside the bin eave to record ambient temperature. Four probes were placed approximately 20 cm (8 in.) below the surface 0.3 m (1 ft) from the north, south, east, and west walls, and one probe was placed in the center of the bin. Five additional probes were placed at the same cardinal positions halfway between the grain surface and the bin floor. The temperature at each location was recorded hourly.

Surveys

In addition to the field trials, data were taken from a one-time survey of farm bins in the summer and a previously unsampled large metal bin in the fall to complement the experimental information. In the field trials, cooperating farmers could not guarantee that grain at experimental sites would be stored into the summer, and most removed the grain by May. Thus a one-time survey of six farm bins not previously sampled was done in July to document typical conditions relative to grain quality, molds, and insects when corn was stored into warm months. Information related to storage management was collected from producers at the time of sampling. Fall conditioning practices varied from energy-intensive (drying in a grain dryer followed by transfer to the bin with subsequent aeration and mixing with a stirring device) to minimal (continuous aeration for several weeks after binning). The grain was sampled and samples were analyzed as described above. Five WB Probe 2 pitfall traps (Gustafson, Inc., Plano, Tex.) were placed in each bin just below the grain surface at the surface sampling locations, and collected after four days. Insects thus captured were frozen and counted.

At another location, a large bin (14.4-m, 48-ft diameter) filled with recently harvested corn was being conditioned with unheated air. Two 18.8-kW (25-hp) centrifugal fans, each attached to a branched floor duct, supplied air under positive pressure. Two roof vent fans were operating. In order to estimate air velocity at the base, apex, and halfway up the slope of the peaked grain, researchers used an apparatus described by Burrell and Armitage (1961), wherein a soap film is propelled inside a graduated, transparent tube by the air passing through the grain. The speed of the film’s movement indicates the air velocity through the grain. This provided information on the effect of the peak and spoutline on air velocity in a large bin. In order to evaluate the effect of this airflow gradient, grain temperatures and moisture contents were determined at the locations where air velocity was measured. These were determined 0.6 m (2 ft) below the grain surface so that over-space conditions did not affect the readings. The findings complemented the information obtained from the small, researcher-controlled field simulation bins and the field trials conducted over several months.

Simulated Field Studies

In order to provide a physical simulation of farm bins under semi-controlled conditions, six corrugated metal grain bins 3.6 m (12 ft) in diameter and 4.6 m (15 ft) tall, located at the Grain Marketing Research and Production Center, Manhattan, Kansas, were filled on 30 and 31 October 1996, to within 1 m (3.3 ft) of the eaves with about 27.5 t (1100 bu) of corn obtained directly from the field after harvest. A simple aeration controller, described previously, was connected to the positive-pressure fans on each bin. Three of the bins were aerated and three were not aerated during the study. After the air velocity at various locations in the peaked grain was tested with the soap-film apparatus described previously, the grain was leveled and samples were taken at the center surface and at 1, 2, and 3 m (3.3, 6.6, and 9.8 ft) below the grain surface at the center. Samples were taken by twice filling a deep-cup probe to provide about 800 g (1.8 lb) of corn. Sampling at the same locations was repeated in March and July 1997. Moisture content and percent mold-invaded kernels were determined as described previously.

Temperature in the grain was monitored with the probes and data-logging equipment described previously. One temperature probe was placed just outside the bin eave to record ambient temperature. Three probes were placed approximately 3.6 m (12 ft) below the surface near the floor of the bin, at positions called north (0.3 m, 1 ft from the north wall), south (0.3 m, 1 ft from the south wall), and center. Three probes were placed at the same positions 1.8 m (6 ft) below the grain surface, and a third set was placed at the same positions 5 cm (2 in.) below the grain surface. The temperature at each position was recorded hourly.

Six cages containing adult insects were placed near the center of each bin at a depth of about 7.6 cm (3 in.) below the grain surface. The insect cages, made of plastic pipe 15.2 cm (6 in.) long and 10.2 cm (4 in.) diameter, with a 0.4 cm (0.17 in.) hole plugged with a no. 7 rubber stopper in the center and fine-mesh screen glued to each end, contained 1000 g (2.2 lb) of corn. Two cages contained 50 mixed-sex adult maize weevils, two contained 50 mixed-sex adult red flour beetles, and two contained 50 mixed-sex adult sawtoothed grain beetles.

Three randomly chosen bins were aerated immediately after filling using a simple aeration controller that activated the fan when the ambient temperature was below 7°C (45°F). Estimates of airflow rates from Kansas farms indicated that 0.6 m^3/min/t (0.5 cfm/bu) would adequately simulate typical farm conditions. The observed airflow rate in these bins when the grain surface was level was 0.67 $\pm$ 0.09 m^3/min/t (0.57 $\pm$ 0.08 cfm/bu) . This aeration cycle was completed within five days, and the fans were sealed with plastic and tape until May 1997. In mid-May, a shorter aeration cycle with air cooler than 10°C (50°F) was accomplished in the three previously aerated bins to cool areas of the grain mass that had rewarmed because of ambient conditions. This spring cooling cycle was completed in 18 h, and the fans were sealed with plastic and tape until the conclusion of the test on 22 August 1997. The fans of the unaerated bins were not sealed, in order to simulate typical farm practice.

One cage of each insect species was removed from each bin on 17 March 1997, after 4.5 month of storage. Adult insects were counted and recorded, and corn from the cages containing maize weevils was incubated for two months at 25°C (77°F) to determine progeny (F1) emergence. On 18 March 1997, two additional cages of each species (50 mixed-sex adults each) were placed in each bin. One set of these cages was removed on 30 June 1997 and processed as described previously. The remaining cages placed in the bins in October 1996 and the cages placed in March 1997 were removed and analyzed when the experiment was concluded on 27 August 1997.

On 14 July 1997, five WB Probe 2 pitfall traps (Gustafson, Inc, Plano, Tex.) were placed just below the grain surface at N, S, E, W, and center coordinates to sample resident populations. They were collected after one week.

Hourly temperature data during the fall and spring aeration cycles for the three aerated and three unaerated bins were summarized using the Statistical Analysis System (SAS Institute, 1987). Hourly data were combined into daily means over all bins, and the means for the eight probes placed near the grain surface, the bin wall, or the bin floor were combined to obtain a mean value for all bins for the peripheral regions of the bins. The middle center probe represented the center of the grain mass. Data for the insect population studies were summarized using the Means Procedure and means were tested for significant differences using the t-test Procedure of the Statistical Analysis System (SAS Institute, 1987).

Results and Discussion

Grain Temperature

In the simulated field trials, grain temperatures at peripheral locations of the grain closely approximated ambient temperatures (fig. 1A). In the center of the unaerated grain masses (those where fans were not operated), the temperature approximated the ambient mean with a lag time of 30 to 40 days (fig. 1B). Only during the first 30 days were mean grain temperatures noticeably lower in the aerated grain, where air was forced through the grain, compared to the unaerated grain. At the center position, the grain temperature was reduced by aeration from nearly 20°C (68°F) to 4°C (39°F) in fewer than five days. However, the rapid natural cooling of the grain in the small simulation bins caused the mean temperature near the center of the unaerated grain masses to cool to the level of the aerated grain within about a month.

The grain temperature in the center of the aerated bins remained slightly warmer than that in the center of the unaerated bins for nearly six months (fig. 1B). This unexpected result appears to have originated shortly after fall aeration, when the fans of the aerated bins were sealed. Unseasonably warm ambient temperatures at two periods during the first month appeared to cause grain at the floor

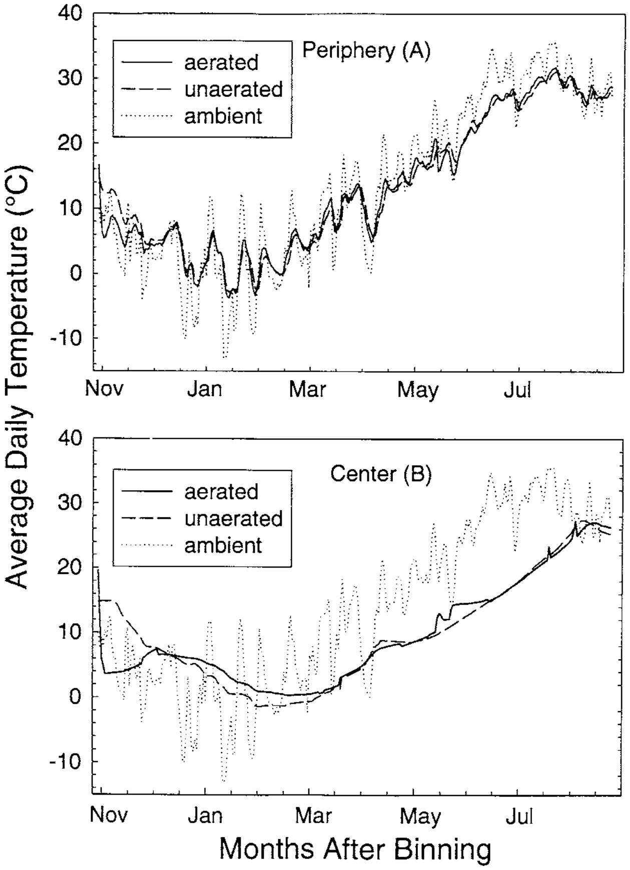

Figure 1–Mean daily ambient and grain temperatures at eight combined peripheral locations (A) and a center probe position (B) in three bins each of aerated and unaerated corn. Bins were 3.6 m (12 ft) diameter, were located in Manhattan, Kansas, contained about 27.5 t of corn, and were equipped with fans that produced about 0.7 m^3/min/t (0.6 cfm/bu).

of the bin just above the plenums (bottom position) to warm (fig. 2). This grain in the sealed, aerated bins appeared to retain more heat than did grain in the unaerated, unsealed bins where air movement through the plenum occurred. The trapped heat appears to have migrated upward through the center of the grain mass, as postulated by Hall (1957), affecting the middle center sensor after about 25 days. By December, natural cooling in the unsealed, unaerated bins caused the mean center temperature to be lower than that in the sealed, aerated grain. The mean temperature at the center of the unaerated grain was also more variable than that of the sealed aerated grain. This may have been due to natural air movement through the grain caused by wind and/or chimney effects.

In the farm bins, which were at least twice as large as those of the simulated field trials, the mean grain temperature at the first sampling time in Oct/Nov 1995 was 21°C (70°F) in unaerated corn and 9°C (48°F) in aerated corn. By early March 1996, the mean temperature was 2°C (36°F) in the farm grain, all of which had been aerated by that time. In the 1996 crop, the grain temperatures at the first sampling time were 13 and 6°C (55 and 46°F) for unaerated and aerated corn, respectively. By late March 1997, they had been reduced to 7 and 3°C (45 and 38°F) mostly by natural ventilation, since even the grain not conditioned after harvest was cool enough to store without aeration. By late May 1997, the grain had warmed to 10°C (50°F) whether or not it had been aerated. Grain in most places within the farm bins remained at least as cold as that in the simulated field trials through most of the storage season.

Grain Moisture

In the simulated field trials, fans were operated only long enough to pass the cooling front through the grain (52 h), so little moisture loss was observed. In addition, the grain initially contained only 13.0% m.c. on average, due to unanticipated delays in harvesting. By March, it had dried to 12.6%, and to 12.5% by the following July in both aerated and unaerated grain. In contrast, in the farm bins, wherein the initial grain moisture was higher due to earlier harvest, and where some producers operated fans for hundreds of hours, much moisture change was observed. After the 1995 harvest, the mean moisture content of the farm-stored grain before conditioning was 17.0% with a range of 16.7 to 17.8%. After the fall conditioning, the mean moisture content was 15.3% with a range of 12.0 to 17.8%. By early March 1996, grain in the bins that still contained grain had a mean moisture content of 14.0% with a range of 11.5 to 17.5%. In the following year, the mean moisture content in farm-stored corn that had been conditioned by air was 13.9% by March, whereas that which was not aerated, or in bins where producers operated fans for only a few hours, was 14.6%.

Grain is merchandised on a wet-weight basis. To maximize the amount of grain weight, it is advantageous to sell corn with the maximum moisture allowed without penalty. This limit is often 15.0% moisture content. Grain can be stored without quality loss at this moisture content if kept cool. Thus, the recommended fall conditioning strategy for producers who intend to sell fall crops after farm storage is to quickly dry them to near the maximum allowable moisture content and immediately cool them to avoid quality deterioration.

Producers cooperating in the field trials appeared to follow disparate strategies relative to conditioning their fall crops with forced air. Some used both high-temperature drying before binning and cooling by aeration during storage in the bin. Others binned grain directly from the field and operated fans without additional heat to dry and cool the grain. Still others field-dried to less than18% moisture before harvest and cooled in the storage bin without operating fans long enough to accomplish significant drying. The effects of two strategies on grain moisture content are described below.

1. In two farm bins (6.3-m, 21-ft diameter) equipped with 6.8-kW (9-hp) fans, corn was field-dried before harvest and binned directly, and fans were operated for less than three days. After this fall conditioning process, grain moisture contents were fairly uniform from top to bottom in the grain masses, with a mean of 17.1%. The producer operated the fans during the winter months for a total of less than 24 h. The large-diameter fans on these bins were not covered, and the rapid temperature response of grain deep in the masses to changes in ambient conditions indicated a significant amount of naturally occurring airflow through the grain. The mean moisture contents were

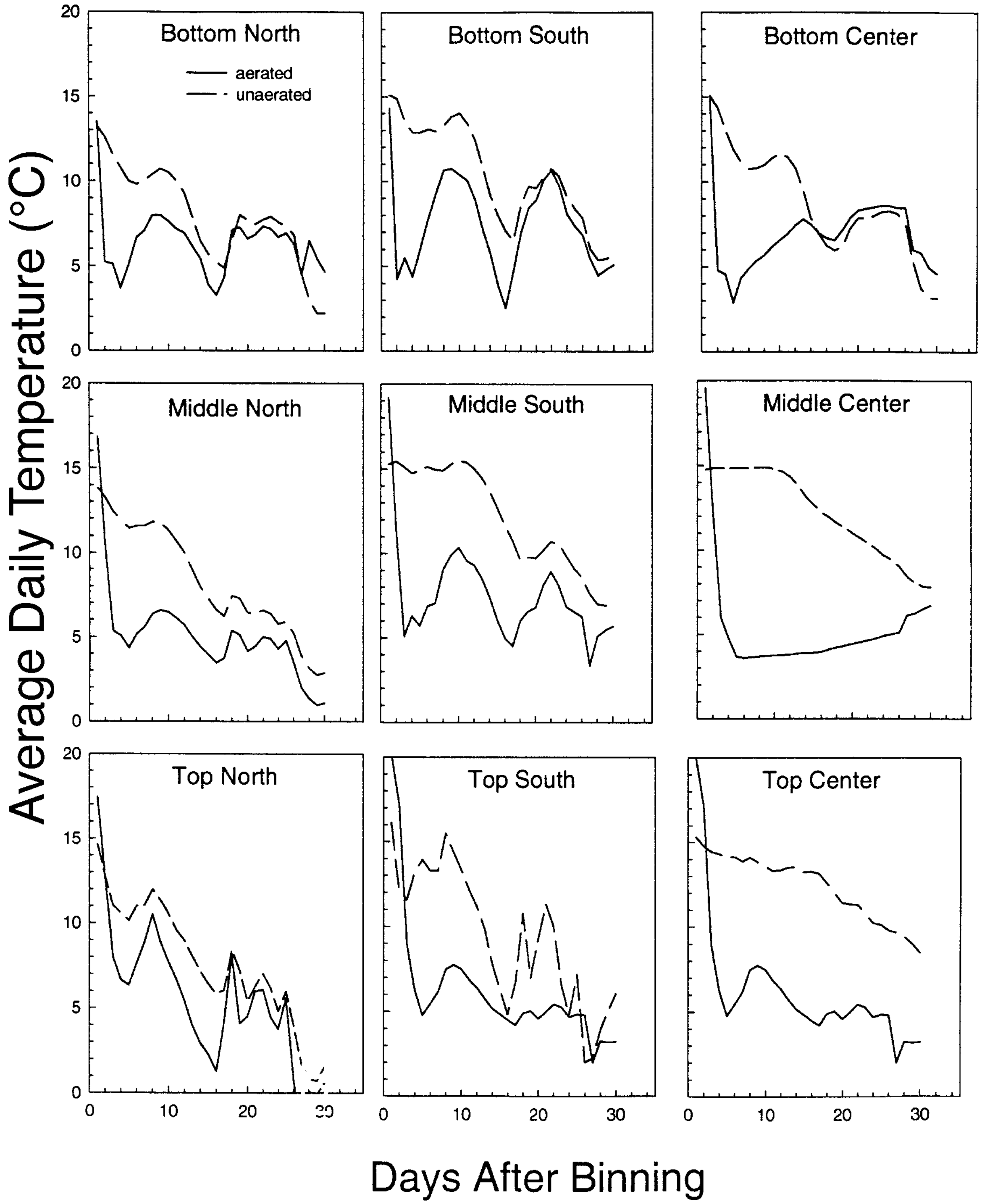

Figure 2–Mean daily grain temperature at each probe position for 30 days immediately after binning in three aerated and three unaerated lots of corn (27.5 t each) in 3.6-m diameter (12-ft) bins at Manhattan, Kansas.

16.0% by February, and 14.1% by May. This was the least expensive and most profitable strategy because more grain weight was conserved and less electricity was consumed.

2. In two other bins, corn was passed through a high-temperature dryer before binning to reduce the grain moisture to about 16%. Aeration fans then were operated for at least 15 days to provide additional cooling and drying. The grain remained peaked during the fan operation. In one, the grain moisture content ranged from 12.8% near the floor to 13.4% near the grain surface after drying and conditioning. In the other, the moisture had been reduced by the long post-drying aeration to 12.9% near the bin floor close to the bin wall but was 17.5 to 17.8% at the center of the grain mass, and was highest in the peak. This bin had a spout from the elevator leg to the center of the roof. Condensed water was observed falling from the spout into the grain during fan operation. Some grain at and just

beneath the grain surface at the center sprouted before the bin was cored several weeks after drying.

In grain that had received more than a few days of aeration "conditioning" without stirring, the average difference in moisture contents between upper and lower layers of the grain mass was 0.5 percentage points. In all the farm bins sampled over the two storage years wherein long aeration (more than seven days) had been accomplished, grain moisture after conditioning and storage was considerably below the optimum market level. In contrast, where short conditioning (less than three days) was accomplished after field-drying, moisture levels after storage were within one point of optimum. In all bins in which fans were not sealed, grain moisture was reduced one to three percentage points from typical harvest levels during winter storage even when fans were used only sparingly. This is consistent with the expected consequences of chimney and wind-induced natural ventilation in farm bins in the south-west corn production regions where ambient conditions in winter are warmer and dryer than in the majority of the corn belt.

Effect of Peaks and Spoutlines

In three of the farm bins sampled in the present study, the mean fine material content of the grain in the spoutline was 4.1 ± 0.35%, significantly ($P < 0.05$) greater than the 1.5 ± 0.08% in other parts of the grain mass. Coring, the removal of grain from the bin before aeration to extract the spoutline and minimize grain height differences, is a standard recommendation (Midwest Plan Service, 1988). However, in all the bins we observed, producers cored the bins after the fall conditioning was finished.

After the small bins used in the field simulation trials were filled, but before the grain was leveled, air velocity was measured during aeration. The mean air velocity at the peak was 0.45 m/min (1.5 ft/min), whereas near the wall, it was 1.44 m/min (4.8 ft/min). This peaked grain was about 0.6 m (2 ft) higher at the apex than near the bin wall. A similar pattern was observed in a 14.4 m (48 ft) diameter bin of recently harvested corn. Here the grain peak was about 1.8 m (6 ft) higher than grain at the bin wall. Air velocities of 4.6, 0.4, and 0.2 m/min (15.2, 1.3, and 0.6 ft/min) were observed near the wall, halfway up the peak, and at the apex, respectively. Grain temperatures 0.6 m (2 ft) beneath the grain surface at the same sampling points were 14, 18, and 22°C (58, 64, and 72°F) respectively, and grain moisture contents were 13.2, 13.5, and 13.9%. Surface grain beneath the entry spout, where condensed water was observed falling onto the grain during aeration, contained 22.1% moisture.

Grain Quality

No insects were observed in any grain sample from the farm bins in which fall conditioning and subsequent storage were studied through the 1995-1996 and 1996-1997 seasons. This was expected because sampling was done during cold weather and the grain had been moved by spring. Thus corn in six farm bins not visited previously was sampled in July. The mean moisture of the corn in these farm bins was 13.9% and ranged from 13.1 to 14.6%. In all cases, the mean moisture content of the surface grain was about 1.5 percentage points lower than the mean moisture of the remainder. One bin contained an insect infestation easily detectable by grain sampling, and pitfall probe traps collected insects in all bins. The traps are sensitive indicators of insect presence. The majority of the insects were saw-tooth grain beetles or hairy fungus beetles, although some *Cryptolestes spp*. beetles and *Tribolium spp*. beetles also were observed.

Grain in two of the bins sampled only in July showed evidence of considerable quality loss, as indicated by mold infection. In both cases, the problem was limited to the top center. In one bin, infection rates of *Aspergillus glaucus* ranged from 60 to 80% of the kernels. In the other, 10 to 45% were infected with *A. glaucus* and/or *A. flavus*. Darkened germs, usually associated with grain heating due to mold, were evident in both cases. The presence of *A. glaucus* in surface-sterilized kernels plated on agar is indicative of grain conditions favorable for mold-induced grain deterioration (Christensen and Meronuck, 1986), and *A. glaucus* infection in 50% or more of the kernels indicates that grain deterioration is already underway.

In the researcher-controlled, field simulation trials conducted at Manhattan, Kansas, neither the aerated nor the unaerated grain exhibited increased mold infection between October 1996 and August 1997. However, grain in these bins contained only about 13.0% moisture at binning. In one of the farm bins during the same time period, in unaerated corn containing 14.6% moisture, infection by *Aspergillus* spp. increased from 0 to 96% and infection by *Penicillium* spp. increased from 8 to 58%.

Aeration Controllers

The simple fan-control devices described previously have proved helpful in reducing costs, optimizing fan operation, and controlling insects in summer-harvested wheat (Reed & Harner, 1998a,b). Investigators wished to determine whether they also would be helpful in optimizing fan operations in fall crops. However, producers did not appear to perceive any advantage to the devices. Although controllers allowed the managers to achieve maximum cooling with minimum hours, many producers believed that operating the fans for an extended period after the grain is cooled provides drying and "conditioning" benefits. Therefore, they were not interested in minimizing the fan-hours. Others filled farm bins late in the fall, when consistently cool weather facilitated manual management of the fan. The large year-to-year variations in harvest time, moisture content, and grain temperature appeared to be factors in the inability to perceive consistent advantages in improved fan management.

In the simulated field trials, the thermostatically controlled cooling contributed to insect control, compared to natural cooling. No live adult maize weevils or red flour beetles were found in the cages stored in either the aerated or the unaerated grain from October 1996 to March 1997 (table 1). No sawtoothed grain beetles were found in the cages from aerated grain in March, but a mean of 12.3 ± 2.2 live adults was recovered from the cages in the unaerated grain. This indicated that some of the initial 50 adult sawtoothed grain beetles survived the winter when fall aeration was not used. By August 1997, all cages placed in the aerated and unaerated grain in October 1996 contained adult insects, indicating that although few adults survived the winter, larval or pupal forms of all test species were able to survive to adulthood. The sawtoothed grain

Table 1. Mean numbers (means ± SEM[a]) of live adults of each insect species inside a cage containing 1-kg of corn at the end of the storage period. Cages were seeded with 50 mixed-sex 1 or 2-wk-old adults and buried in the top surface of the aerated and unaerated corn

	Maize Weevil		Saw-Toothed Grain Beetle		Red Flour Beetle	
Storage Period	Aerated	Unaerated	Aerated	Unaerated	Aerated	Unaerated
10/31/96 to 3/17/97	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0*	12.3 ± 2.2*	0.0 ± 0.0	0.0 ± 0.0
10/31/96 to 8/27/97	44.0 ± 2.5	48.0 ± 2.1	35.0 ± 15.3*	419.7 ± 70.8*	47.3 ± 2.7	39.3 ± 6.9
03/18/97 to 6/30/97	30.0 ± 2.3	56.3 ± 12.7	203.7 ± 12.1	156.0 ± 27.1	60.3 ± 14.9	71.0 ± 10.6
03/18/97 to 8/27/97	278.7 ± 35.4	332.8 ± 21.8	234.6 ± 105.3	320.7 ± 90.3	56.0 ± 3.8	55.0 ± 9.2

[a] Means in a row followed by an * are significantly different ($P < 0.05$, Proc t-test).

beetles were able to reproduce in the aerated corn, despite the lack of adult survival through March. Nevertheless, cages in aerated corn contained 10 times fewer sawtoothed grain beetles than those in unaerated corn.

In the field simulation trials, a cooling cycle was accomplished in the spring. The controller was set to select only the coldest, night-time air so that the grain would not be warmed significantly near the air entrance point. Because the objective of the spring aeration was to pass only enough air through the cold center of the grain mass to re-cool surface grain that had warmed during the spring, the duration was less than that required for a complete aeration cycle. The unintended result of this aeration was that grain at the center of the aerated bins became warmer than that in the unaerated bins (fig. 1B) for approximately 30 days in May and June. Minor cooling effects were seen at the periphery of the grain, but this effect was short-lived and had no significant effects on the populations of caged insects (table 1).

The numbers of adult maize weevils in incubated corn from cages after each storage period were not significantly different for aerated versus unaerated bins (table 2). Ninety adult maize weevils were collected from one of the incubated samples of corn that had been stored in unaerated bins from October 1996 to March 1997, but none of the other samples from this time period contained more than one live adult. When cages stored from October 1996 to August 1997 were incubated, only one weevil was collected. No maize weevil adults survived the winter (October 1996 to March 1997), but an average of 46 adults/cage were found in cages that remained in the grain from October 1996 to August 1997 (table 1). This indicated that some F1 progeny must have emerged between the March and August sampling times. However, these F1 adults were unable to reproduce effectively, as evidenced by the lack of progeny when grain that had been in the bins all winter and summer (October 1996 to August 1997) was incubated (table 2). The numbers of F1 adults were considerably greater in the incubated samples of corn stored from March 1997 to either June 1997 or August 1997 than in the corn that had been placed in the bins in October 1996, but there was no significant effect of aeration.

Six different insect species were collected from the pitfall traps placed in the aerated and unaerated field simulation bins from 14 July 1997 to 21 July 1997. Data for all traps inside a bin were summed as one value and averaged for the aerated and unaerated bins (table 3). Some of the sawtoothed grain beetles might have escaped from the cages, but adults of the other species probably immigrated into the bins. The most abundant species was the hairy fungus beetle. There were no significant effects of aeration for any insect species.

Table 2. Mean numbers (means ± SEM) of F1 adult maize weevils in 1-kg lots of corn from the cages buried in the top surface of aerated and unaerated corn, after incubation for 2 months at 25 °C

Storage Period	Aerated	Unaerated
10/31/96 to 03/01/97	0.3 ± 0.3	31.0 ± 30.5
10/31/96 to 08/27/97	0.3 ± 0.3	0.0 ± 0.0
3/18/97 to 06/20/97	441.7 ± 140.2	683.3 ± 72.6
3/18/97 to 08/27/97	750.0 ± 327.9	717.7 ± 292.0

Table 3. Mean numbers (means ± SEM) of insects collected from pitfall traps placed in corn bins from 7/14/97 to 7/21/97

Insect Species	Aerated	Unaerated
Hairy fungus beetle	218.7 ± 90.7	350.0 ± 70.8
Indian meal moth	0.3 ± 0.3	0.3 ± 0.3
Larder beetle	2.3 ± 2.0	2.0 ± 2.0
Red flour beetle	4.0 ± 3.5	0.3 ± 0.3
Rusty grain beetle	4.0 ± 2.3	1.0 ± 0.6
Sawtoothed grain beetle	21.3 ± 10.3	23.0 ± 8.5

Conclusions

This series of studies in the south-west part of the U. S. corn belt indicated that producers' conditioning practices for corn were variable and often resulted in moisture loss in excess of that required for quality maintenance and to avoid market penalties. Many producers operated their fans for long periods of time, resulting in moisture gradients from top to bottom in the grain mass. Coring or leveling before conditioning with forced air was not observed, and the lack thereof resulted in air velocity differences as great as 25-fold between the cleaner grain near the bin walls and grain in the spoutline beneath the apex of the peak. This airflow gradient noticeably reduced the intended cooling and drying. Certain insects were able to survive in corn that cooled naturally without forced air. Mold and insect-produced deterioration was detected in farm-stored corn, especially that remaining in storage during summer months. The use of a simple, thermostat-based fan controller did not appear to provide significant benefits.

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