Pest management of stored maize using chilled aeration — a mid-west United States perspective

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Abstract

Management of stored-grain pests such as insects and fungi requires an integrated system approach that combines engineering, biological and economic principles. Chilled aeration is a non-traditional, non-chemical preservation technology for storage of cereal grains. Although it has been used effectively throughout the world to prevent and control insect infestations in stored grains, chemical pesticides are still the primary method utilised in the United States. The process of chilled aeration followed by low temperature storage is a technically feasible alternative to pesticide application for controlling stored-grain insects in the mid-western region of the United States.

This paper presents a preliminary summary of a comprehensive study in progress under midwestern United States conditions that includes physical, biological, and economic factors. Maize in four 250 bushel bins has been stored since July 1992, and was intentionally infested with insects. Four different management techniques have been employed as treatments (i.e. fumigation, chilled aeration, ambient aeration, and no aeration). Temperature, moisture content, mould development and insect population levels have been measured throughout the year. Although the study is not yet complete, preliminary results favour chilled aeration as a pest management strategy for optimum grain quality preservation.

Introduction

A stored-grain bulk is an ecological system created by humans in which deterioration results from interactions among physical, chemical, and biological variables, such as temperature, moisture, carbon dioxide, oxygen, microorganisms, insects, mites, rodents, birds, geographical location and storage structure. Among these variables, insects create numerous quality problems, and cause substantial economic losses (estimated at over $12 million in Indiana, USA in 1990). Preventing insect infestations of stored commodities requires an integrated system management approach that combines engineering, biological, and economic principles.

At a recent USDA workshop on alternatives for methyl bromide, (29 June-1 July 1993, Crystal City, Virginia) ambient and chilled aeration of stored grains, pulses, milled products and animal feeds was rated as one of only four high priority research areas. Although aeration is an existing technology, its utilisation as a preventative pest management tool has not been fully investigated to date. Other high priority research areas designated were monitoring, decision-support systems, and modified atmospheres. The consensus among workshop participants was that no direct substitute for methyl bromide exists that is as effective and fast-acting, nor is the development of such a therapeutic tool expected. Thus, we believe that research efforts should focus on preventative pest management techniques, such as aeration.

Insects and fungi create numerous quality problems in stored grain. Preventing insect infestation and mycotoxin occurrence begins on the farm with sanitation in storage facilities and grain cleaning. Application of a grain-protecting pesticide treatment is currently recommended for long-term (over one-season) storage. As grain is marketed and moves through various facilities, the identity of a lot is lost and additional pesticide treatments may occur. Thus, the number of pesticide applications can increase and toxic residues may accumulate in the final food or feed product.

Recent reports from the mid-western United States indicate that the lesser grain borer, *Rhyzopertha dominica* (F.), may be developing resistance to chlorphyrifos-methyl (Reldan) (Beeman and Wright 1990; Zettler and Cuperus 1990). As a result, this pest has been removed from the label. The label for pirimiphos-methyl (Actellic) now specifies that it will only suppress, not control *R. dominica* (F.). As additional insects develop resistance to currently available pesticides, greater emphasis must be placed on alternative methods of protecting our food supply including pheromone and pitfall traps, managing grain temperature and moisture content to limit insect reproduction and growth through aeration cooling, plant resistance, and biological control. Integrated pest management (IPM) is one strategy that can replace or reduce the use of synthetic chemicals as the primary control method. It involves insect sampling, risk-benefit analysis, aeration management, and the use of several control strategies (Hagstrum and Flinn 1992).

Insects are very sensitive to temperature changes in their environment (Mullen and Arbogast 1984). These changes in turn can influence population growth by reducing rates of development, survivorship, and age-specific fecundity (Hagstrum and Throne 1989). Most stored-product insects will not lay eggs below 15°C, and eggs laid above 15°C will not hatch below that temperature (Sinha and Watters 1985). Larval development is slowed in the range of 5-10°C and may result in death after a very short period of time (Sinha and Watters 1985). Conversely, stored-product insects thrive at approximately 29°C, and after 80 days of storage at or above 21°C any grain lot is likely to reach the economic threshold of insects if no protective measures are taken. Aeration cooling of grain as an insect control measure has potential for several reasons. In temperate climates the rate of growth of an insect population can be slowed by aeration with cool ambient air (Cuperus et al. 1986, 1990). Additionally, if low temperatures are attained rapidly and are maintained long enough, insects may be killed. Chilling to 3–4°C of barley infested with *Sitophilus granarius* (L.) prevented the development of a

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severe infestation, with approximately 97% control (Burrell 1967). Another reason for utilising aeration cooling is that lower temperatures if applied quickly prevents insects from acclimatising and insect population growth is slowed. Desmarchelier et al. (1979) examined the influence of chilling fumigated grain. Populations that were not cooled recovered to detection levels after just 10 weeks, while those subjected to a fast cooling did not achieve a detection level until week 34.

Evans (1979, 1983) examined the effects of thermal acclamation and humidity on the survivorship of several species of beetles. There was considerable interaction between temperature and humidity; as well as considerable variation between species. In another study, Fields (1990) demonstrated that if cooling occurred rapidly during the fall when insects had not been previously exposed to cool temperatures, all adult rusty grain beetles (*Cryptolestes ferrugineus*) (Stephens) were killed. Conversely, if cooling occurred mid-winter, there was a 60% survival rate. Thus, the rapid application of cold temperatures in warm grain appears to be an effective pest management tool.

Many experts do not recommend freezing maize during aeration. However, at the 1992 NC-151 (Marketing and Delivery of Quality Cereals and Oilseeds) annual meeting it was noted that an elevator in northern Minnesota killed insects in grain by aerating with air at −18°C (DeJean 1992). Related strategies which may hold promise include cycling the grain between warm and cold conditions over a period of several days. The additional stress placed on the insects may result in killing of larger percentages of adults and larvae. Under certain conditions, aeration cannot completely inhibit insect activity even in temperate climates because it cannot prevent the development of grain temperatures that are optimum for stored grain insects (i.e. 21–29°C). Such temperatures occur in recently harvested wheat and carry-over shelled maize stored in the summer. For such situations, chilled aeration may be utilised to maintain quality grain without the use of chemical protectants as compared to ambient aeration or no aeration (Maier and Bakker-Arkema 1993).

Although numerous aeration cooling studies have been conducted in the past, none has been published for maize stored in the mid-west corn belt region of the U.S. In addition, few studies have presented the potential synergistic effect between insects and fungi. The principal investigators are aware of pest management practices in numerous commercial popcorn and food-grade maize handling facilities that are implemented on a calendar basis. In most cases the aeration fan is operated manually, and its operation is generally neglected after fall cool-down is complete. In other cases, fumigation treatments occur once a month during the spring and summer whether insects are detected in the grain or not. In other cases, grain protectants are sprayed onto inbound grain originally binned on farms and delivered to the handling facility throughout the season. It is apparent that even these food-grade grain operators, who are generally considered more sophisticated than commercial grain handler, lack understanding of the potential of aeration as an alternative pest management strategy.

Agricultural engineers and entomologists at Purdue University are cooperating to examine the engineering and biological aspects of four different storage management techniques and their impact on stored-grain insects. The techniques examined include fumigation, chilled aeration, continuous/controlled aeration with ambient air, and undisturbed storage. The research trials are designed to evaluate 'real world' storage situations. The research objectives are to:

- compare the practices of fumigation, chilled aeration, continuous/ controlled aeration with ambient air, and undisturbed storage to manage stored-grain insects;
- add to the database of integrated pest management (IPM) knowledge and use this knowledge to investigate preventative and therapeutic management strategies; and
- aid in the development of computer models to simulate aeration, storage and pest management techniques more efficiently.

Only data from the first objective will be presented in this paper.

Information generated in this research could be used in stored-grain management decision-support systems such as the Stored Grain Advisor (SGA) being developed by the United States Grain Marketing Research Laboratory, USGMRL (Hagstrum and Flinn 1992), or the Stored-Corn Management Instruction System being developed at Purdue University. Computer-based management programs provide the flexibility and capability needed to implement a comprehensive IPM program. They can estimate insect densities and potential spoilage, and recommend alternative control measures, such as chilled aeration, or operate aeration fans more intelligently than current control schemes.

Materials and Methods

On 28–29 July 1992 four round metal bins were each filled with approximately 6.5 t of maize. The maize was acquired from a commercial elevator and had been in storage since autumn 1991. The average initial moisture content of the No. 2 maize was 14% wet basis. No visible insect or fungal damage was apparent. The bins are 2.2 m (7 ft) in diameter and were filled to approximately 2.2 m (7 ft) depth.

The maize in all bins has been continuously monitored since 30 July 1992. However, the storage period can be divided into two distinctly different trials. The first trial ran from 28 July 1992 until 16 June 1993. The second trial began on 16 June 1993 and is in progress. Insects were introduced into all bins to establish uniform initial populations. During the first trial the insect population failed to become fully established. The reason for this failure has not been fully determined except that initial infestation may have been too low and development too slow to reach detectable levels. Insects were reintroduced during the summer of 1993, and have reached detectable levels. Data for the second trial only will be reported in this paper.

Bins were assigned one of four treatments: chilled aeration, fumigation, ambient aeration, and undisturbed. Chilled aeration was accomplished through the use of a prototype grain chiller developed jointly by Purdue University and AAG Manufacturing (Milwaukee, Wisconsin, USA). A small 0.0125 hp centrifugal fan has been used for ambient aeration. It was sized to deliver 0.1 m^3/minute/t. From the beginning of the storage period to the autumn of 1993 the fan was operated continuously. In the autumn of 1993 control over the aeration fan was changed by installing a Sentry PAK (Sentry Technologies, Chanhassen, Minnesota) automatic aeration controller. The unit is operated in storage mode and activates the fan intermittently to maintain grain temperature near the 21-day average ambient temperature.

The grain is monitored for temperature, moisture content, insect activity, and fungal growth. Temperatures are taken hourly with an automatic data acquisition system. Thermocouples are placed in five locations throughout the bin (three centre and two perimeter). Centre thermocouples are vertically located 0.6 m apart starting 0.6 m from the bottom (bottom, middle and top centre, respectively). Perimeter thermocouples are located 15-25 cm from the southern side wall and 0.6 and 1.5 m from the bottom (bottom and top perimeter, respectively). Maize samples are taken approximately each month to determine fungal growth and moisture contents.

Fungal growth is evaluated by using a serial dilution method (Marks 1992). The moisture content is determined using the drying oven method (ASAE standard S352.2).

Insect populations are monitored with probe traps. Five probe traps are placed in each bin just below the grain surface on the north, south, east, west sides and centre of the bins. During the first trial the probes were inserted on a weekly basis and left in for 3 days. During trial 2 the bins are monitored continuously. Trap catches are collected on a weekly basis and the number and species of insects recorded. The longer sampling time in trial 2 has allowed the acquisition of a more representative insect population. During the winter months traps are checked only once per month due to lower insect activity.

In the first trial the bins were infested with *Sitophilus oryzae* (L.) (rice weevil) at a rate of 250 insects per bin. After the completion approximately of one complete life cycle, the treatments were applied beginning on 24 August 1992. The fumigated bin was treated with phosphine (Phostoxin; Degesch) at the recommended label rate. After the recommended period of fumigation the bin was aerated. The fans in both the fumigated bin and the non-fumigated ambient aeration bin were continuously operated until the end of October 1992. At that time ambient temperatures were determined to be low enough to maintain grain temperatures through the winter. The ambient aeration bin was turned on again on 5 May 1993. For the chilled aeration treatment, 10°C air was moved through the grain mass for a 24-hour period on 23 August 1992. The bin was chilled three more times on 11 September 1992, 16 October 1992 and 11 May 1993. The control bin was left undisturbed for the entire period.

On 16 June 1993 three new populations of insect species were introduced into the bins. The species included *S. zeamais* (Motsch.), *S. oryzae* (L.) and *Tribolium confusum* (Jacquelin du Val) (maize weevil, rice weevil and confused flour beetle, respectively). The rate of infestation was 250 insects/species per bin. The chilled bin was cooled with 7°C air on 27 September 1993. The fumigated bin was treated on 24 September 1993 with phosphine, same as the first trial. In August 1993 fungal growth was detected on the surface of the grain in the chilled and undisturbed bins. To assess the extent of visible fungal growth and grain heating, the maize in each bin was turned in late September. This process included removing the maize from each bin, cleaning any mouldy grain from any of the surfaces of the bins and returning the grain to the bin. Due to the unloading, thorough mixing of each batch of maize occurred. Visible inspection and sampling of the maize showed it to be in good condition, and thus the trial was continued.

Results and Discussion

The results of trial one proved to be inconclusive due to the lack of detectable insect levels. Rice weevil populations failed to become established throughout the trial period. It was not possible to distinguish between the treatment effects because of the limited numbers of insects collected. However, during this trial the grain temperature control due to ambient, chilled and no aeration performed as expected (Fig. 1). The temperature of the control bin displays a steady decrease into the winter months. When compared with ambient temperatures, it follows the same pattern with a small time delay. The ambient aeration bin shows a great deal of fluctuation. This is due to the daily temperature changes. Temperatures in the chilled bin show a number of steps. These are the chilling cycles. The sudden drops and slow increases are very pronounced. The grain temperature at the centre of the four bins decreased from an initial 25°C to about 8°C by 5 December 1992. [Note: The temperature in the fumigated bin is not shown but it displayed the same pattern as the aerated bin during this period.]

The second trial is proving to be more successful. The introduction of new insects contributed substantially to the establishment of populations. Figures 2–5 illustrate the total number of insects trapped per bin per species during each sampling. Internal infesters (*Sitophilus* spp. (rice and maize weevils)) detected in each bin are shown in Figure 2 between 14 May through 25 December 1993. For most of the summer the populations were essentially non-detectable. The sudden increase in populations by October seem to indicate an incubation period of about three months for the population to establish. Observations in October indicated populations to be largest in the fumigated and untreated (control) bins. Clearly, the eradication treatment with phosphine fumigation was not effective. Additionally, fumigation has no residual effect and the potential for reinfestation exists. Populations were again high in the fumigation bin by 15 October 1993. Controlled and chilled aeration appear to maintain grain temperatures sufficiently low to suppress *Sitophilus* spp. populations during warmer weather. However, intermittent chilling for short duration shows slightly poorer treatment effects, and without additional chilling populations increased in November. By mid-December, populations declined to below detectable levels.

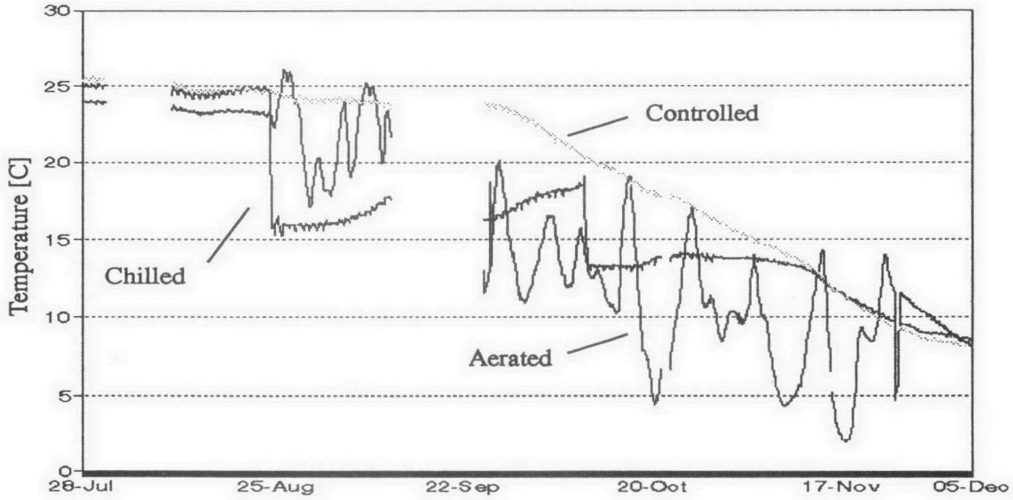

Fig. 1. Grain temperatures during summer, autumn and winter 1992.

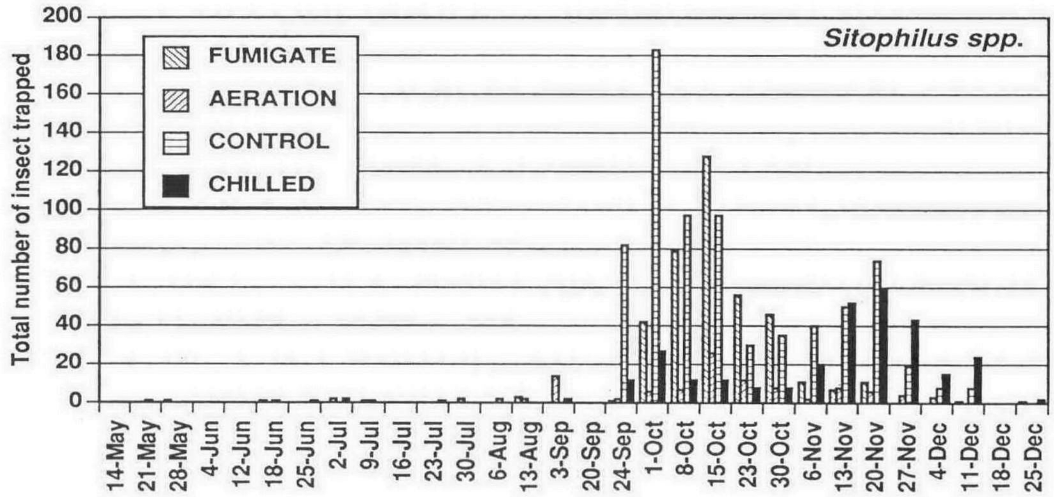

Fig. 2. Total number of *Sitophilus* spp. (rice and maize weevils) collected in probe traps during trial 2.

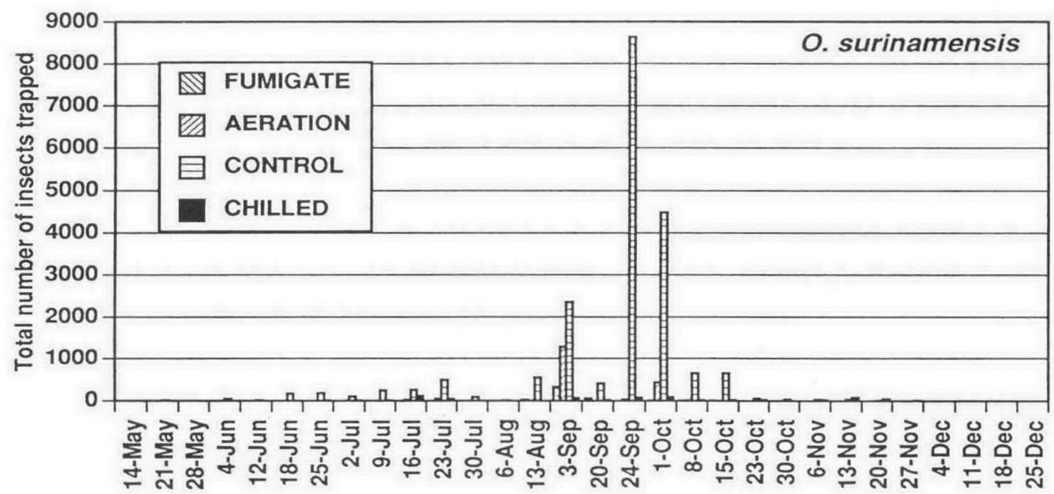

Fig. 3. Total number of *Oryzaephilus surinamensis* (sawtoothed grain beetle) collected in probe traps during trial 2.

The external feeders detected in large numbers include *Oryzaephilus surinamensis* (L.) (sawtoothed grain beetle) and *T. confusum* (confused flour beetle) (Figs 3 and 4). The control bin shows a gradual increase in sawtoothed grain beetle (Fig. 3) and confused flour beetle (Fig. 4) populations through the summer and into September when populations exploded (>8000/bin sawtoothed grain beetle and >4500/bin confused flour beetle). This increase corresponds to the steady increase in grain temperature throughout the summer. The substantial drop in the population in early October corresponds to the rotation of the bins and a decrease in grain temperature. The fumigation treatment shows a considerable decrease in the confused flour beetle population within 2 weeks of treatment from nearly 300 insects on 20 September to approximately 50 on 15 October (Fig. 4). The reason the population remained high on 1 October was probably due to the fact that the insects had 4 days to get trapped before fumigation occurred on 24 September; and because populations were on the increase. The bin under ambient aeration showed little change in population levels over the sampling period. An increase in confused flour beetles can be seen in the chilled bin during the 20 September 1993 trapping. However, population levels were considerably lower than in the control. Population decreased from 544 insects to a total of 10 insects in the chilled bin once the bin was chilled on 27 September 1993. Populations remained low throughout the rest of the 1993 season.

Fungal growth in all the bins resulted in large numbers of fungus-feeding insects. The primary fungi found were *Fusarium monilifourne*, *Aspergillus flavus* and *A. glaucus*. The most prominent fungus/feeding insect was *Typhaea stercorea* (hairy fungus beetle). Sampling results are summarised in Figure 5. The control bin showed a gradual increase of *T. stercorea* until decreasing significantly through August. Population rebounded in September and October and finally dropped of near zero in November. The ambient aerated and chilled bins both show substantial increases through August with populations exceeding 4500/bin per week in the aerated bin and 3500/bin in the chilled bin. Subsequently, *T. stercorea* numbers in the aerated, chilled and control bins decreased while the population in the fumigated bin increased. This probably indicates insect movement between bins due to excessive population densities. The fumigation treatment successfully controlled the increase in *T. stercorea* at the end of September. The chilled aeration treatment on 27 September 1993, reduced insect populations from 500 in September to zero after 1 October. Low temperatures in late autumn helped to maintain smaller populations in all bins.

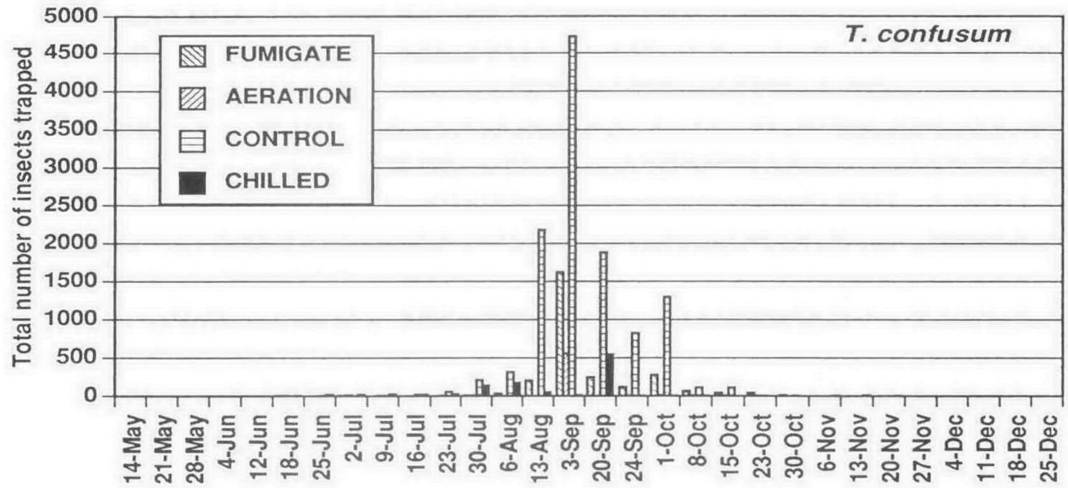

Fig. 4. Total number of *Tribolium confusum* (confused flour beetle) collected in probe traps during trial 2.

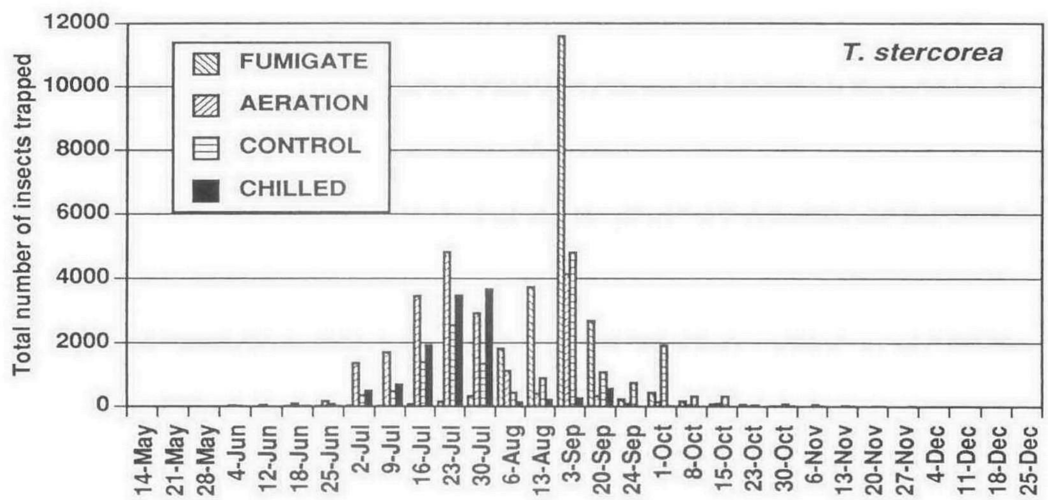

Fig. 5. Total number of *Typhaea stercorea* (hairy fungus beetle) collected in probe traps during trial 2.

The current trial will continue through the spring of 1994. This will provide a full year of data to see how the insects react to the treatments and the change of season. Preliminary results indicate that ambient and chilled aeration have beneficial therapeutic effects on insect populations in mid-west stored maize. Optimising the timing of chilling will be investigated further and will be part of the trial in year three. Storing maize without the availability of temperature control through aeration appears clearly undesirable.

The condition of the grain is such that the trial will not likely continue through the summer of 1994. However, a third trial is planned which will use 1993 maize currently in storage at Purdue University. The information gathered during these trials will be the basis for laboratory studies on the effects of environmental conditions on insect development and provide data needed for computer modelling of insect population dynamics in the stored-grain ecosystem.

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