Area-Wide IPM for Commercial Wheat Storage

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ABSTRACT The United States Department of Agriculture's Agricultural Research Service (USDA-ARS) funded a demonstration project between 1998 and 2003 for area-wide integrated pest management (AW-IPM) of commercial stored wheat in Kansas and Oklahoma. The AW-IPM concept is useful to stored grain because it reduces the mixing of infested and uninfested grain at the terminal elevator by controlling insect problems in small country elevators before the grain is shipped to the terminal elevator. This project was a collaboration of the USDA-ARS Grain Marketing and Production Research Center in Manhattan, Kansas, Kansas State University, and Oklahoma State University. The project utilized two elevator networks, one in each state. Over the five years of the study, researchers worked in approximately 55 country elevators and four terminal elevators, and collected and analysed more than 125 000 grain samples. Wheat at elevators was frequently infested by several insect species, which sometimes reached high numbers and damaged the grain. Fumigation using aluminum phosphide is the main method for controlling insect pests in grain elevators in the USA. Fumigation decisions tended to be based on past experience with controlling stored-grain insects, or were calendar-based. The best sampling method for estimating insect density in commercial elevators without having to transfer the grain from bin to bin was the vacuum probe sampler. Decision-support software "Stored Grain Advisor Pro (SGA Pro)" was developed that interprets insect sampling data and provides grain managers with a risk analysis report for their elevator that specifies the current and predicted risk for each bin. Recommended treatment strategies and economic analysis were presented to the elevator managers at six-week intervals. Elevators that followed the recommendations reduced the number of bins they normally fumigated by at least 50%. The AW-IPM programme was superior to calendar-based management because it ensured that the grain in each bin was only treated when insect densities exceeded economic thresholds. This approach reduced the frequency of fumigation while maintaining high grain quality. Minimizing the use of fumigant improves worker safety and reduces control costs and harm to the environment. A grain-scouting company was started that uses SGA Pro and the sampling tools that were developed in this project. The company is in its third year and has over 30 commercial elevators on contract.

KEY WORDS area-wide, integrated pest management, stored-grain, insect damage, decision-support software

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1. Introduction

Area-wide integrated pest management (AW-IPM) involves coordinating insect pest management programmes against a targeted pest population to reduce the overall densities of insect pests and to minimize the risk of initial infestation and reinfestation after insect pests have been controlled (Rabb 1978, Knipling and Stadelbacher 1983, Bellows 1987).

The USA is a world leader in wheat production. Stored-grain insects and moulds cause USD millions in losses annually in this multi-billion dollar industry. AW-IPM is particularly important for stored grain because insects are moved through the marketing system with the grain (Hagstrum and Flinn 1992, Hagstrum et al. 1999). Wheat is stored in large networks of country (smaller elevators) and large terminal elevators, and grain from several million hectares ultimately ends up in a few very large terminal elevators. Failure to control insects at country elevators early on can provide a source of infestation that can infest much larger quantities of grain as it is combined and blended at the terminal elevator. Often, the country and terminal elevators are owned by the same company, and by controlling insects in the country elevators, the company is assured of high quality grain by the time it arrives at the terminal elevator.

Blending infested grain with uninfested grain can increase the cost of insect pest management because many more bins will need to be fumigated. Currently, insect problems are managed at most elevators by calendar-based fumigations. These fumigations do not distinguish between high and low insect densities, and do not optimize the timing of the fumigation. Insect problems can be managed much more effectively, and with less fumigation, if insect are detected by sampling the grain at regular intervals, and fumigating bins in which insect problems are found.

From 1998-2003, the United States Department of Agriculture-Agricultural Research Service (USDA-ARS) funded a demonstration project for AW-IPM for stored wheat in Kansas and Oklahoma. This project involved collaboration between researchers at the USDA-ARS Grain Marketing and Production Research Center in Manhattan, Kansas, the Kansas State University in Manhattan, and the Oklahoma State University in Stillwater. The project was conducted in working elevators and was designed to document the efficacy of current insect control practices, and test new approaches and technologies to further the adoption of integrated pest management (IPM) practices. An IPM approach involves data-driven decision-making based on benefit/cost ratios, especially when toxic pesticides are used. The USDA and the Environmental Protection Agency (EPA) promote IPM technologies because they bring increased profits while reducing pesticide use in many areas of US agriculture.

Over the five years of the study, project investigators worked in 55 country (smaller elevators) and four terminal elevators in Kansas and Oklahoma, collecting and analysing more than 125 000 samples. Special projects on grain aeration, grain fumigation, sanitation, pesticide use, and many other topics were carried out. The wheat at these elevators was harvested from over 32 400 hectares. Elevators were selected for the project so that the wheat could be followed as it moved from farm to country elevator to terminal elevator. Roughly, 70% of the wheat sampled at the country elevators moved to the four terminal elevators that were collaborating in the AW-IPM project.

The objectives of the study were to: (1) develop practical sampling methods for insects in elevator bins, (2) develop risk-analysis decision-support software, and (3) determine if a sampling-based risk analysis programme maintains grain quality and reduces fumigation compared to calendar-based fumigations.

2. Methods

Traditionally, elevator managers have depended on thermocouples to alert them of potential mould and insect problems. However, grain heating occurs only when large numbers of insects or severe mould problems are present. Another insect monitoring and grain conditioning practice is to "turn" the grain from one bin to another, sampling the grain as it moves. However, grain turning is expensive. Fumigation is usually done as the grain is turned; thus, if the manager decides to turn, they often fumigate at the same time to save the cost of turning again to fumigate. For the AW-IPM study, a method was needed to monitor insect populations in grain bins without having to turn the grain. A newly developed gasoline-powered vacuum probe worked well. The vacuum probe was used to take a three kilogram sample from each 1.2 metre layer of grain as the probe was pushed down into the grain to a depth of 13 metres (about half the depth of grain in an average bin). Because of the large sample size (three kilograms), a specially designed inclined sieve was used to separate insects from the grain (Hagstrum 1989). In addition to the vacuum sampling, grain temperature and moisture were also monitored.

During the project, a decision-support software, Stored Grain Advisor Pro (SGA Pro) was developed and validated. This software interprets insect sampling data, and provides grain managers with a risk analysis report detailing which bins are at risk for insect-caused economic losses. This software uses rules to evaluate the risk based on current insect density, predicted insect density, grain temperature, and grain moisture. Insect density was predicted up to three months in the future using computer simulation models, based on grain temperature and moisture inputs (Flinn et al. 1997, Flinn et al. 2002).

3. Results and Discussion

3.1. Vacuum Probe Sampling

Data collected with the vacuum probe sampler were well correlated (r^2 = 0.79) with grain samples taken as the bin was unloaded.

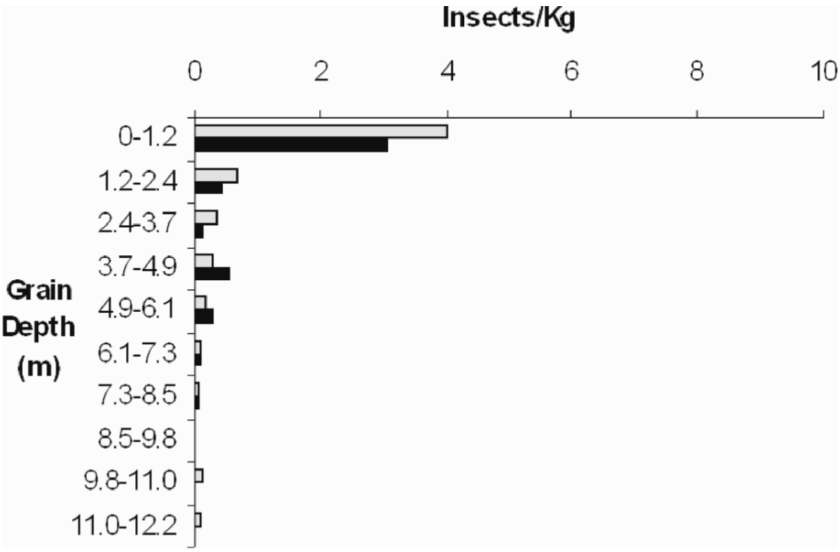

Figure 1. *Average insect density for* Cryptolestes ferrugineus *(grey) and* Rhyzopertha dominica *(black) as a function of grain depth in 30-metre-tall upright concrete grain bins in September. Ten, three kilogram grain samples were taken in each bin, and 172 elevator bins were sampled in September.*

The vacuum probe provided the most convenient and reliable method of routinely sampling bulk grain for insects without having to move the grain from bin to bin.

In general, insect density was found to decrease with grain depth, and in most cases, the majority of insects were found in the top half (13 metres) of the grain bin (Fig. 1). Therefore, it was not necessary to sample the entire depth of the grain bin, only the top 13 metres (most bins were over 26 metres in depth). The time required to probe a bin was greatly reduced by sampling only the top 13 metres of the grain mass instead of the entire 26 metres. Using the inclined sieve, samples were sieved at the elevator, and only the fine material containing the insects was transported to the laboratory for identification and counting.

The three most common insects infesting stored wheat in Kansas and Oklahoma were the rusty grain beetle *Cryptolestes ferrugineus* (Stephens), lesser grain borer *Rhyzopertha dominica* (F.), and red flour beetle *Tribolium castaneum* (Herbst) (Reed et al. 2003). Of these three, the lesser grain borer is by far the most damaging because the immature stages develop inside the kernel. These same three species have been reported as major stored grain pests in other counties, so the same IPM programme used in this study could be used in other parts of the world. The relative proportion of the species changed with time of year. In general, the rusty grain beetle was most common during the first months of storage. However, after about three to four months of storage, the lesser grain borer often became the dominant species (Reed et al. 2003).

The value of the insect monitoring programme to the elevator manager was evaluated by providing the managers with information about the insect density in each of their bins every six weeks. In some cases, this information was shared with the terminal elevator that was expected to receive the grain. How this information was used by the manager to make insect pest management decisions was also evaluated.

3.2. Fumigation and Aeration

In addition to fumigation, other methods, such as aeration to cool the grain, can be used instead of fumigation to suppress insect growth in bins with low insect densities (less than two insects per kilogram). Inexpensive automatic aeration controllers can be used to turn on aeration fans when outside air temperatures are below a set temperature threshold. Insect development and reproductive rates are directly related to temperature. The optimal temperature for stored grain insects is about 30-32°C. Most stored grain insects fail to develop and reproduce at temperatures below 20°C.

Currently, insect pests in stored grain are managed at most elevators by calendar-based fumigations. These do not distinguish between bins with high and low insect densities, and normally do not select the best time of year to fumigate infested grain. Fumigating grain with low insect densities in the summer increases the cost of elevator operations unnecessarily because the grain will probably need to be fumigated again in the autumn. Many elevators in this study fumigated grain within one month of storage. Based on sampling data, there were very low numbers of insects at that time. Elevator managers also believed fumigations to be very effective. However, the data obtained from this study showed that the efficacy of fumigation at two terminal elevators was quite variable. At one elevator, fumigation failed to reduce insect populations by 80% in all of the bins; while in two other elevators, insect populations were reduced by over 80% in nearly all bins. Insect problems can be managed much more effectively if the grain manager has information about which bins in their elevator have high insect densities, so that these bins can be fumigated before damage occurs. Often, the only indication of an insect problem is a hot spot indicated by the temperature cables. By the time the hot spot is noticed, significant insect damage has already occurred to the grain.

Determining when to fumigate grain for

insect control is complicated. A typical elevator has many bins, each with grain at a different temperature and moisture, with different insect densities, and stored for different time periods. These factors directly affect insect population growth. The problem with calendar-based fumigation is that bins either are fumigated unnecessarily, or are fumigated after the grain has already been damaged by high insect densities. IPM uses sampling to determine if insect numbers have exceeded an economic threshold. Turning grain from one bin to another can be used to sample grain. It is not cost-effective, however, to turn grain just for the purpose of sampling. There are costs for labour, electricity and shrink (loss of grain volume). Fumigating grain is normally accomplished by adding the phosphine pellets to the grain as it is turned from one bin to another empty bin. If grain is going to be turned, it is more cost-effective to simply add the fumigant pellets at the same time rather than having to turn the grain twice. However, the problem with this approach is that grain that does not need to be fumigated may be unnecessarily turned and fumigated (if the grain has not been sampled, the insect density is unknown).

What was needed for an elevator IPM programme was a cost-effective method to sample the grain for insects without having to turn the grain. A major objective of the study was therefore to determine whether insect-monitoring-based fumigation was more effective in reducing the risk of economic losses from insect problems than calendar-based fumigation. With calendar-based fumigation, some bins are fumigated too soon, and others are not fumigated soon enough. Newly harvested grain has a very low insect density and does not need to be fumigated. Grain that is fumigated early becomes infested soon after fumigation because there is no residual effect. Leaving newly-harvested grain undisturbed as long as possible minimizes the blending of infested and uninfested grain within a grain elevator. This occurred because the bottom half of the bin usually contained uninfested wheat, while the top of the grain was infested. Fumigating in the autumn is a good strategy because cooler air temperatures will lower the grain temperature following fumigation, which will reduce the growth rate of any surviving insect populations.

Sampling bins with a vacuum probe every six weeks ensures that bins are not fumigated unnecessarily, and that bins that have insect densities above economic thresholds (more than two insects per kilogram) are treated promptly. This way, the manager continually knows the status of the grain, and therefore does not have to fumigate their bins two to three times a year to reduce risk. In this project, sampling at elevators has shown that usually only a few bins have insect densities that justify fumigation. Thus, treating only the bins that require fumigation reduces the cost of pest management and results in better overall grain quality. The area-wide approach is also applicable within an elevator; by keeping overall insect density low for the entire elevator, the manager reduces the probability of insects spreading from one bin to another within the facility.

3.3. Validation of SGA Pro

The SGA Pro software was field-tested for two years. Every six weeks, the bins were resampled, the predicted insect densities were compared with actual insect densities, and the manager's bin treatment actions were recorded. To test the accuracy of SGA Pro's predictions, bins that were sampled at least twice were used, starting in autumn, in which the grain was not moved or fumigated. SGA Pro was used to analyse the data and to provide recommendations to the elevator managers. A report was generated for each elevator, and a bin diagram showed which bins were at low, moderate, or high risk (Fig. 2). Because grain managers were accustomed to working with bin diagrams, the output was intuitive to them. SGA Pro did an excellent job in predicting which bins were at risk for high insect densities. In Kansas elevators, the software correctly predicted that bins were either "safe" or at "high risk" in 285 out of 399 bins. It failed to

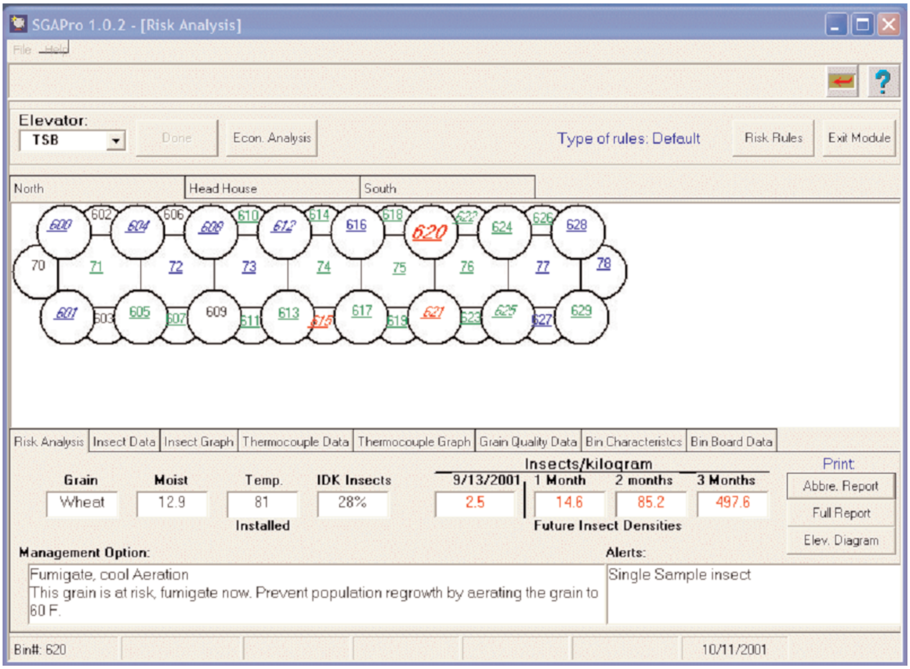

Figure 2. *SGA Pro computer screen shot: bin numbers in green, blue and red are predicted to be at low, moderate, and high risk for insect damage. In this figure, bin numbers in light grey are at low risk, bins 620, 621 and 615 are at high risk, and the rest are at moderate risk. In this example, the user has clicked on bin 620, and its data and recommendation are shown in the lower part of the screen.*

predict unsafe insect densities in only two bins (0.5%) and the insects in these isolated instances were mostly near the surface, suggesting recent immigration. That left 112 bins for which the software predicted moderate risk, and these bins did not have high insect densities when they were sampled six weeks later. Because the software recommended that the manager "consider fumigation and resample six weeks", it was not felt that this was a major concern, and that it was better to err on the side of caution then to not recommend treatment when it was necessary. All of the bins that the software indicated as being at high risk turned out to have insect densities greater than the threshold at the next sampling interval.

In Oklahoma, the SGA Pro correctly predicted bins that were safe or at high risk in 107 out of 133 total bins. All of the bins that the software indicated as being safe turned out to have insect densities below the thresholds six weeks later. Elevators that followed SGA Pro's recommendations reduced the number of bins fumigated by at least 50%.

3.4. Current Status of SGA Pro

Currently, a private company is using SGA Pro and the sampling methods developed in this project to provide services for over 30 elevators in several states. The company is in its third year of business and continues to expand. The consulting company has found that most grain handling companies in the USA are likely to have grain managers who are conservative in their approach to pest control. However, a few early adopters of grain scouting, those who appeared to be open to major change in grain management because of unique market factors, embraced the entire information-based decision-making concept. In contrast, most clients perceive value only in parts or components of the software and services offered by the grain scouting company. Several of the scouting company's clientele purchased only grain sampling and grading services that had obvious benefits to the grain merchandiser. Some clients were initially attracted to the inexpensive grain quality information generated by SGA Pro, and only slowly began to perceive the potential benefits of the insect-sampling service. When presented with vacuum probe sampling data for their elevators, managers were often surprised at how few bins had damaging numbers of insects, and how ineffective fumigation could be. Grain managers were very interested in the spatial distribution of insects in their bins and the implication that insects are immigrating into their grain from the top of the grain bin.

To quantify the effect of the information-based approach to insect control, the incidence and density of insect-damaged wheat kernels in samples collected in the autumn of 2003, the first year of the scouting company's operation, were compared with samples collected during the same time period two years later. Data from four elevators were used in this analysis, providing 2132 data points. The frequency of samples with a high density (more than 10 per 100 g) of kernel damage was reduced by 24% (Chi square = 34.8, $P < 0.01$), and the difference in the mean density of kernel damage (2.5 per 100 grams versus 1.9 per 100 grams) was significant at $P < 0.05$.

AW-IPM will be adopted by grain elevator managers only if it is more effective and profitable than their traditional approach, and if it fits into their current marketing and grain management practices. Every effort has been made to determine how elevator managers might use insect-monitoring information to manage insect problems in their grain bins. The findings of the AW-IPM project have been communicated to managers through nine newsletters, at training programmes in Kansas, Oklahoma, Nebraska, and Minnesota, and at two recent International Grain Elevator and Processing Society annual meetings. Information gathered in this study was used to develop extension publications for stored grain integrated pest management. In addition, SGA Pro software is freely available to the public at the USDA-ARS, Grain Marketing and Production Research Center website: http://ars.usda.gov/npa/gmprc/bru/sga/. Learning to use the software is fairly easy; however, using the sampling equipment and identifying the insects does require some training.

4. Conclusions

Insect monitoring-based fumigation has several advantages over calendar-based fumigation. Treating bins only when insect densities exceed economic thresholds and treating only those bins that need to be treated can minimize the risk of economic losses from unexpected insect problems, while reducing the cost of pest management and the use of fumigant. Minimizing the use of fumigant improves worker safety by reducing exposure to phosphine, and reduces the probability that insect populations will develop resistance to phosphine. Aeration can also be used to cool grain to suppress insect population growth. Aeration should be started as soon as possible to reduce storage risk. SGA Pro software improved insect pest management by reducing the frequency of fumigation, while also maintaining grain quality. In addition, grain sampling provided unexpected benefits, such as the profiling of protein content in each bin, which allowed better grain blending. Improved cost-effectiveness of insect pest management, while maintaining grain quality, can improve the competitiveness of the grain company. Potential area-wide benefits include reducing the overall insect pressure within an elevator facility, and reducing the transfer of infested grain from small country elevators to large terminal elevators.

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