The economics of IPM in stored grain: Why don’t more grain handlers use IPM?

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Introduction

Much grain is lost or damaged in storage. The estimates range from about 5% in the U.S. (Worley, 2002) to 10% in some other developed countries and up to 50% in developing countries. The FAO (1988) reported that India’s storage losses were about 6% in 1988, with half due to insects and fungi and half due to rodents, while FAO’s 1994 report on developing countries reported that surveys suggested storage losses of between 1.5% and 3.9%.

Even at the lower numbers, however, such as in the U.S., Kenkel et al. (1994) estimated that insect, mold, heating, and sprouting losses approached $300 million for hard red winter and spring wheat alone. So the losses are not small, even in developed countries.

How much loss is too much? Are the losses enough to say that grain handlers are not properly protecting their grain? Or are the losses at the point at which the costs of “properly” protecting their grain just equal the benefits of doing so? What level of protection should grain handlers be purchasing?

Mumford and Norton (1984) suggest that entomologists contributed greatly (perhaps even more than economists did) to answering this question when Stern introduced the concept of “economic threshold,” in which treatment is applied when the treatment just exceeds its cost. However, this is easier said than done. In the case of stored products, there is uncertainty in the current level of pest population, the future level of pest population (because of uncertain weather conditions), and in the efficacy of various treatments, for example. Should a manager apply treatment now, and risk the extra cost of treating again later, or should one wait to apply treatment and risk the possibly larger cost of grain damage from the elevated insect population levels?

Several years ago a research team composed of entomologists, agricultural engineers, grain scientists, and an agricultural economist from Oklahoma State University, Kansas State University and Agricultural Research Service (ARS/USDA) at Manhattan, began a project intended to assist grain elevator managers in implementing IPM practices for hard red winter wheat. Some in the group were technicians who sampled for insects, managed the temperature controllers, and assisted the grain elevator managers in making appropriate decisions about managing insects.

As the project progressed, some elevators adopted IPM practices. Some didn’t adopt IPM completely, but adopted some practices, such as better cleanliness or better aeration. And some didn’t change anything. They would fumigate everything at a particular time during the storage season and once before selling the grain, no matter what.

Why did some adopt IPM, while others didn’t? Clearly, an IPM approach is a better technology, isn’t it, with its use of more information to select the best approach to controlling grain pests? One would think that since the best approach could include the same treatment they would have used anyway, IPM should be at least as good as what they already do.

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The stored product team recognized that elevator managers will not typically adopt new technology, a new way of doing things, if it costs more than what they’re doing. Lukens (2002) conducted an economic engineering analysis, based on work Rulon et al. (1999) had done evaluating the economics of chilling popcorn.

That economic engineering analysis suggested that IPM-based treatments may not be any more costly than chemical-based approaches. For example, fumigating all the bins in an elevator would cost about 2.8 ¢/bu, while sampling all the bins and fumigating only half of the elevator’s bins that needed it would cost 2.7 ¢/bu. (these numbers are updates from the work reported by Lukens, 2002 and by Mah, 2004).

So why weren’t all the elevator managers adopting an IPM approach? The rest of this paper describes one part of a study attempting to answer this question, and illustrates one possible answer. The study is set in the context of Kansas and Oklahoma elevators that store hard red winter wheat and sell using U.S. grades and standards, but I believe the principles apply more widely.

**Costs and benefits of IPM in grain elevators**

The purpose of this research was to measure the costs of alternative insect management strategies. The specific focus was to compare the costs of IPM approaches with those of traditional non-IPM approaches. Two components of cost were considered. The first was treatment cost, which has been examined by Lukens (2002). The second was costs of insect damage resulting from failing to control insects. If insects reach a certain population, they can cause grain damage which triggers large discounts, or at least increase the need for additional insect treatments.

Applying treatments when they are not needed adds unnecessary costs. However, not applying treatments when they are needed results in potentially large costs. Typically, IPM practices use monitoring to decide when treatments are needed. However, monitoring itself is costly. Further, the manager must choose when to sample, and then at what level of insect population detected by sampling action should be taken.

An elevator’s profit is reduced by insect costs, both cost of treatment and cost due to insect damage. The elevator manager wants to find a treatment strategy that will reduce these costs. For each insect management strategy, this cost can be expressed as

\[ C = TC + D \]

where \( C \) is the cost function, \( TC \) is the treatment cost and \( D \) is the discount caused by grain damage. Insects also cause loss of grain weight, but the effect is small compared to other effects, so we ignore it here.

In order to focus on the costs that a typical grain elevator operator would face, several potential benefits of IPM strategies are not explicitly considered. First, there may be marketing advantages to using IPM strategies if consumers perceive that pesticide residuals are likely to be smaller. Second, reducing pesticides may reduce insect resistance and lower environmental impact. Third, reducing the use of pesticides also reduces the chance that their use will be restricted or eliminated through government regulation, which would reduce the range of tools available for effective insect management. These are important, and greatly increase the complexity of the decision maker’s choice, but we ignore them here.

**Procedures**

Lukens (2002), based on work by Rulon (1996) and by Rulon et al. (1999), has created a spreadsheet model for calculating direct costs of various treatments, both IPM and chemical-based. These costs are substituted for \( TC \) in equation (1). However, those cost calculations implicitly assume that 100% of the insects are killed or otherwise controlled. Subsequent work by Mah (2004) added to the analysis the potential costs of grain damage and discounts due to less-than-complete control of insects.

A portion of this cumulative work by Mah (2004)
was used here to help answer the questions raised above. The work was done in several steps. The first step was to estimate the effects of treatments on insect populations. In order to predict the insect population that would result under various environmental conditions and under alternative insect control strategies, an insect growth model developed and validated by Flinn et al. (1997) (also see Flinn et al., 1992; Flinn and Hagstrom 1990a, b) was used to simulate insect growth under various environmental conditions and under alternative treatments, as well as under alternative assumptions about operator ability. This deterministic model predicts daily populations of grain-damaging insects in the larvae, pupae, and adult stages, as a function of the previous day’s population, temperature, moisture, insect immigration rate, and mortality rate due to fumigation and natural death.

The second step was to use the predicted insect numbers to predict economic damage. The cost of failing to control insects is nonlinear and potentially very large, because of the nonlinear relationship between insect population and grain discounts and because of the exponential nature of insect population growth.

The elevator manager wishes to minimize expected total cost due to insects by choosing the lowest-cost insect management strategy,

\[ \text{Min} \sum_j \left[ E(C_j) \times TC + E(D_j) + E(L_j) \right] \]

where \( E(C_j) \) is the expected cost of insect control strategy \( j \), \( TC \) is the treatment cost associated with the \( j \)th insect control strategy; \( E(D_j) \) is the expected discount due to damaged grain and \( E(L_j) \) is the expected discount due to live insects at time of marketing. Further details are available in Mah (2004).

**Costs**

Lukens (2002) economic engineering approach to estimating components of costs of each treatment was used with updated information. These cost components include equipment, chemicals, sanitation, turning, aeration, and labor. Figure 1 shows the annual cost of several IPM and conventional strategies in a storage system with total capacity of 250,000 bushels.

The lower portion of each bar (strategy) measures cost of labor used for sampling, aeration, and fumigation. The second component is aeration costs, composed of electricity costs and shrink (reduction in total grain weight). Savings can be achieved if aeration fans are shut off when outside temperatures are higher than the grain temperature,

**Figure 1.** Economic engineering costs of several stored grain treatments.
and turned on only when outside temperatures are lower than grain temperature. This can be done manually, but perhaps more economically and effectively using temperature controllers.

The third component is turning cost, composed of electricity, labor, and shrink. Grain is emptied from one silo (bin) and transported on a moving belt to another silo within the facility. In concrete facilities, turning is usually required for effective fumigation; turning is done in conjunction with turning by inserting phosphine pellets or tablets into the moving grain flow. Turning may also be done as part of other management practices such as blending for particular quality characteristics, or to break up sections of “fines” or “hot spots” to prevent grain infestation or spoilage.

The fourth component is sanitation, composed primarily of labor costs. This practice includes cleaning out empty bins, elevator legs and boots, and areas surrounding bins.

The fifth component is cost of chemicals. An IPM sampling strategy in which only some of the bins are fumigated reduces fumigant costs compared with routine fumigation.

The sixth component is equipment. It is assumed for IPM strategies that sampling equipment is required (a Power-Vac sampler is specified here), and for fumigation strategies that fumigation equipment is needed. Both fumigation and sampling equipment costs are included where Power-Vac sampling has determined that fumigation is needed. These costs are amortized over the expected life of the equipment. Also, note that once the choice is made to acquire fumigation or sampling equipment, the manager should not consider equipment cost when choosing among strategies.

**Insect growth model**

To measure the cost of failing to control insects, the insect growth model developed by Flinn et al. (1997) is used to predict the number of insects living on any given day within a grain structure. In this model, growth in insect population depends on grain temperature and moisture, as well as on an assumed immigration rate of insects into the structure. For this analysis, grain temperature is based on random sampling from weather data observed in five different locations in Oklahoma and Kansas (Oklahoma City and Tulsa in Oklahoma, and Wichita, Goodland, and Topeka in Kansas). (One could instead think of these different locations as different bins – with different insect immigration rates, for example – within a single facility.)

The growth model assumes that when grain is fumigated, 90% of insects in the pupal stage, 99% of insects in the adult stage, and 99.9% of eggs and larvae are killed over a 5-day period. The model predicts number of adults of the lesser grain borer (*Rhyzopertha dominica* F). Since rusty grain beetles are also common in stored wheat, the total number of insects (to determine if the grain is “infested”) is calculated by multiplying the prediction of lesser grain borers by two. Lesser grain borers are the most damaging, however, because they eat part of the infested kernel, causing 'insect damaged kernels' (idk), which the model also predicts. Insect-damaged kernels result when a lesser grain borer lays an egg in a crevice of a wheat kernel. When the egg hatches, the larva eats the inside of the kernel until the adult burrows out, which results in an idk. The life cycle of a lesser grain borer is approximately four weeks, so there is approximately a four-week lag between immigration of an adult insect until appearance of adult offspring.

**Simulation procedures**

The simulation assumes that grain is stored for ten months (approximately 304 days). The starting storage date is set for June 20. The selling date is set for April 20 the following year. A 25,000-bushel bin 28.2 feet wide and 50 feet deep is assumed. The grain temperature on the starting date is 84 °F and the moisture is 12 %. Insect numbers were predicted using the software SGAPro 3.0, based on the model by Flinn et al. (1997).

Several scenarios were simulated. First, a baseline scenario assumed that insects grew
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Unchecked during the storage period. A second scenario used routine (calendar-based) fumigation. A third set of scenarios used sampling to determine whether and when to fumigate. This is a major component of many IPM approaches, in which a firm fumigates only if sampling indicates that it will be necessary. The rule used here was to fumigate if sampling detected 0.5 or more lesser grain borers per kilogram sample. Sampling itself costs about one cent per bushel (variable costs of about 0.2 ¢/bu, and amortized equipment costs of about 0.8 ¢/bu.).

For each scenario, insect numbers and idk were predicted each day based on grain temperature, moisture, number of insects at each life stage the previous day, and any fumigation treatment. The effects of fumigation are reflected in the insect numbers predicted by the growth model. For scenarios using fumigation it was assumed that fumigation was of average effectiveness.

For scenarios using aeration it was assumed that automatic aeration controllers were available. For automatic aeration, the fan runs automatically when the air temperature is lower than the grain temperature. July 1 was set as the starting date for aeration.

“Failure-to-Control” discounts

Cost of failing to control insects is made up of three parts. First is a discount due to “infestation”, an observation of two or more live grain-damaging insects per sample. Grain with this designation is penalized with a discount of $ 0.05/bu., basically to cover the cost of fumigating to kill all live insects (in practice, the discount is often imposed even when one live insect is observed in a sample of any size). Second is a discount due to idk. Third is a sample-grade discount when the number of idk reaches 32 in a 100-gram sample.

Insect damaged kernels reduce the quality of wheat, and discounts are imposed depending on the number of insect-damaged kernels present in a 100-gram sample. A typical discount schedule a terminal elevator would charge to country elevators is as follows:

<table>
<thead>
<tr>
<th># of Insect-Damaged Kernels (idk)</th>
<th>Discount ($/bu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 &lt; idk &lt; 5</td>
<td>0.00</td>
</tr>
<tr>
<td>6 &lt; idk &lt; 20</td>
<td>0.01/idk in sample</td>
</tr>
<tr>
<td>21 &lt; idk &lt; 31</td>
<td>0.02/idk in sample</td>
</tr>
<tr>
<td>32 &lt; idk 70</td>
<td>0.40 cleaning charge</td>
</tr>
<tr>
<td>71 &lt; idk &lt; 100</td>
<td>0.60 cleaning charge</td>
</tr>
<tr>
<td>101 &lt; idk &lt; 140</td>
<td>0.90 cleaning charge</td>
</tr>
<tr>
<td>140 &lt; idk</td>
<td>0.01/idk in sample</td>
</tr>
</tbody>
</table>

Results

Doing nothing

Figure 2 shows the insect numbers predicted by the insect growth model when no treatment strategies were used. Number of lesser grain borers had reached more than 100 lesser grain borers/kg by February 20 in locations 1 and 4, and by the end of March in locations 2, 3, and 5.

Figure 3 shows the costs of doing nothing in all five locations. There was no treatment cost, so all costs were due to failure to control insects. Insect numbers grew to a level high enough that there was an “infested” designation in all locations, a discount due to idk (this discount is less in location 2 because insects didn’t grow as quickly there), and a discount due to a sample grade designation. The cost of doing nothing ranged from 36 ¢/bu to 93 ¢/bu.

Automatic aeration

Figure 4 shows insect numbers when automatic aeration was used. Insect numbers remained low throughout the storage period. The cost of this treatment, then, was just the cost of aeration itself – electricity costs and shrink – about 1.5 ¢/bu.

Routine fumigation

Figure 5 shows the insect numbers from fumigating once during the storage period on October 1. Fumigating October 1 arrested insect growth as it
reaches 0.3 lesser grain borers/kg, and even though insect growth began to recover, it did not reach 0.4/kg at any location before the sale date of April 20. Thus, there was no insect damage cost, and the total cost of this approach was the treatment cost of about 2.8¢/bu., the first bar in Figure 1.

**IPM: fumigation based on sampling**

Figure 6 shows number of lesser grain borers that resulted when sampling was conducted on October 9 and fumigation was conducted in those locations where number of lesser grain borers was greater than 0.5/kg. Insect numbers in locations 1 and 4 reached this trigger, so those locations were fumigated on October 10. Locations 2, 3, and 5 were not fumigated because they did not reach the trigger on October 9. However, by time of sale, lesser grain borers in those locations reached very high numbers (similar to those shown in Figure 2).
The cost of this approach in locations 1 and 4 was the costs of a fumigation, about 2.8 \( \text{¢/bu.} \), plus the costs of sampling, for a total of about 3.8 \( \text{¢/bu.} \). However, in locations 2-5 the cost of this approach in locations 2-5 was the cost of sampling (about 1 \( \text{¢/bu.} \)) plus 35 \( \text{¢/bu.} \) to 90 \( \text{¢/bu.} \) of insect damage cost, because the insects were not controlled.

Since sampling only once resulted in unchecked insect growth in locations 2-5, the analysis was conducted using two samplings, one on October 9 as before, and a second sampling on January 6. As Figure 7 shows, when sampling was conducted a second time on January 6, fumigation was conducted in locations 2, 3, and 5 on January 7. That fumigation prevented insect population in those locations from growing large enough to trigger discounts. The dilemma with the IPM practice of sampling and fumigating only when insects reached a particular
threshold was that because of the environmental conditions and immigration rate of insects assumed here, fumigation was eventually needed in each location (or bin) anyway; sampling changed only the timing, but not the frequency, of fumigation. Thus, sampling did not reduce the use of fumigation, but increased management costs. However, this sampling-based IPM strategy is less costly than one in which all locations are fumigated twice, perhaps once in October and once in April just before sale, a strategy that some managers in fact follow to be certain that insects are controlled before sale (see rightmost bar in figure 1).

It is likely that some grain storage facilities have some bins with substantially lower insect populations than other bins within the same facility. As Figure 1

Figure 6. Insect numbers using selective fumigation: sample on October 9, fumigate if insect numbers > 0.5/kg.

Figure 7. Insect numbers using selective fumigation: sample on October 9 and January 6, fumigate if insect numbers > 0.5/kg.
indicates, if the number of bins with insect populations requiring fumigation is half or less than half of the facility’s total bins (see fifth and sixth bars of figure 1), the cost of sampling-based fumigation is less than that of all other strategies except controlled aeration.

**Conclusions**

It is clear that of the scenarios considered, aeration was the least costly strategy that was also effective in controlling insects; the cost of aeration was low, and there were no costs due to insects. However, many storage facilities, particularly concrete facilities, do not have aeration capability. Therefore, they must consider other alternatives.

The approach with the second-lowest cost was one routine fumigation at the right time of the year. It controlled insects well and had a fairly low treatment cost. An IPM strategy, sampling twice (at appropriate times) during the year and fumigating only when needed, also controlled the insects. However, it had a higher cost because of sampling twice and because fumigation was needed once in each of the five locations. Sampling changed the timing, but not the frequency, of fumigation.

Thus, to the extent that this simulation reflects reality, it is understandable why more elevator managers have not adopted IPM practices, particularly sampling. Sampling is costly and, depending on prevailing weather and other conditions in a particular location, may not substantially change the preferred insect control strategy. In these cases, sampling adds unnecessary cost.

Some caveats should be noted, though. First, these calculations do not recognize any environmental benefits from reducing the use of pesticides, since firm managers do not currently realize those benefits. Second, these simulations have used weather information from only one year. Weather conditions may be sufficiently variable from year to year that sampling may indeed reduce the number of fumigations required. Further work will incorporate weather variability in the simulation.

Third, a constant immigration rate of insects into each bin within a storage facility has been assumed. Taking variable immigration rates into consideration would likely increase the attractiveness of sampling relative to routine fumigation, since variable immigration rates would increase the uncertainty about the need for fumigation. Research in progress by the authors is incorporating variable immigration rates.

Fourth, these calculations do not take into account probabilities that insects will or will not be detected in sampling procedures. Essentially, the simulation assumes that sampling is perfect. For example, if sampling occurs on October 9, the simulation assumes that the number of insects predicted by the growth model is the number that sampling detects. Also, the simulation assumes that when the insects are sold, the number of insects predicted by the simulation is the number that is detected by the purchaser.

In spite of these limitations, however, it appears rational that many grain elevator managers have not chosen to adopt IPM practices in managing insects in stored wheat in Oklahoma and Kansas. However, reductions in sampling cost, using less costly information (such as that provided by the insect growth model used here), increased cost of pesticide use, or increased uncertainty in the need for pesticides could increase the attractiveness of IPM practices.

**References**


