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"Is There Any Reason for Grain Storage and Processing Firms Not to Adopt Integrated Pest Management Practices? The Economics of IPM in Stored Grain"

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Integrated Pest Management

Two major trends in the food industry are in conflict. On the one hand, consumers demand wholesome products, free of insects and other pests. On the other hand, consumers are increasingly concerned about pesticide and herbicide residues on their food (Senauer, Asp, and Kinsey 1991).

Because of food safety as well as worker safety and environmental concerns, many of the pesticides currently used to control pests in stored products such as grain are being phased out or significantly restricted by regulations (Ramaswamy et al. 2000). Also, in order to reduce potential for pesticide residues on their food products, some food manufacturers are severely limiting the amount of pesticides that can be applied to inputs they purchase (Phillips et al. 2002). Moreover, insects are developing resistance to some of the pesticides currently used (Zettler and Cuperus 1990; Zettler and Beeman 1995).

The reduced arsenal of pest control tools combined with demands for wholesome and pest-free food poses a challenge for managers of food processing firms and stored grain facilities. Some authors have proposed Integrated Pest Management (IPM) as a solution to this dilemma. IPM is a process in which information about the pest, the environment and the infested commodity are assessed and decisions made about use of one or more pest control methods, including cultural, biological, genetic, and chemical. The goal is to prevent or reduce pest damage by the most economical means and with the least negative impacts to human health, safety, property or the environment (Phillips et al. 2002).

IPM Adoption

Many elevator operators, though, have been reluctant to use IPM practices. There is little published evidence that IPM is cost-effective. Although it reduces pesticide use and associated costs, it requires more management skill and more labor, both expensive inputs. Whereas pesticide applications can be explained as providing "insurance" against insect damage (Feder 1979), operators may view IPM as increasing risk. An emphasis in IPM is sampling to determine if insect population is high enough to require treatment, possibly chemical. Sampling may fail to detect an insect problem that will later cause damage; a grain elevator operator may not wish to bear that risk when conventional methods are working. Or, temperatures in a particular storage season may not permit adequate cooling with aeration, an important IPM tool.

Moreover, because the demands on management expertise are higher with IPM, some managers may not have the inclination or ability to follow recommended IPM practices for maximum effectiveness. Even if IPM practices were shown to be as effective as chemical pest control methods when practiced correctly, there is a risk that a manager would fail to apply IPM methods correctly, resulting in higher insect numbers than if conventional practices were followed.

On the other hand, it is possible that IPM practices could reduce risk of insect damage compared with chemical-based practices. Noyes (2002) argues that conventional phosphine fumigations (the most commonly used pesticide in stored wheat) "…are typically poorly managed due to leaky [storage facilities], improper application methods, incorrect dosages, and incorrect timing. These poor fumigation practices have resulted in failure to kill all life stages of stored grain insects, contributing to breeding new generations of stored grain insects with increased vigor and resistance to phosphine (p.9).”

The cost of using IPM for stored grains has been previously analyzed by Lukens (see Figure 1). However, that study did not measure the costs of grain damage caused from incompletely controlling insects. If the insect population in stored grains is not controlled effectively, the insects will damage grain, which in turn triggers large discounts. Also, if two or more live insects are detected in a grain sample, the grain is not permitted to be sold for human consumption.

There are several reasons a particular (IPM or chemical-based) strategy may not be effective. Insects may not be detected early enough for effective control, insects may have developed resistance to a particular chemical, temperature and moisture conditions may be favorable to insect growth so that control is difficult, a particular treatment may be effective only for a certain part of the insect growth cycle, leaving insects at different stages free to grow and reproduce, or a particular treatment may be incorrectly applied, reducing its effectiveness.

Thus, a possible reason for few elevator operators adopting IPM methods may result from the abnormally large costs they face if they fail to control insects effectively. Applying treatments when they are not needed adds unnecessary, though typically small, costs. However, not applying treatments when they *are* needed results in large costs. Typically, IPM practices use monitoring to decide when treatments are needed. However, monitoring itself is costly.

The effectiveness of insect control treatments depends on environmental conditions as well as on management ability of the elevator operator. This study uses an insect growth model developed by entomologists and validated in field trials to simulate insect growth under various environmental conditions and under alternative treatments (Flinn, Hagstrum, and Muir; Flinn et al.; Flinn and Hagstrum 1990a, b), as well as under alternative assumptions about operator ability. 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 costs of treatment and the costs of failing to control insects will be combined to compare the full costs of IPM and chemical-based insect control treatments.

Model and Procedures

Cost of treatment is based on work by Lukens that used an economic engineering approach to estimating components of costs of each treatment. These 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 labor cost. Since a significant portion of IPM costs are related to sampling, the sampling-based IPM strategies have the highest labor costs. However, if sampling is done upon receipt of grain, and grain is stored for less than one year much of this cost can be avoided.

The second component is aeration costs, composed primarily of electricity costs. Aerating immediately upon receipt of grain is less effective than aerating after outside temperatures drop, so electricity cost is higher for the same amount of cooling. Savings can be achieved if aeration fans are shut off when outside temperatures are higher than the grain temperature, 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 and transported on a moving belt to another silo within the facility. Fumigation can be done while turning by inserting phosphine pellets or tablets into the moving grain flow. Turning is often done in concrete silos in order to fumigate when closed loop fumigation is not used. 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. For both an IPM sampling strategy in which not all of the bins are fumigated, and a closed loop fumigation which requires less fumigant for the same level of effectiveness, fumigant costs are lower than with routine fumigation. Closed loop fumigation would typically require 1/3 less fumigant to achieve the same level of effectiveness, and would not require turning of the grain. Also included in chemical costs is the cost of protectant used. Here, Reldan is assumed to be the protectant used, at a cost of $.022/bu.

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. For closed loop fumigation, amortized installation costs of the closed loop system are included in this cost. For IPM strategies that do not require additional sampling while grain is in storage, this cost could be reduced. However, both fumigation and sampling equipment costs are included where Power-Vac sampling has determined that fumigation is needed. Also, note that once the choice is made to acquire fumigation or sampling equipment, this cost should not be considered when choosing among strategies.

Insect Growth Model

To measure the cost of failing to control insects, the insect growth model developed by Flinn, Hagstrum, and Muir 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).

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).

Cost of failing to control insects is made up of three parts: discount due to “infestation”, an observation of two or more live grain-damaging insects per sample (in practice, the discount is often imposed even when one live insect is observed in a sample of any size); discount due to idk; and a sample-grade discount when the number of idk reaches 32 in a 100-gram sample.

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. Thus, it is assumed here that one adult insect correlates with one 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 19 the following year. A 25,000-bushel bin 26.2 feet wide and 50 feet deep is assumed. The grain temperature on the starting date is 84ºF and the moisture is 12%. Insect numbers were predicted using the software SGAPro 2.0, based on the model by Flinn, Hagstrum, and Muir.

Aeration

For the scenario 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. The possible starting dates for aeration were June 20, September 20, and October 16.

Fumigation

Three fumigation scenarios were considered: fumigating once on any of three dates (October 1, January 18, and February 10).

“Failure-to-Control” Discounts

A sample of grain is designated “infested” if two or more live grain-damaging insects are present. In practice, the “infested” label is often assigned even if only one grain-damaging insect is detected. 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.

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. The discounts are as follows:

# of Insect-Damaged Kernels (idk)	Discount ($/bu)
1 < idk < 5	0.00
6 < idk < 20	0.01/idk in sample
21 < idk < 31	0.02/idk in sample
32 < idk 70	0.40 cleaning charge
71 < idk < 100	0.60 cleaning charge
101 < idk < 140	0.90 cleaning charge
140 < idk	0.01/idk in sample

Ten scenarios were simulated. First, a baseline scenario assumed that insects grew unchecked during the storage period. Scenarios #2-#4 used an aeration strategy in which the fan was automatically turned on when outside temperature dropped below grain temperature and automatically turned off when outside temperature was grain temperature or above. Scenario #2 allowed fans to turn on starting June 20, immediately after binning, Scenario #3 allowed them to turn on starting September 20, and Scenario #4 allowed them turn on October 16.

A third set of scenarios (#5 - #7) used routine fumigation. Scenario #5 fumigated on October 16, Scenario #6 fumigated on January 18, and Scenario #7 fumigated on February 10.

Scenarios #8 - #10 used monitoring/sampling to determine whether and when to fumigate. This is a major component of many IPM approaches, in which a firm should fumigate only if sampling indicates that it will be necessary. The rule used was to fumigate if sampling detected 0.5 or more insects per kilogram sample. Sampling itself costs about one cent per bushel, adding to the treatment cost. Scenario #8 samples once on October 9. Scenario #9 samples once on October 9 and once on April 1. Scenario #10 samples once on October 9 and once on January 6..

For each scenario, insect numbers were predicted each day based on grain temperature, moisture, number of insects at each life stage the previous day, and any fumigation treatment. It is assumed that the effect of aeration is through reducing the temperature of the grain. The effects of both aeration and fumigation are reflected in the insect numbers predicted by the growth model.

Results

Results are shown in Figures 2 - 16. For cost estimates, the lower part of each bar in the graphs shows the cost of any "infested" designation, the second part shows the discount due to a determination of sample grade, the third part shows discounts due to insect damaged kernels, and the upper part shows the treatment cost.

Doing Nothing

Figure 2 shows the insect numbers predicted by the insect growth model when no treatment strategies are used. Number of lesser grain borers had reached more than 100 live insects/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 is no treatment cost, so all costs are due to failure to control insects. Insect numbers grow to a level high enough that there is 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

Figures 4-6 show the insect numbers when using aeration starting June 20, September 1, and October 16. Starting the fan earlier results in lower insect numbers, because the grain is cooled earlier, and insects have less opportunity to grow and reproduce. However, even when fans are not started until October 16, number of lesser grain borers never reaches 0.8/kg at any location.

As a result, as Figure 7 shows, there is no cost due to insects themselves. The only cost is treatment cost. This cost differs among locations because different weather conditions trigger the fan to turn on for different amounts of time. The earlier the starting time, the higher the cost. Thus, in the case of aeration, the best insect control is not the most economical strategy. However, the cost is below 1¢/bu. for all locations and for all starting times.

Routine Fumigation

Figures 8-10 show insect numbers from fumigating once during the storage period. Figure 8 shows that fumigating October 1 arrests insect growth as it reaches 0.3 lesser grain borers/kg, and even though insect growth begins to recover, it does not reach 0.4/kg at any location before the sale date of April 19.

Figure 9 shows that waiting until January 18 to fumigate allows number of lesser grain borers to reach 20-35/kg, depending on location, but the later fumigation prevents their recovery to a significant level before sale. Figure 10 shows that waiting until February 10 allows lesser grain borers to reach a high level of 50-75/kg before the fumigation reduces them to approximately zero.

As Figure 11 shows, this late fumigation date allows the insects to damage wheat by causing idk, so that in addition to the treatment cost of almost 3¢/bu, an idk discount of 1/3¢/bu to 2 1/3¢/bu. The earlier fumigation dates do not lead to idk discounts.

IPM: Fumigation Based on Sampling

Figure 12 shows number of lesser grain borers that result when sampling is conducted on October 9 and fumigation is conducted in those locations where number of lesser grain borers is greater than 0.5/kg. Insect numbers in locations 1 and 4 reach this trigger, so those locations are fumigated on October 10. Locations 2, 3, and 5 are not fumigated because they did not reach the trigger on October 9. Thus, by time of sale, lesser grain borers in those locations reached very high numbers (similar to those shown in Figure 2).

In Figure 13, when sampling is conducted a second time on April 1, fumigation is conducted in locations 2, 3, and 5 on April 2 because of the high insect numbers. Even though the fumigation is assumed to be quite effective, because of the very high insect numbers reached before fumigation and increasing temperatures, they recover quickly. Even by the time of sale, though, number of lesser grain borers is less than 0.4/kg at all locations.

Figure 14 shows the insect numbers that result when the second sampling is conducted earlier, on January 6. This earlier sampling leads to fumigation of locations 2, 3, and 5 much earlier, so that insect numbers do not reach as high levels.

Figure 15 shows that sampling only once leads to high costs of grain damage in locations 2, 3, and 5 because insects are not controlled. There is no fumigation cost, but there is a cost of sampling, plus a high cost of idk and, in locations 3 and 5, a sample-grade designation. Sampling October 9 and again on April 1 reduces the idk costs substantially, but adds to the treatment costs, because all locations are sampled twice, and all are fumigated. Sampling October 9 and on January 6 eliminates all costs due to insect damage, but the treatment cost is still cost of sampling in all locations plus cost of fumigation in all locations.

Figure 16 compares on a common scale the cost of each of these strategies, using the most economical approach. The strategies compared are: automatic aeration starting October 16, fumigating January 18, sampling October 9 and January 6 and fumigating if needed, and, for comparison purposes, fumigating January 18 and April 1, without sampling, to represent a manager who fumigates once during the storage period, and then again before sale “to be sure”.

For locations where aeration is available, automatic aeration is clearly the best strategy. Where aeration is not available (e.g., in many concrete silos), fumigating on January 18 is the lowest cost strategy. The IPM strategy of sampling October 9 and January 6 and fumigating only if necessary also controls insects well, but is higher cost than simply fumigating once without sampling. All locations are sampled twice, which adds about 2¢/bu to the cost, but since fumigation is required once in each location, there are no savings in fumigation. Sampling changed only the timing, but not the frequency, of fumigation. However, this strategy is preferred to one in which all locations are fumigated twice, a strategy that some managers may follow to be certain that insects are controlled before sale.

Conclusions

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

The second best treatment is a routine fumigation at the right time of the year. It controls insects well and has a fairly low treatment cost. An IPM strategy, sampling twice during the year and fumigating only when needed, also controls the insects. However, it has a higher cost because of sampling twice and because fumigation is needed once in each of the five locations. Sampling changes 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 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 storage facilities 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. Future work will incorporate 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, increased cost of pesticide use, or increased uncertainty in the need for pesticides could increase the attractiveness of IPM practices.

References

Feder, G, “Pesticides, Information, and Pest Management under Uncertainty,” *American Journal of Agricultural Economics*, (1979):97-103.

Flinn, P.W., D. W. Hagstrum, and W. E. Muir. “Effects of Time of Aeration, Bin Size, and Latitude on Insect Populations in Stored Wheat: A Simulation Study.” *Journal of Economic Entomology* 90(1997):646-51.

Flinn, P.W., D.W. Hagstrum, W. E. Muir, and K. Sudayappa. “Spatial Model for Simulating Changes in Temperature and Insect Population Dynamics in Stored Grain, *Environmental Entomology* 21(1992):1351-56.

Flinn, P. W. and D. W. Hagstrum, “Simulations comparing the effectiveness of various stored-grain management practices used to control Thyzopertha dominica (Coleoptera: Bostrichidae). *Environmental Entomology*, 1990a.

Flinn, P. W. and D. W. Hagstrum, “Stored Grain Advisor: A Knowledge-Based System for Management of Insect Pests of Stored Grain,” *Artificial Intelligence Applications in Natural Resource Management* 4(1990b):44-52.

Lukens, T. *Costs and Effectiveness of Chemical-Based and Integrated Pest Management Strategies in Stored Wheat*, M.S. Thesis, Oklahoma State University, 2002.

Noyes, R. “Developing Sustainable Stored Grain IPM Systems in Oklahoma and Texas,” a Proposal to the Southern Region SARE Proposal, 2002.

Phillips, T., B.Adam, G. Cuperus, R. Danley, P. Kenkel, T. Lukens, D. Maier, L. Mason, and R. Noyes, “Integrated Pest Management for Grain Elevators that Supply the Breakfast Cereal Industry: Case Studies and Economic Analysis,” a report to the *Grocery Manufacturers of America* and the *National Foundation for IPM Education*, 2002.

Ramaswamy, S., T. Phillips, Bh. Subramanyam, F. Arthur, and D. Maier, “Consortium for Integrated Management of Stored Product Insect Pests,” a funded proposal to Environmental Protection Agency, 2000.

Senauer, B., E. Asp, and J. Kinsey. *Food Trends and the Changing Consumer*, St. Paul, MN: Eagan Press, 1991.

Zettler, L., and R. Beeman, “Resistance to Chemicals,” Ch. 21 in *Stored Product Management*, Oklahoma State University Cooperative Extension Service Circular Number E-912, 1995, pp. 163-6.

Zettler, L., and G. Cuperus, "Pesticide Resistance in Tribolium Castaneum and Rhyzopertha Dominica in Wheat," *Journal of Economic Entomology* 83(1990):1677-81.

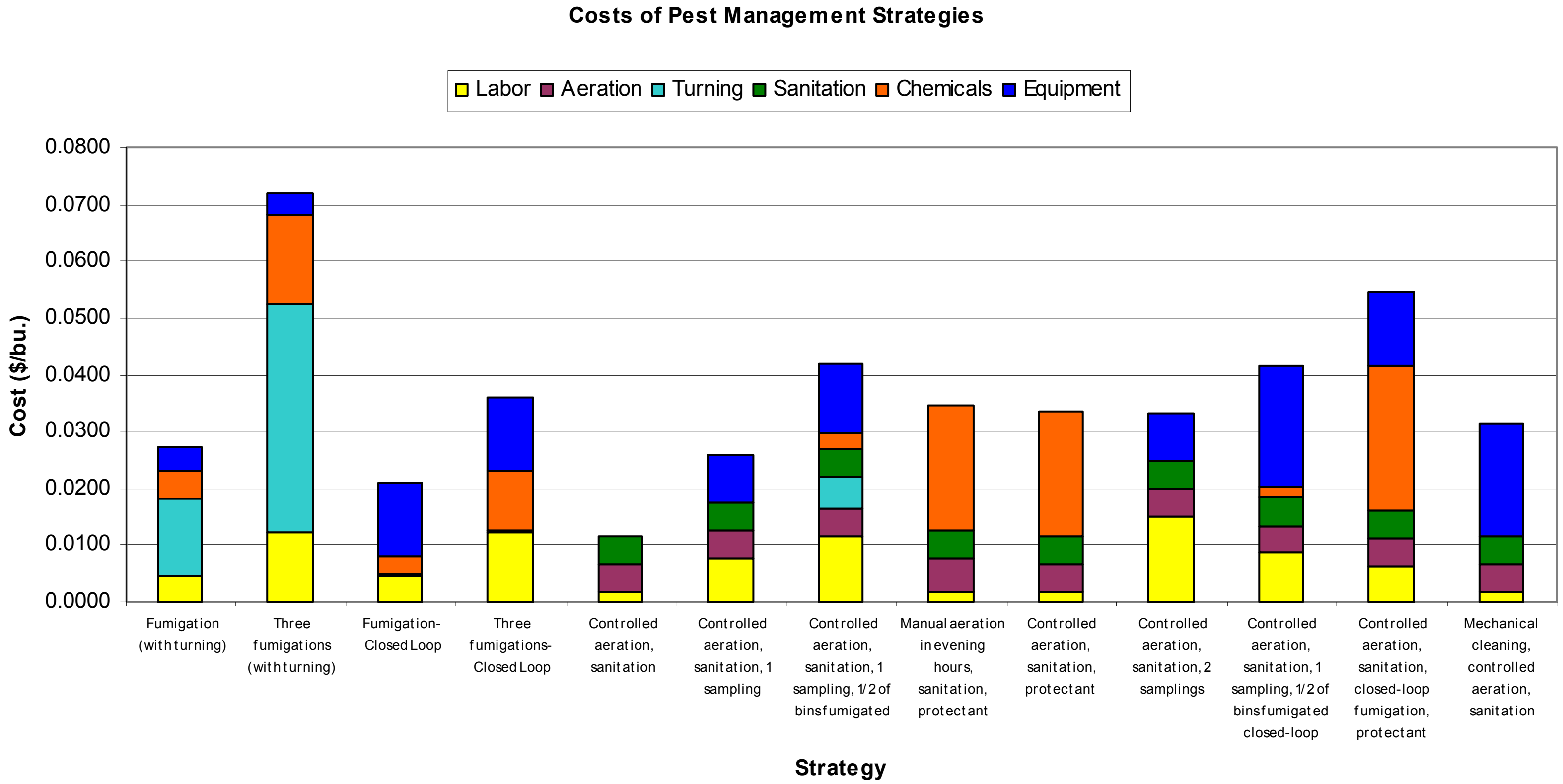


Figure 1: Costs of Pest Management Strategies (source: Lukens)

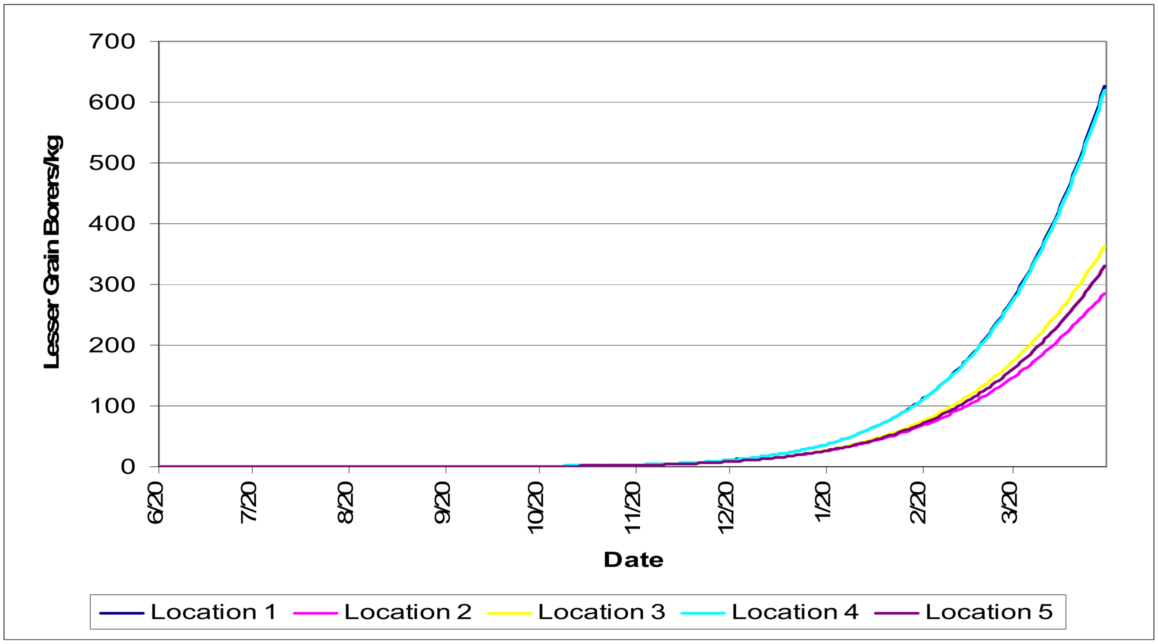


Figure 2. Insect Numbers by Location: Doing Nothing

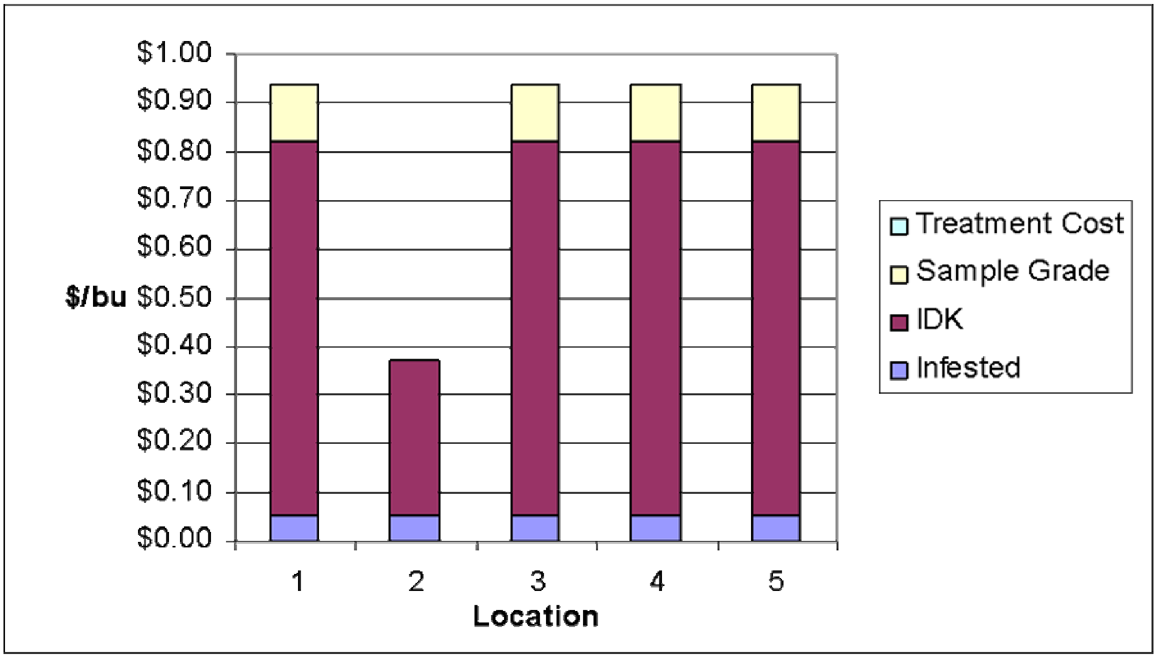


Figure 3: Costs of Doing Nothing

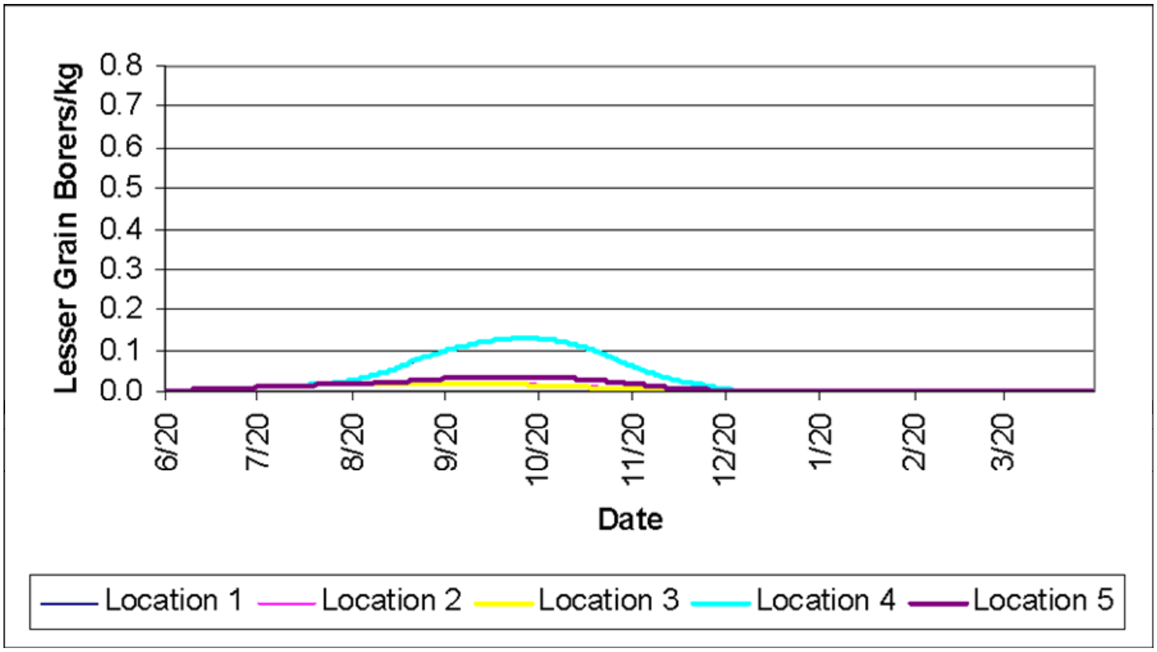


Figure 4. Insect Numbers by Location: Automatic Aeration Starting June 20

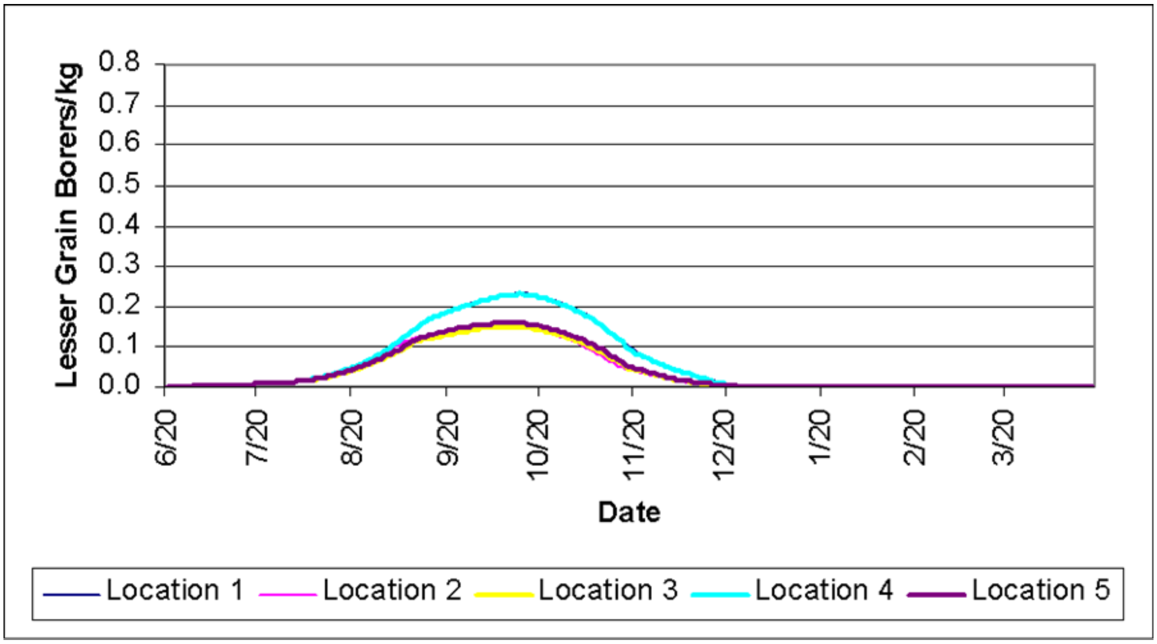


Figure 5. Insect Numbers by Location: Automatic Aeration Starting September 1

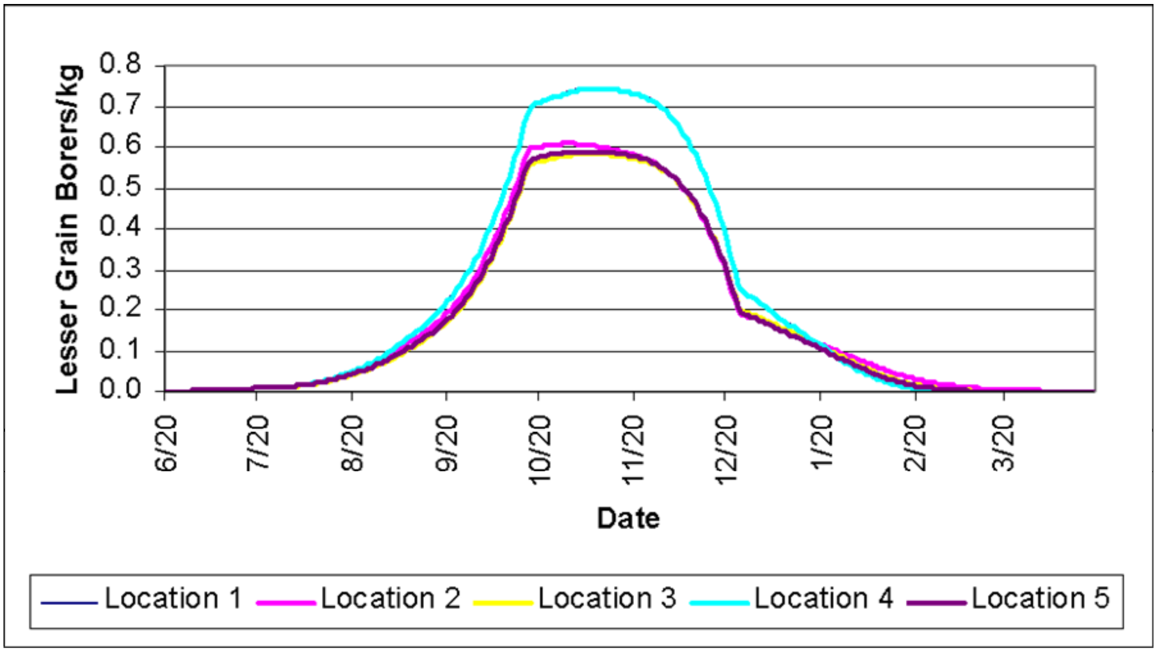


Figure 6. Insect Numbers by Location: Automatic Aeration Starting October 16

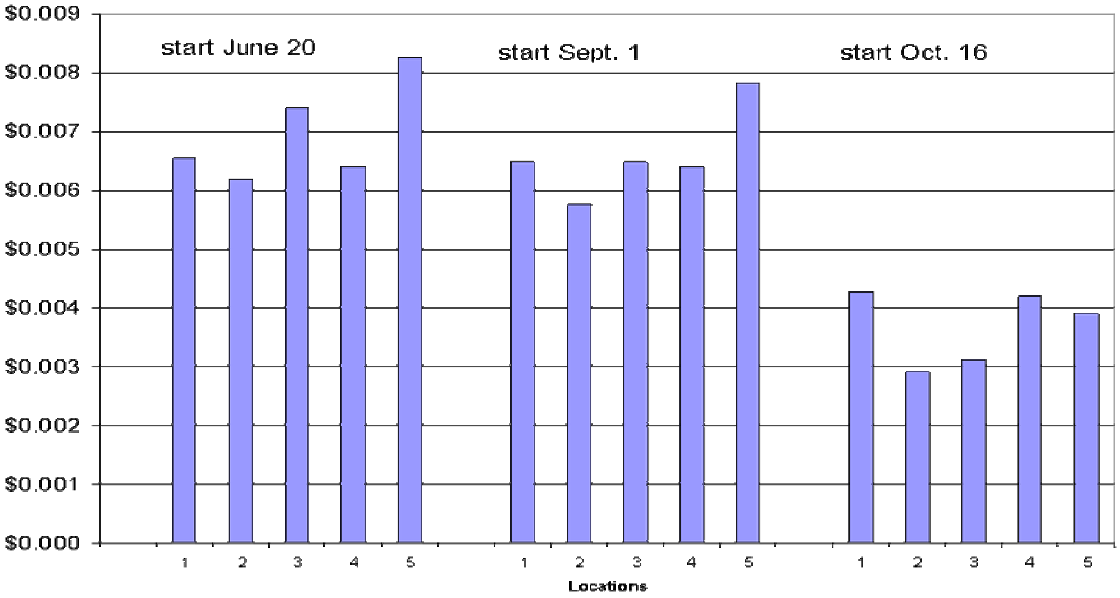


Figure 7. Cost of Automatic Aeration by Starting Date

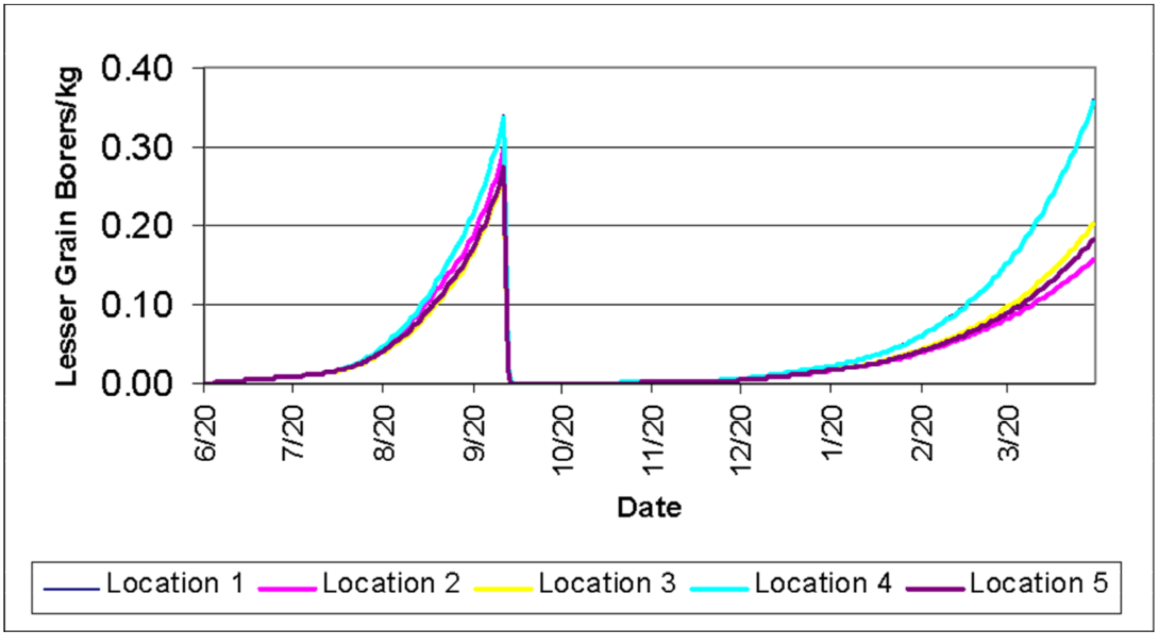


Figure 8. Insect Numbers: One Fumigation on October 1

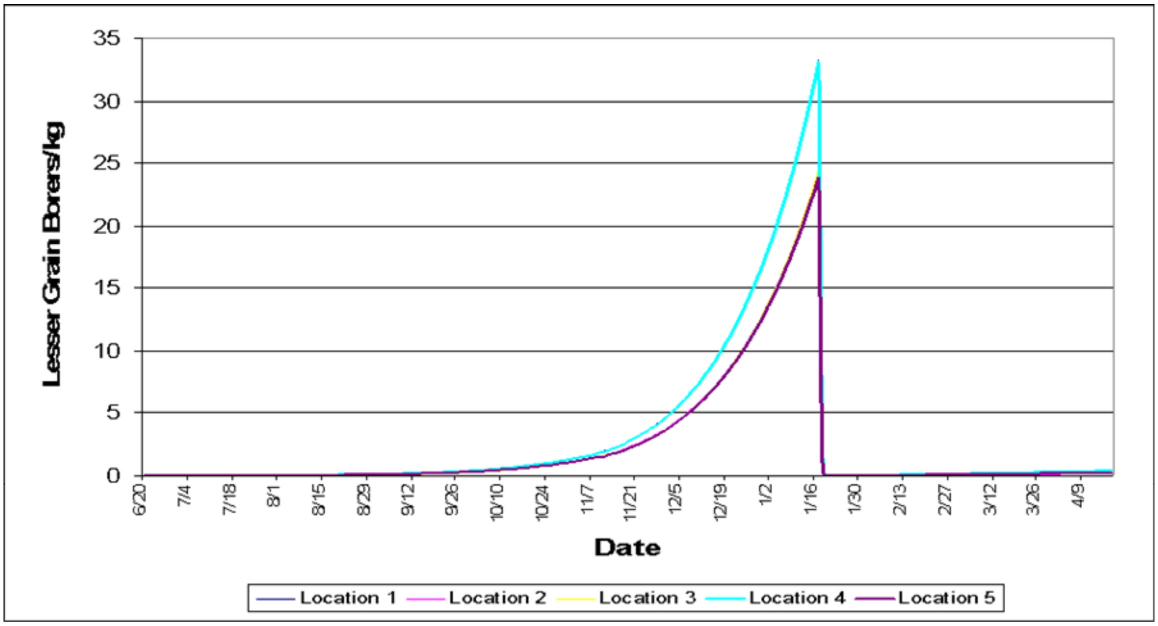


Figure 9. Insect Numbers: One Fumigation on January 18

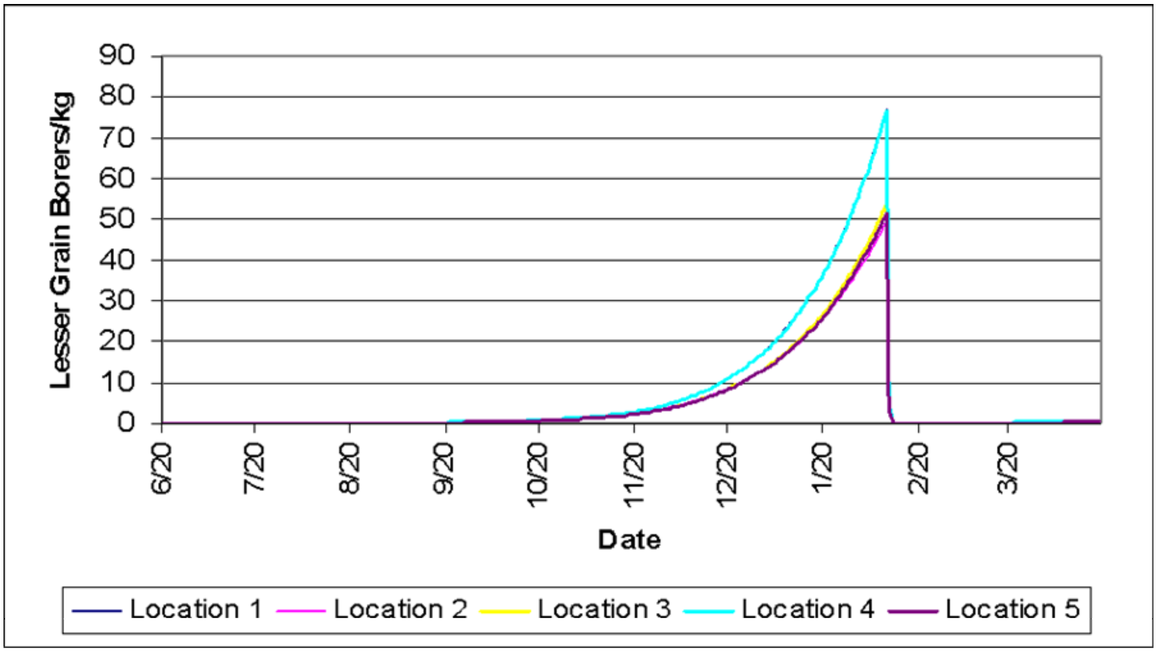


Figure 10. Insect Numbers: One Fumigation on February 10

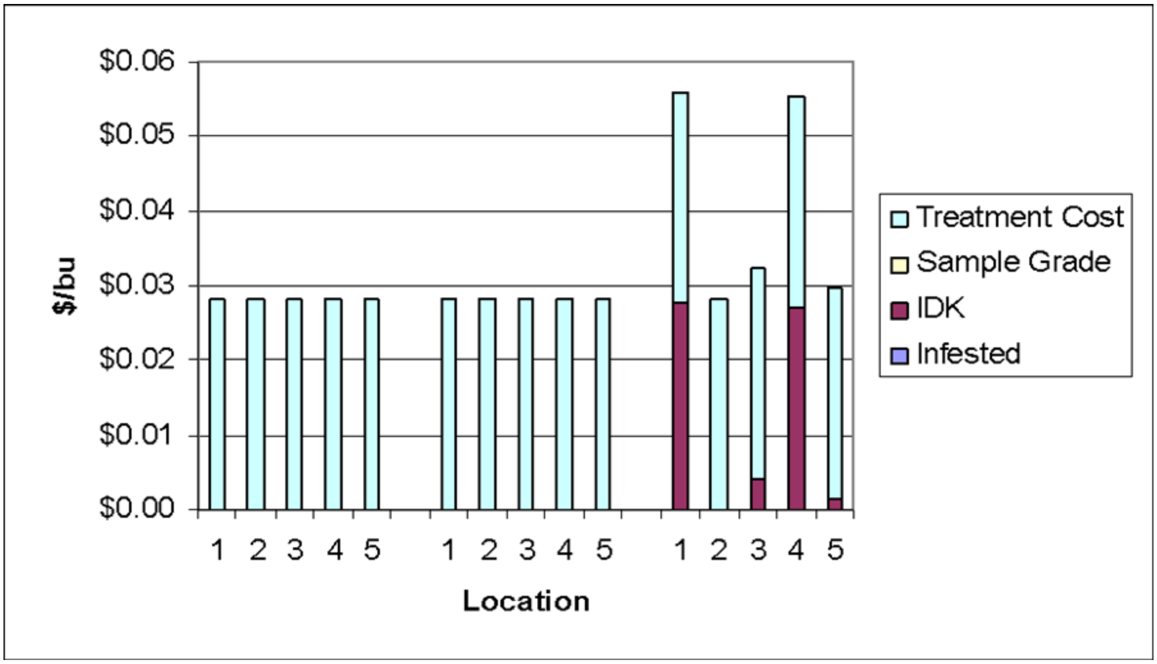


Figure 11: Cost of Fumigation by Date

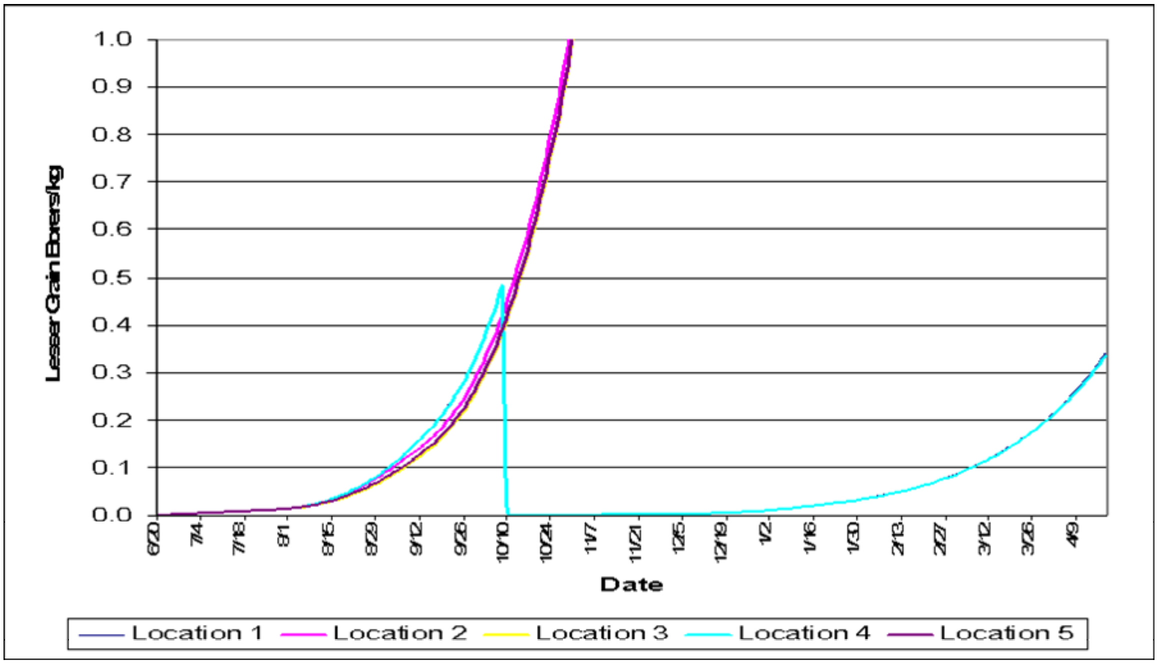


Figure 12: Insect Numbers Using Selective Fumigation: Sample on October 9, Fumigate if Insect Numbers > 0.5/kg

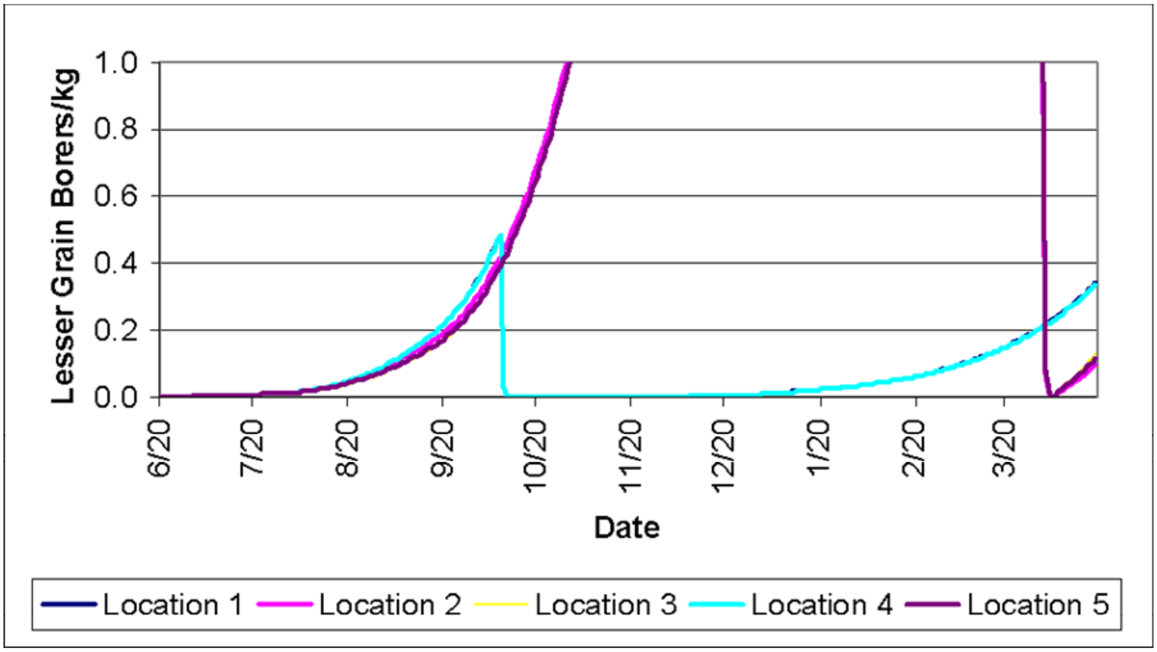
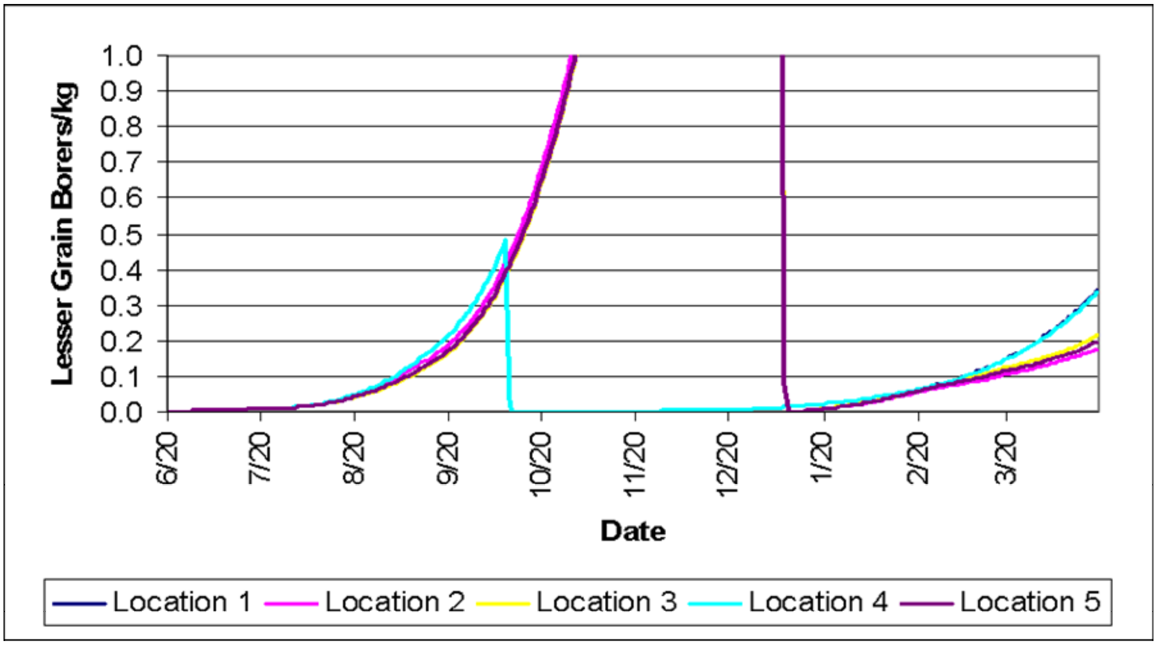


Figure 13: Insect Numbers Using Selective Fumigation: Sample on October 9 and April 1, Fumigate if Insect Numbers > 0.5/kg



Sample October 9

Figure 14: Insect Numbers Using Selective Fumigation: Sample on October 9 and January 6, Fumigate if Insect Numbers > 0.5/kg

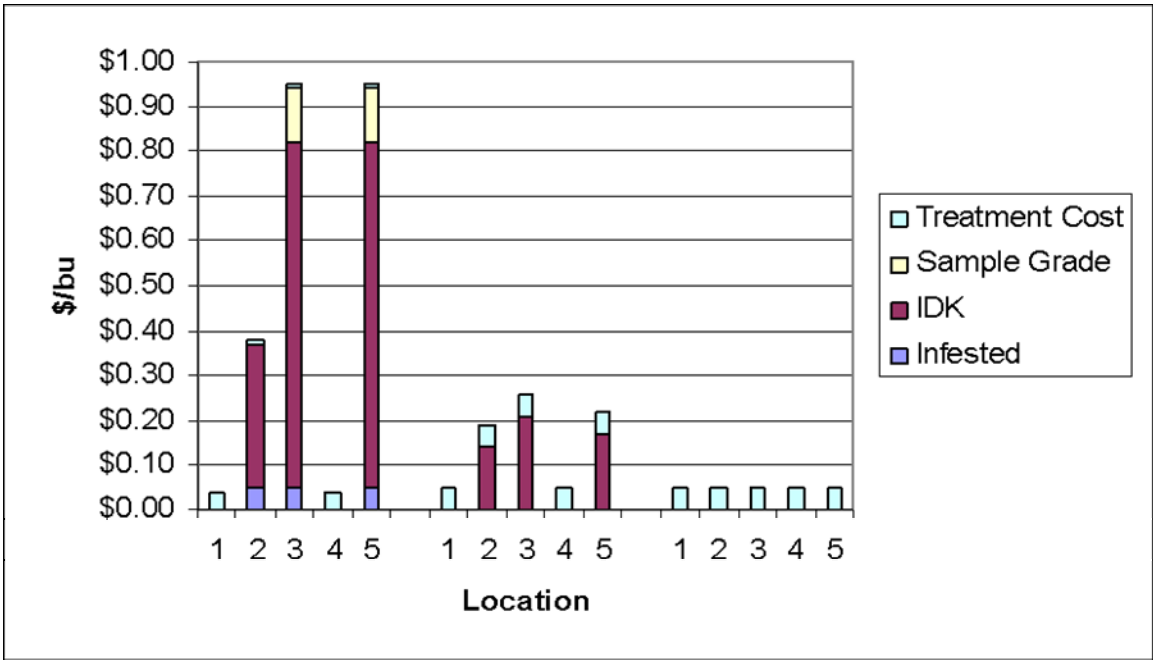


Figure 15: Cost of Selective Fumigation

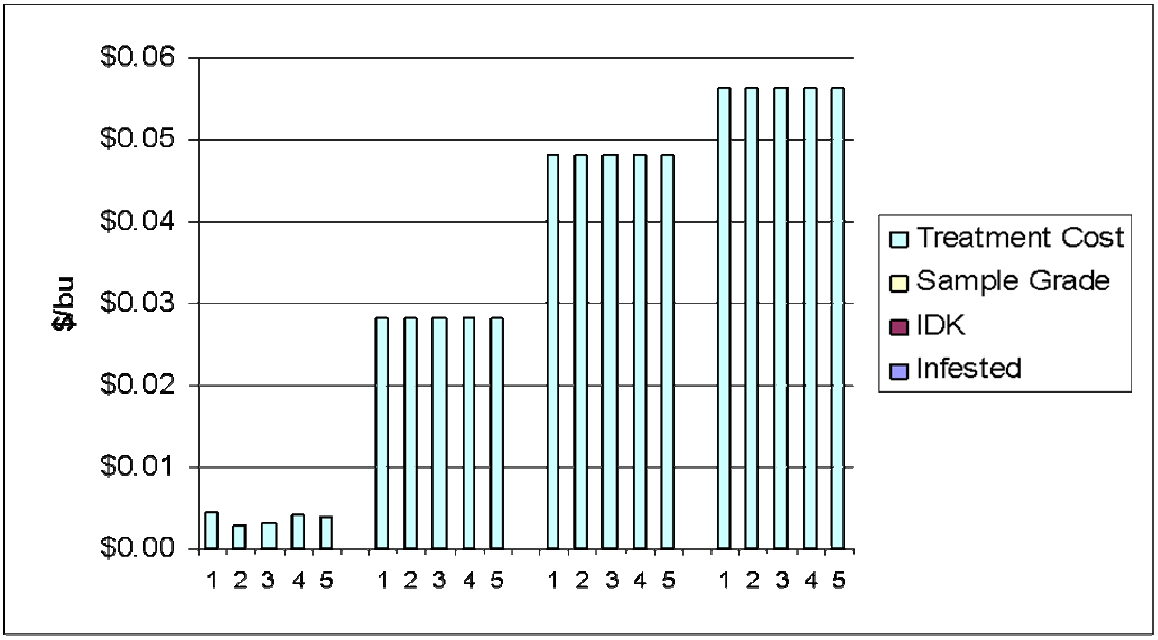


Figure 16: Comparing Best Practices: Automatic Aeration Starting Oct 16; Fumigating Jan 18; Sampling Oct 9 and Jan 6; and Fumigating Jan 18 and April 1