28 Economics of IPM Decisions

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Introduction

Two aspects of consumer preferences for food conflict with one another. On one hand, consumers demand wholesome products free of insects, molds, other pests, and toxins. On the other, they are increasingly concerned about insecticide and herbicide residues on their food (Senauer et al. 1991; Magnusson and Cranfield 2005).

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

Integrated Pest Management

The reduced arsenal of pesticides combined with increased demands for wholesome and pest-free food poses a challenge for managers of grain storage and food processing facilities. Some authors have proposed Integrated Pest Management (IPM) as a solution. IPM is information based and is a balanced use of biological, chemical, and cultural control tactics. While conventional pest management typically uses regular pesticide applications, IPM programs treat for insect pests only when necessary to prevent economic losses. Stored products are sampled for insect pests to determine how many and what kinds of insects are present and the risk of economic losses. Less risky and nonchemical methods are used first, and additional pest control methods, including chemical pesticides, are employed only when these are insufficient.

Choosing from among grain storage management alternatives requires careful consideration of the costs and benefits of each. With no treatment, damage costs can be high. Treating grain can reduce damage costs, but as treatment costs increase, the benefits of reduced damage costs decrease. The following paragraphs highlight major factors managers should consider when evaluating these tradeoffs. This section compares IPM and non-IPM approaches to storing wheat in Oklahoma and discusses the economics of managing mold.

IPM vs. Non-IPM Approaches to Storage Management

Calendar-based fumigation is a typical non-IPM approach that elevator managers use to control insects. Phosphine fumigation is conducted at one or more predetermined times of the year, based on experience, without sampling for insects. Fumigating too early allows insect populations to rebound before the time of grain sale; fumigating too late allows insect populations to cause irreversible damage before they are killed. In contrast, a sampling-based IPM approach uses insect density estimates to determine when pest management is needed (Flinn et al. 2007). Treatment may or may not include chemical application such as phosphine fumigation.

If in an IPM approach, sampling indicates that further treatment is not necessary, those treatment costs are avoided. But sampling itself adds cost even when treatment is not necessary. When treatment is necessary, both treatment and sampling costs are incurred. IPM thus requires more management skill and labor. Some managers may not follow recommended IPM practices for maximum effectiveness, resulting in higher insect numbers than if conventional practices were followed. For example, sampling too infrequently, either to save money or because workers were working on other projects, may not detect insects that calendar-based fumigation would have killed.

Non-IPM fumigation approaches have their own concerns. Because insect population growth is determined by temperature, moisture content, and time, differences in weather from year to year may result in calendar-based phosphine fumigation being done too early or too late for effective control.

For both IPM and non-IPM, conventional phosphine fumigations are typically poorly managed due to leaky storage facilities, improper application methods, incorrect dosages, and incorrect timing (Noyes 2002). Poor fumigations result in insect resistance to phosphine. Also, some insect stages are more susceptible to fumigant than others.

Stored-product mold damage, like insect damage, also can be managed with IPM strategies. Any management strategy that includes monitoring for molds can be considered an IPM strategy. One key difference when managing molds is that to date there are no proven treatment options. Because mold damage, like insect damage, cannot be reversed, the management goal is to prevent the formation of molds by putting the grain into storage at a safe moisture content and using aeration to prevent the formation of hotspots or to further dry the grain. If mold damage develops, the producer's only option to halt mold damage is to sell the grain immediately. The primary value of using an IPM strategy to manage molds is to have a monitoring protocol that identifies mold development in its early stages so that the crop can be sold before mold damage reduces quality significantly. The non-IPM mold strategy would be to put grain into storage at a safe moisture and then ignore it.

Balancing Costs of Control and Costs Due to Insects and Molds

The goal of both IPM and non-IPM approaches is to manage insect population and mold damage in a storage structure most cost effectively. Insect population growth in a grain storage structure depends on grain temperature and moisture, and immigration rate of grain-damaging insects into the stored grain. Immigration into elevators and stored grain depends on environmental conditions such as wind and temperature, as well as cleanliness and structural integrity of the facility. The effectiveness of insect control treatments also depends on these factors. The cost of loading and unloading grain is an important storage cost, but it is not considered here because it is assumed to be the same for both calendar-based and sampling-based approaches.

Insect control must be done thoroughly and carefully to prevent large discount penalties for insect contamination and damage. The cost of this damage must be balanced against the cost of treatments to control insect populations. The treatments that could be used as part of any approach to insect control include fumigation, use of grain protectants, turning grain (either separately or with fumigation), aeration, sampling, sanitation, and bin sealing. For mold, turning or aerating the grain help to minimize hot spots and prevent mold growth. The cost of these treatments can be estimated by considering costs of activities and materials needed for these treatments including equipment, labor, chemicals, materials, electricity, grain weight lost, and safety training.

Table 1 summarizes the cost components of each of these treatments. Cost components of fumigation include chemicals, labor, training (including safety training and certification), and equipment such as fumigant monitoring devices. In concrete facilities, turning is usually required for effective fumigation; grain is emptied from one silo (bin) and transported on a moving belt to another silo within the facility. Fumigation is conducted by adding aluminum phosphide tablets into the moving grain as the bin is filled. Closed-loop circulation of fumigant typically

Table 1. *Cost components of alternative treatment approaches for stored grain.*

	Sampling	Fumigation	Aeration	Turning	Fumigation with turning	Sanitation	Bin sealing
Equipment	X	X	X		X		
Labor	X	X		X	X	X	X
Chemicals		X			X		
Materials							X
Electricity			X	X	X		
Grain weight lost				X	X		
Safety training		X			X		

requires one-third less fumigant to achieve the same level of effectiveness. It does not require turning of the grain, but it does require an investment in equipment. Bin sealing is important for fumigation-based and IPM approaches. Carefully sealing holes, even very small ones, reduces insect entry into the bin (immigration) and increases fumigation effectiveness by limiting the escape of the gas. There are some material costs for this, but the biggest cost is labor.

Turning also may be done as part of other management practices such as blending for particular quality characteristics, to break up sections of "fines" or "hot spots" to prevent grain infestation or spoilage, or simply to cool the grain. Cost components for turning grain are electricity to run the belts, labor, and shrink, which is a loss of grain weight that occurs while turning, typically 0.25% to 1% by weight.

Cost components of using grain protectants (not shown in the table) include the cost of the chemicals, labor (including safety training and certification to apply the chemical), equipment needed to apply the chemicals, and loss of revenue due to disruption or slowdown of grain handling.

Aeration costs are made up primarily of electricity costs, although some weight loss of grain may occur. Aerating immediately upon receipt of grain is more costly than aerating after outside temperatures drop because electricity cost is higher for the same amount of cooling. Early aeration is more likely to reduce insect damage and avoid fumigation. 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 aeration fan controllers. Aeration can be an effective component of an IPM, but most concrete facilities do not have aeration capability.

Sampling costs incurred with IPM are primarily the cost of sampling equipment and trained labor needed to conduct sampling and analysis. Sampling may indicate that fumigation is not needed or that only some bins need fumigation. Although sampling is an added cost, it may actually reduce treatment cost by reducing the cost of fumigation.

Sanitation is also an important part of IPM. Its biggest cost is labor. Sanitation includes cleaning out empty bins, elevator legs and boots, and areas surrounding bins. For additional information on sanitation costs for on-farm bins see Alexander et al. (2008).

Application to Wheat Storage in Oklahoma

This section compares the cost of treatment and the cost of insect damage for both sampling-based IPM and conventional calendar-based fumigation for stored wheat in Oklahoma. To provide a baseline for evaluating the IPM and non-IPM approaches, the example shows the results if the manager did nothing to protect the grain. The cost of treatment is estimated using economic engineering methods in a partial-budgeting approach, and the cost of insect damage is estimated by simulating insect growth under various environmental conditions and treatments. Adding these two sets of costs provides an estimate of the total cost of using each insect control approach.

Cost of Insect Damage

Cost of insect damage is made up of three parts: discount due to infestation, discount due to insect-damaged kernels (IDK), and a sample-grade discount when the number of IDK reaches 32 in a 100-gram sample. Insect damage may slightly reduce grain weight, but compared to the loss from discounts, cost of the quantity loss is relatively small. Insect population can increase rapidly in warm or moist grain, a common situation in Oklahoma. Lesser grain borers (*Rhyzopertha dominica*), in particular, cause IDK in wheat. The larvae feed inside the kernel until they mature into adults and burrow out of the kernel, which results in an IDK. The life cycle of the lesser grain borer (LGB) is approximately 5 weeks at 32°C, so there is approximately a 5-week lag between immigration of an adult insect until appearance of new adults.

Also, if two or more live insects injurious to grain are detected in a 1-kilogram grain sample at time of sale, the U.S. Department of Agriculture (USDA) does not permit the grain to be sold for human consumption. This prohibition can be overcome by fumigating to kill live insects, but the discount charged by buyers is commonly somewhat larger than the cost of fumigating. Often in practice, this discount is imposed by commercial firms if only one live grain-damaging insect is detected in a 1-kilogram sample.

An insect population growth model developed by Flinn et al. (2007) was used to predict the number of live insects on any given day within a grain structure. This, in turn, was used to predict the amount of insect damage.

Cost of Treatment

Cost components shown in Table 1 were estimated using economic engineering and partial budging methods. For illustration purposes, a grain elevator with a group of 10 concrete bins, each 24 feet (7.28 meters) in diameter and 80 feet (24.4 meters) deep, holding 25,000 bushels (680 tonnes) of wheat, is assumed. Table 2 shows component costs of sampling and Table 3 shows component costs of fumigation with turning. The cost of sampling includes the amortized cost of an investment in a PowerVac sampling machine, labor used to set up and take down the sampling equipment, and labor used in sampling. The cost of sampling is $0.011/bushel ($0.404/tonne), including amortized equipment costs of $0.0084/bushel ($0.309/tonne), and variable costs of $0.009/bushel ($0.33/tonne), including labor required to separate and count insects.

The cost of fumigation includes amortized equipment cost, insurance and training, labor, chemical costs, electricity used to turn grain, and value of grain lost in turning. Fumigation with turning costs $0.033/bushel ($1.20 tonne). The component of fumigation that costs the most is the value of grain lost in turning. Assuming a wheat loss of 0.25% based on Kenkel (2008), and a wheat price of $6.50/bushel ($239/tonne), that cost is $0.016/bushel, or $0.588/tonne. Thus, wheat lost in turning makes up nearly one half of the cost of fumigation. Turning may have an added benefit, not quantified in these calculations, of cooling grain.

Simulation Procedures

Adam et al. (2010) compared the cost of a calendar-based fumigation (non-IPM approach) in which fumigation is conducted the same time every year (for example, December 20), with the cost of a sampling-based fumigation (IPM approach). In sampling-based fumigation, the manager samples December 20, and if the sampling detects an average density of 0.5 or more adult LGB per kilogram sample, then he fumigates.

Because insect growth depends heavily on temperature and moisture, the insect growth model was simulated using weather data observed in four locations in Oklahoma and Kansas: Oklahoma City, Oklahoma, and Wichita, Topeka, and Dodge City, Kansas. The only difference across these locations that affected the simulation was the weather, so these locations were conceptualized as representing four sets of weather conditions.

Results

No treatment: Total costs (treatment cost plus insect damage cost) – Figure 1 shows insect population at each of the four locations if insects were to grow unchecked from the time the wheat is binned at harvest. Figure 2 shows the IDK that result from these insect populations. If the manager were to hold this grain for sale until mid-April, there would be discounts for live insects and IDK. As shown in Figure 3, these costs range from

Table 2. *Component costs of sampling.*

Sampling Cost Components	Rate	$/bu
Fixed		
PowerVac ($8,000 amortized over useful life of 10 years) + insurance + maintenance	$2,102/year	$0.0084/bu
Setup/takedown labor		
3 people, 3 hours each, @$16/hour	$144/fumigation	$0.0006/bu
Sampling labor		
3 people @$16/hour, 0.08 hours/sample, 10 samples/bin	$384/fumigation	$0.0015/bu
Average Cost (10 bins each 25,000 bu)		$0.011/bu

Table 3. *Component costs of fumigation with turning.*

Fumigation Cost Components	Rate	$/bu
Fixed		
Liability insurance	$200/year	$0.0008/bu
Fumigation training (training hours/employee x number of employees x labor cost + training fee)	$434/year	$0.0017/bu
Fumigation equipment ($3,800 amortized at 10% over 10 years + insurance + maintenance)	$998/year	$0.004/bu
Labor		
2 people, 3 hours per bin, @$16/hour	$960/fumigation	$0.0038/bu
Fumigant		
120 tablets/(1,000 bu) x $0.04286/tablet	$5.14/1,000 bu	$0.0051/bu
Grain lost in turning (shrink)		
0.25% x grain price ($6.50/bu)		$0.0163/bu
Turning Electricity		
$0.10/kwh x 250 kwh/bin (3 hours x 83 kwh)	$25/bin	$0.001/bu
Average Cost (10 bins each 25,000 bu)		$0.033/bu

$0.12/bushel in Wichita and Topeka to $0.18/bushel in Oklahoma City. The problem is worse, and the discounts higher, in locations with warmer, moister weather conditions. Selling earlier (by mid-January, for example) would substantially reduce discounts due to IDK, but there would probably still be an “infested” discount. There are no treatment costs.

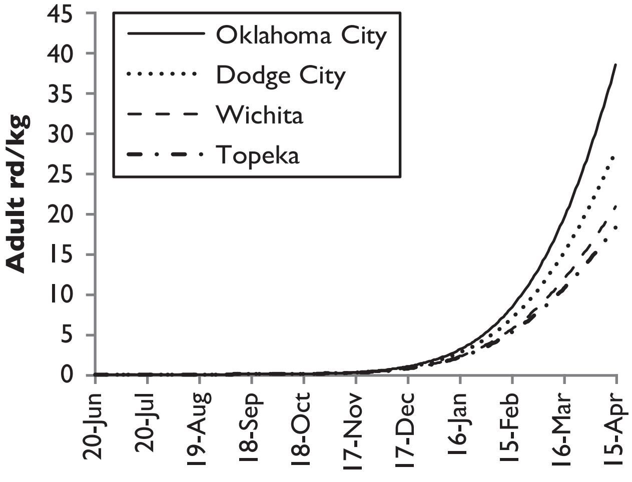

Figure 1. *Population of adult lesser grain borer in four locations (adult/kg), medium immigration rate, no treatment.*

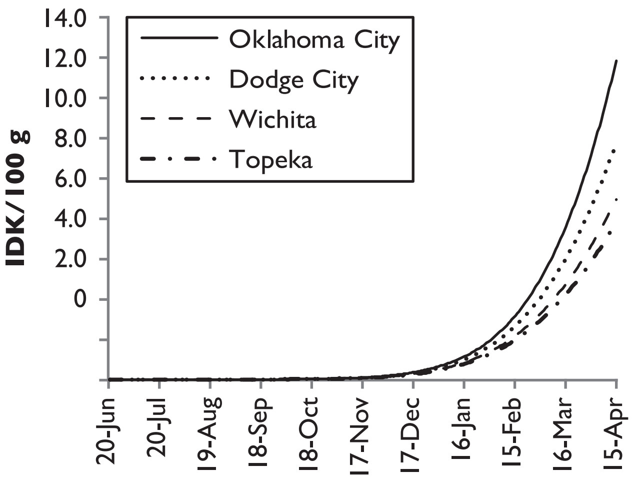

Figure 2. *Insect-damaged kernels (IDK) in four locations (IDK/100g), medium immigration rate, no treatment.*

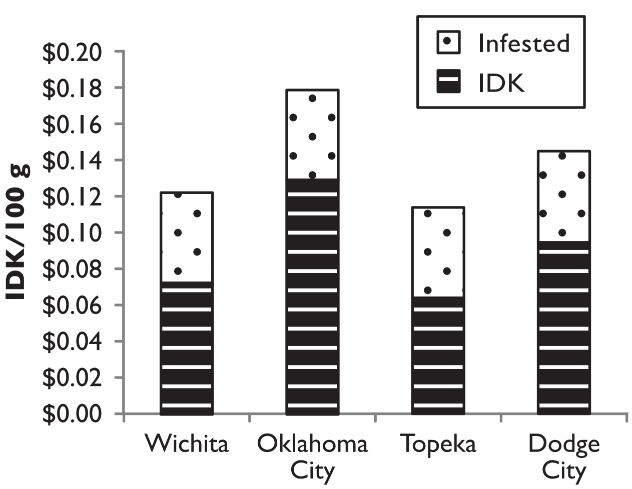

Figure 3. *Costs of doing nothing (discount in $/bu).*

Calendar-based fumigation: Total costs (treatment cost plus insect damage cost) – Figures 4 and 5 show the adult lesser grain borer numbers and resulting IDK with calendar-based fumigation on December 20. Insect numbers begin to increase rapidly in November even though outside temperatures cool considerably, because the grain mass stays warm and favorable to insect growth without aeration until fumigation on December 20.

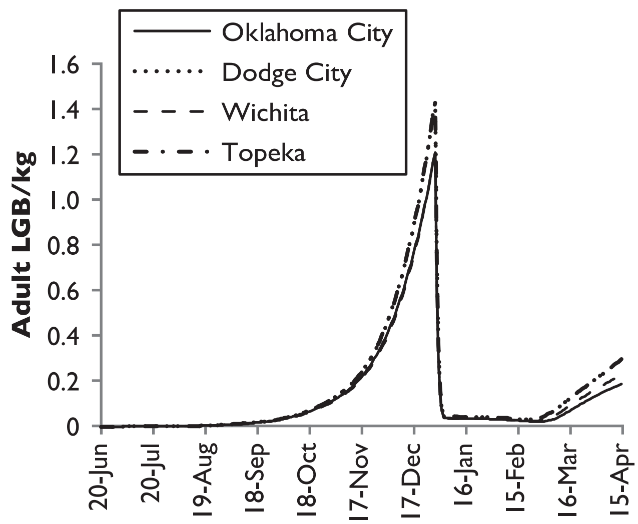

Figure 4. *Population of adult lesser grain borer in four locations (adult/kg), medium immigration rate, fumigation on December 20.*

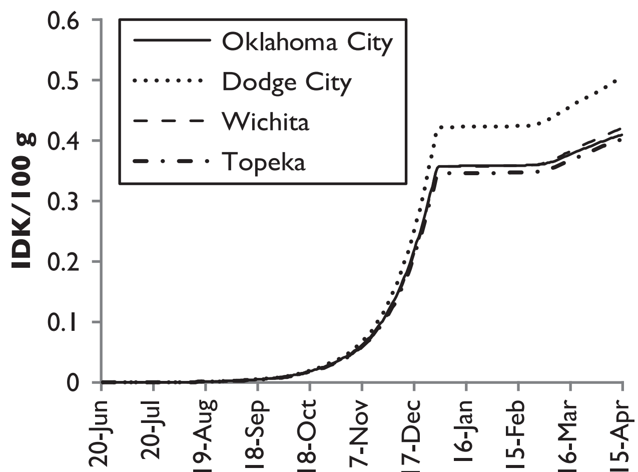

Figure 5. *Insect-damaged kernels (IDK) in four locations (IDK/100 g), medium immigration rate, fumigation on December 20.*

After fumigation, few new adult insects emerge, and IDK increases are halted. In March, the insects surviving fumigation renew population growth, but not enough to cause a problem before mid-April,when it is assumed the grain is sold. There are no discounts due to insect damage, so the total cost is a fumigation cost of $0.033/bu ($1.21/t).

Sampling-based fumigation (IPM): Total costs (treatment cost plus insect damage cost) – Under this approach, sampling every year on December 20 results in a sampling cost of $0.011/bushel. Depending on weather conditions, the rate at which insects immigrate into bins from the outside, and other factors, if sampling indicates that fumigation is necessary, a fumigation cost of $0.033/bu is also incurred. Thus, treatment cost may be $0.011/bushel or $0.044/bushel. There are no insect damage costs. For the weather conditions simulated here, there were no locations in which fumigation was not necessary, so sampling simply adds unnecessary costs compared to a calendar-based fumigation approach.

That result changes significantly if the rate at which insects immigrate into bins from the outside can be reduced. Sanitation around the bins and bin sealing, for example, can substantially reduce the rate at which adult insects enter a bin. Similarly, cleaning the inside of a bin thoroughly after it is emptied can reduce insect problems when the bin is filled again. Complicating this, within an elevator, some bins may have normal insect immigration rates, and some may have lower immigration rates. Bin sealing and sanitation also add expense, but that cost is much less on a per bushel basis than either sampling or fumigation.

With a reduced immigration rate, the simulation indicates that cooler, dryer weather may make fumigation unnecessary, while warmer, more humid weather may still require fumigation. Even in warmer weather, fumigation may be avoided by selling the grain earlier. Sampling can help distinguish between those situations. Also, expert-system computer software such as SGAPro (see Flinn et al. 2007), used together with sampling, can use weather information to help determine whether fumigation is necessary.

Given the relative costs of sampling and fumigation with turning, results reported by Adam et al. (2010) indicate that if an elevator has at least four out of 10 bins that do not require fumigation, a sampling-based approach achieves the lowest combined total treatment cost plus insect damage cost. If more than six out of 10 bins require fumigation, a calendar-based fumigation approach is lowest cost.

Elevator managers can increase the probability that sampling-based fumigation would be economical by reducing the insect immigration rate (by better sanitation practices or by sealing holes in grain bins), or by storing the grain a shorter amount of time. Sampling would help them assess the success of these efforts.

Figure 6 illustrates these factors and their effects on total cost (insect damage cost plus treatment cost). Clearly, doing nothing (perhaps because of failing to notice a problem) or improperly fumigating can be expensive, as in the first bar. Although there is no treatment cost, cost due to insect damage is high. In the second bar, when sampling is conducted and fumigation is always required (because of weather or because insect immigration rate cannot be reduced), there is no insect damage cost, but treatment cost is relatively high. In the third bar, doing no sampling but conducting a calendar-based fumigation every year reduces treatment cost slightly compared with sampling and fumigating. In the fourth bar, if the elevator can use a sampling-based fumigation IPM approach in which an average of 60% of its bins must be fumigated in any year, the treatment cost is just as low. In the fifth bar, if an elevator uses a sampling-based fumigation IPM approach in which only 40% of the bins must be fumigated in any given year, the treatment cost would be reduced even further.

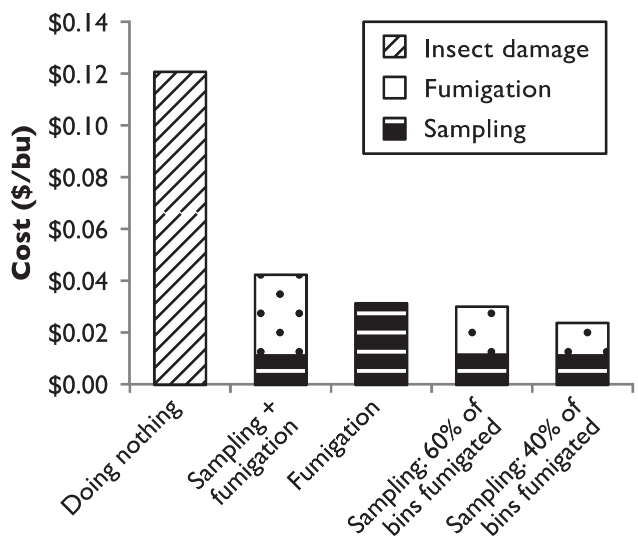

Figure 6. *Cost of alternative approaches to insect control.*

Finally, elevator managers may wish to consider investing in closed-loop fumigation systems (which significantly reduce chemical costs and increase fumigation effectiveness). Such an investment would likely pay for itself in about 3 years (Jones and Adam unpublished data). They may also wish to consider installing automatic (conditional) aeration capabilities, retrofitting concrete facilities that do not have them. Use of conditional aeration, which aerates only when outside temperature is cooler than grain temperature, would reduce the need for fumigation and potentially increase the profitability of sampling-based IPM. Work in progress is evaluating the payoff from such an investment.

IPM Strategies for Mold

One of the major challenges in managing mold growth is that the worst mold and mycotoxin problems occur in the field and are beyond the control of the farmer. Johnson, Wilson, and Diersen (1995) conducted one of the few economic studies measuring the impacts of a severe vomitoxin infestation in 1993 and 1994 in spring planted crops. If vomitoxin (or any other mold-produced toxin) is present, the grain handling system can respond by either destroying the grain or blending the infested grain with clean grain to meet the regulatory limits established by the FDA. When weather-induced mold outbreaks occur, the entire grain supply chain faces economic losses. The Johnson, Wilson, and Diersen study found that the 1993 vomitoxin infestation reduced the value of wheat production in North Dakota by $86 million.

Producers, processors, and grain elevators that are storing grain are also concerned about mold growth during the storage period. The three major storage conditions that favor mold growth and are necessary for mycotoxin formation in stored grain are warm temperatures, high grain moisture content, and high humidity (Shanahan et al. 2003). When these storage conditions are present, molds can grow rapidly, leading to grain spoilage (Sweets 1996). Growth of mold populations is generally low at temperatures below 50˚F (10˚C), but slow growth will occur even at low temperatures when the moisture conditions are favorable. Moisture levels below 12% will prevent mold formation (Shanahan et al. 2003).

Two other factors may affect mold growth in stored grain. Friday et al. (1989) suggest that mold damage levels depend on the grain hybrid being stored. Several studies have found that the extent of grain kernel mechanical damage is also important in determining the level of mold damage (Wilcke et al. 2001; Gupta et al. 1999). Farmers can mitigate both of the factors by choice of hybrid and care taken to reduce mechanical damage during the harvesting and handling of the grain.

Because molds are difficult to manage, monitoring becomes even more important. An IPM strategy based on regular monitoring is effective at controlling molds. Several scientists suggest that the best strategy for controlling molds is to control the storage environment (Wilcke et al. 2001, Pitt 1993, Northolt and Bullerman 1982). IPM-based strategies of monitoring and aeration have been found to be very effective in controlling the atmospheric conditions in on-farm storage (Ileleji et al. 2007, Maier et al. 1996, Arthur et al. 1998, Thompson 1972).

To date, there has been only one economic study of integrated pest management related to molds. Yigezu et al. (2008) examined the case of IPM for molds for corn stored on-farm in Indiana. They used a stochastic dynamic programing model to compare the profitability of a monitoring-based IPM strategy where farmers use aeration and sales to manage mold damage, to the traditional non-IPM strategy of keeping the grain cold during the winter with minimal monitoring and delivering the corn before March. One of the contributions of Yigezu et al. (2008) was to explicitly recognize the decision to sell grain as a strategy to halt the economic losses due to further mold damage. Overall, they found that the monitoring-based IPM mold program is profitable for farmers who are delivering food-grade corn, especially if they have a contract to store the corn into the warmer summer months. Yigezu et al. (2008) also identified management rules of thumb, such as, if the level of mold-damaged kernels is approaching the limit set by the food-grade corn buyer, the farmer should sell the grain immediately.

Conclusion

Integrated pest management has been shown to be potentially profitable in the case of managing both insects and molds. For producers, processors, and elevator managers interested in adopting IPM principles, the primary change from non-IPM to IPM management is the introduction of regular grain sampling. This practice offers decision makers information with which to make storage management decisions, and it will be profitable as long as the benefit of more informed decisions exceeds the cost of sampling.

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