Should Grain Elevator Managers Adopt Integrated Pest Management?

Brian D. Adam, Professor
Mounir Siaplay, Graduate Research Assistant
B. Wade Brorsen, Regents Professor and Jean & Patsy Neustadt Chair
Dept. of Agricultural Economics, Oklahoma State University
Paul W. Flinn, Entomologist
Agricultural Research Service/USDA

Contact: *Brian.Adam@okstate.edu*

Selected Paper prepared for presentation at the American Agricultural Economics Association Annual Meeting, Portland, OR, July 29-August 1, 2007.

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; (Subramanyam 2003; Magnusson and Cranfield 2005).

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).

Many elevator operators, though, have been reluctant to use IPM practices. The purpose of this paper is to consider and evaluate reasons for this. 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. Since 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 the insect population is high enough to justify treatment, which is usually fumigation in the case of grain. 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)."

Lukens compared the costs of IPM approaches to controlling insects in stored grain with costs of chemical-based approaches. 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, USDA does not permit the grain 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. Although applying treatments when they are not needed adds unnecessary costs, those costs are relatively small. However, not applying treatments when they *are* needed results in large costs, because of the nonlinear relationship between insect population and grain discounts and because of the exponential nature of insect population growth. Moreover, the monitoring, or sampling, that IPM practices use to decide when treatments are needed is itself costly.

Insect growth in a grain storage structure depends on environmental conditions (particularly temperature and humidity), condition of the grain, and rate of immigration of grain-damaging insects into the structure (which itself depends on environmental conditions such as wind and temperature as well as cleanliness of the facility). The effectiveness of insect control treatments depends on environmental conditions as well as on management ability of the elevator operator.

Environmental conditions in the Southern Plains (including Kansas and Oklahoma) promote rapid insect growth in grain. Although aeration to cool grain as quickly as outside temperatures permit is a recommended IPM practice that controls insects inexpensively (Adam et al., 2006), most commercial grain storage structures in this region do not have aeration capability. A typical structure is a group of concrete silos joined with interstices. In contrast to corn and soybean elevators in the Midwest, storage structures for wheat in the Plains states were built with smaller bins to segregate the wheat for more diverse quality characteristics (Schnake and Stevens 1983). Few of these structures were fitted for aeration capability, so most elevator managers resort to phosphine fumigation one or more times per year to control insects.

A common IPM recommendation is to periodically sample the grain in a storage structure, and to fumigate only if the information, combined with known insect growth patterns, suggests that insects are likely to cause damage in the future. This is in contrast to a more typical practice, calendar-based-fumigation, in which the elevator manager fumigates all structures at one or more pre-determined calendar dates. The assumption with the IPM strategy is that some bins within a storage structure might have lower insect populations and thus would not need to be fumigated along with the other bins. However, in an attempt to determine why few elevator managers have adopted IPM practices, (Adam, Phillips et al. 2006) showed that under typical environmental conditions and insect growth, and standard assumptions about storage facilities and the immigration rate of adult insects into those facilities, fumigation was always necessary at some point in the storage period. In other words, even if sampling at a particular date would have indicated that some bins did not need fumigation, those bins eventually had sufficient insect growth that fumigation was required at a later date. Thus, sampling as an IPM practice added cost but provided no benefit because it changed only the timing of fumigation, but not the need for it.

However, the authors noted that the simulations in that study used weather information from only one year, and that weather conditions may be sufficiently variable from year to year that sampling may indeed reduce the number of fumigations required. They also noted that the study had assumed a constant immigration rate of insects into each bin within a storage facility, and that if immigration rates actually differed from bin to bin, the attractiveness of sampling relative to routine fumigation would be increased since varying immigration rates would increase the uncertainty about the need for fumigation.

Subsequent information received from continual on-site sampling at several grain elevators in Kansas and Oklahoma conducted as part of a regional study suggests that since some bins within some grain elevators did not need fumigation during a storage season, the normal immigration rate specified in the original simulation software was too high for those situations (Flinn; Hagstrum).

Thus, the current study determines the expected return from IPM using a more recent version of the insect growth model developed and validated by Flinn, Hagstrum, and Muir (also see Flinn et al.; Flinn and Hagstrum 1990a, b) to simulate insect growth. The revised version allows modeling lower immigration rates of grain-damaging insects into a storage structure, and thus can consider greater variability in insect immigration rates.

The approach used here is to estimate cost of treatment using economic engineering methods, and to predict cost of failing to control insects by simulating insect growth under various environmental conditions and treatments. Combining the two costs provides an estimate of the total cost of using each insect control strategy.

Model and Procedures

The work was done in two steps. The first step was to model the effects of location (weather), varying immigration rates, and fumigation on insect population. 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, Hagstrum, and Muir 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, insect immigration rate, mortality rate due to fumigation and natural death, and hourly observations of temperature, moisture, solar radiation, cloud opacity, dew point temperature, dry bulb temperature, relative humidity, barometric pressure, and wind speed.

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:

$$\min_j \{[E(Cj)\ TC+E(D_j)+E(L_j)]\ ;\ j = 1,\ldots J\} \tag{1}$$

where $E(C_j)$ *is* the expected cost of insect control strategy j, TC *is* the treatment cost associated with the jth 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, turning, aeration, and labor.

The cost of fumigation, for example, includes electricity, labor, equipment, and chemical costs. 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 accomplished by inserting phosphine pellets or tablets into the moving grain flow.

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.[1]

The analysis simulates conditions in five different locations in Oklahoma and Kansas (Oklahoma City in Oklahoma, and Wichita, Goodland, Topeka and Dodge City in Kansas). The only difference across these locations in the simulation is the weather, so one could think of these locations as representing five different sets of weather conditions.

It was assumed that any fumigation conducted was of average effectiveness, so that 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 (Flinn 2006). 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

---

[1] While this analysis considers the full costs of fumigation and sampling, including amortized equipment cost, a decisionmaker who has already acquired such equipment should not consider equipment cost when choosing among alternative treatments, since the cost of equipment cost would be a "sunk" cost.

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 either ten months (approximately 304 days, from June 20 to April 19), or eight months (approximately 254 days, from June 20 to February 28). The longer storage period reflects storage for nearly an entire crop year. The shorter storage period is used since most Oklahoma wheat is sold by then (see Klumpp, Brorsen and Anderson). A 25,000-bushel bin 23.9 feet wide and 80 feet deep is assumed. The grain temperature on the starting date was set to 84ºF and the grain moisture to 12%. Insect numbers were predicted using the software SGAPro 3.0, based on the model by Flinn, Hagstrum, and Muir.

The model uses hourly weather data from 1989 and 1990. Figures 1 and 2 show daily averages of the hourly observations for temperature (C°) and relative humidity (%) for the five locations.

Several scenarios were simulated. First, a baseline scenario assumed that insects grew 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 on December 31 detected 0.5 or more lesser grain borers per kilogram sample. This date was chosen late enough so that if sampling indicated fumigation was not necessary, no grain damage would in fact result, and if sampling indicated fumigation was necessary, there would be insufficient time for the insect population to rebound enough to cause damage before the grain is sold. It was chosen early enough so that damage was not likely to occur before sampling was conducted.

The criterion of 0.5 lesser grain borers/kg was set low enough that no grain damage occurred before sampling was conducted, but high enough so that there was some possibility fumigation would not always be prescribed. Based on Mah (2004), sampling is assumed to cost one cent per bushel (variable costs of 0.2¢/bu, and amortized equipment costs of 0.8¢/bu.), and fumigation is assumed to cost 2.8¢/bu.

"Failure-to-Control" Discounts

Cost of failing to control insects is made up of three parts. First, a determination of "infested", an observation of two or more live grain-damaging insects per sample, incurs 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, the number of insect-damaged kernels (idk) in a 100-gram sample determines the amount of idk discount. 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 1. Discount Schedule for Insect-Damaged Kernels

# 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

A third, additional, discount of 12¢/bu. is triggered when the number of idk reaches 32 in a 100-gram sample. At this level, the wheat is designated "sample grade," and is no longer permitted to be sold for human consumption.

Results

No Treatment

Figures 3 and 4 show the insect numbers and resulting idk predicted by the insect growth model when no treatment strategies are used under assumptions of low and normal rates of insect immigration into the storage facility. Number of lesser grain borers reached nearly 4 live lesser grain borers by April 19 in Oklahoma City and Goodland under a low immigration rate, and 10 times that many under a normal immigration rate. Insect and idk numbers were much lower, though, on February 28.

Figure 5 shows the costs of doing nothing in all five locations under low and normal immigration rates, assuming wheat is stored until April 19. 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, with an associated cost of 5¢/bu. With a low immigration rate, no idk discounts are incurred because insect numbers do not reach high levels until near the end of the storage period. In contrast, with a normal immigration rate, idk discounts range from about 6¢/bu to more than 12¢/bu., depending on location.

Figure 6 shows the costs of doing nothing in all five locations under low and normal immigration rates, assuming that wheat is stored only until February 28. Under this assumption, no idk costs are incurred under either low or normal immigration rates. Three locations – Wichita, Topeka, and Dodge City – do not even incur an "infested" discount under a low immigration rate.

Calendar-based Fumigation

Figures 7 and 8 show the insect numbers and resulting idk of fumigating on December 31 in all five locations, assuming a normal rate of insect immigration and storage until April 19. Insect numbers begin to increase rapidly in November (even though outside temperatures cool considerably, the grain mass stays warm and favorable to insect growth, since aeration is not possible) until the fumigation on December 31.

With few new adult insects emerging, idk increases are halted. In March, the insects surviving fumigation combined with immigrants renew population growth, but grain is sold before a problem develops. Figure 9 shows the costs of this scenario. The cost in all locations, for both low and normal immigration rates, is a fumigation cost of 2.8¢/bu.

IPM: Sampling-Based Fumigation

Figure 10 shows the cost of sampling on December 31, and fumigating only in those locations where the number of lesser grain borers is greater than 0.5/kg. Under normal immigration rates, the insect population reaches this threshold at all locations, so fumigation is conducted at all locations. Under low immigration rates, the threshold is not reached at any of the locations. However, storing grain in those locations until April 19 results in enough insect growth to incur an "infested" designation and a discount of 5¢/bu. Storing grain in those locations only until February 28 (Figure 11) allows insects to grow to the point of an "infested" designation and a 5¢/bu discount only in Oklahoma City and Goodland.

Tables 2 and 3 summarize these results. Table 2 shows the costs for each scenario for each location assuming normal insect immigration rates. The highest-cost approach is to use no treatment, which results in high "failing-to-control" costs, primarily idk discounts as well as an "infested" designation. The lowest-cost approach is to conduct a calendar-based fumigation. Sampling-based fumigation is higher cost because sampling does not change the treatment; the elevator manager would be paying for information that made no difference.

Table 3 shows the same costs but for low insect immigration rates. Here, the highest-cost approach is sampling-based fumigation, storing until April 19. At the time of sampling, fumigation was not prescribed, but by the end of the storage period insect numbers had reached numbers that incurred an “infested” designation. This is the same result as for the approach of no treatment, storing until April 19, except that the elevator incurs an additional cost for sampling. The lowest cost approach, averaged over all five locations, is that of no treatment and storing until February 28. Some locations using this approach – Wichita, Topeka, and Dodge City – incurred zero costs.

Conclusions

The best approach overall with normal insect immigration rates is calendar-based fumigation. With low insect immigration rates, the best approach is to do nothing but to store only until February 28; this approach is only slightly better than the calendar-based approach. Thus, to the extent that this simulation reflects reality, it is understandable why 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.

At individual locations, though, the results are not quite as clear. In Wichita, for example, under a low immigration rate, the best approach is no treatment, storing only until February 28, followed closely by a sampling-based fumigation, storing until February 28. If insects immigrate at a normal rate, though, the best approach is a calendar-based fumigation, followed closely by a sampling-based fumigation. If an elevator facing weather conditions similar to those in Wichita in 1989 has some bins with low and some bins with normal immigration rates, a sampling-based approach may be best, since sampling may help identify the bins with normal immigration (in which case fumigation is necessary) and the bins with low immigration (in which case no treatment is necessary).

Also, to the extent that weather at an individual location differs from one year to the next, in some years the best approach might be the one that appears best for Wichita, whereas in warmer years the best approach might be the one best for Oklahoma City.

For elevator managers considering IPM, though, it is clear that a prerequisite for using a sampling-based approach is to achieve low insect immigration rates for at least some bins or some years. This might be a function of the elevator's location and environmental surroundings, but more likely it is a function of cleanliness of the facility.

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. Although different locations may effectively represent varying weather possibilities in the same location, it is likely that weather variability in a single location is less than the differences between locations represented here. Work in progress is incorporating weather variability in the simulation.

Third, 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 December 31, 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

Adam, B. D., T. W. Phillips, and P.W. Flinn. “The Economics of IPM in Stored Grain: Why Don’t More Grain Handlers Use IPM?” Proceedings of the 9th International Working Conference on Stored Product Protection. Edited by I. Lorini et al.. Campinas, Sao Paulo, BRAZIL: ABRAPOS, 2006:3-12.

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

Flinn, P.W. Email conversations, August - September 2006.

Flinn, P. W. and D. W. Hagstrum. “Simulations Comparing the Effectiveness of Various Stored-Grain Management Practices Used to Control Rhyzopertha 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.

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.

Hagstrum, D. W. Email conversation, August - September 2006.

Klumpp, J.M., B.W. Brorsen, and K.B. Anderson. “Determining Returns to Storage: Does Data Aggregation Matter?” *Journal of Agricultural and Applied Economics* 39(2007): forthcoming.

Lukens, Tamara L. “Cost and Effectiveness of Integrated Pest Management Strategies Compared to Chemical Methods in Stored Wheat.” M.S. Thesis, Oklahoma State University, 2002.

Magnusson, E. and J. A. L. Cranfield (2005). "Consumer Demand for Pesticide Free Food Products in Canada: A Probit Analysis." Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie 53(1): 67-81.

Mah, Poh Mun. “Cost of Controlling (or Failing to Control) Insects in Stored Grain: A Comparison of Chemical-based and Integrated Pest Management Strategies.” M.S. Thesis, Oklahoma State University, 2004.

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

Schnake, L. D. and J. Stevens, C. A. (1983). "Inland Grain Elevator Operating Costs and Capital Requirements, 1982," Kansas Agricultural Experiment Station Bulletin 83-219-B: 32.

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

Subramanyam, B. (2003). "Pesticide Residue an Important Issue." Milling Journal(4th Quarter): 42-44.

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.

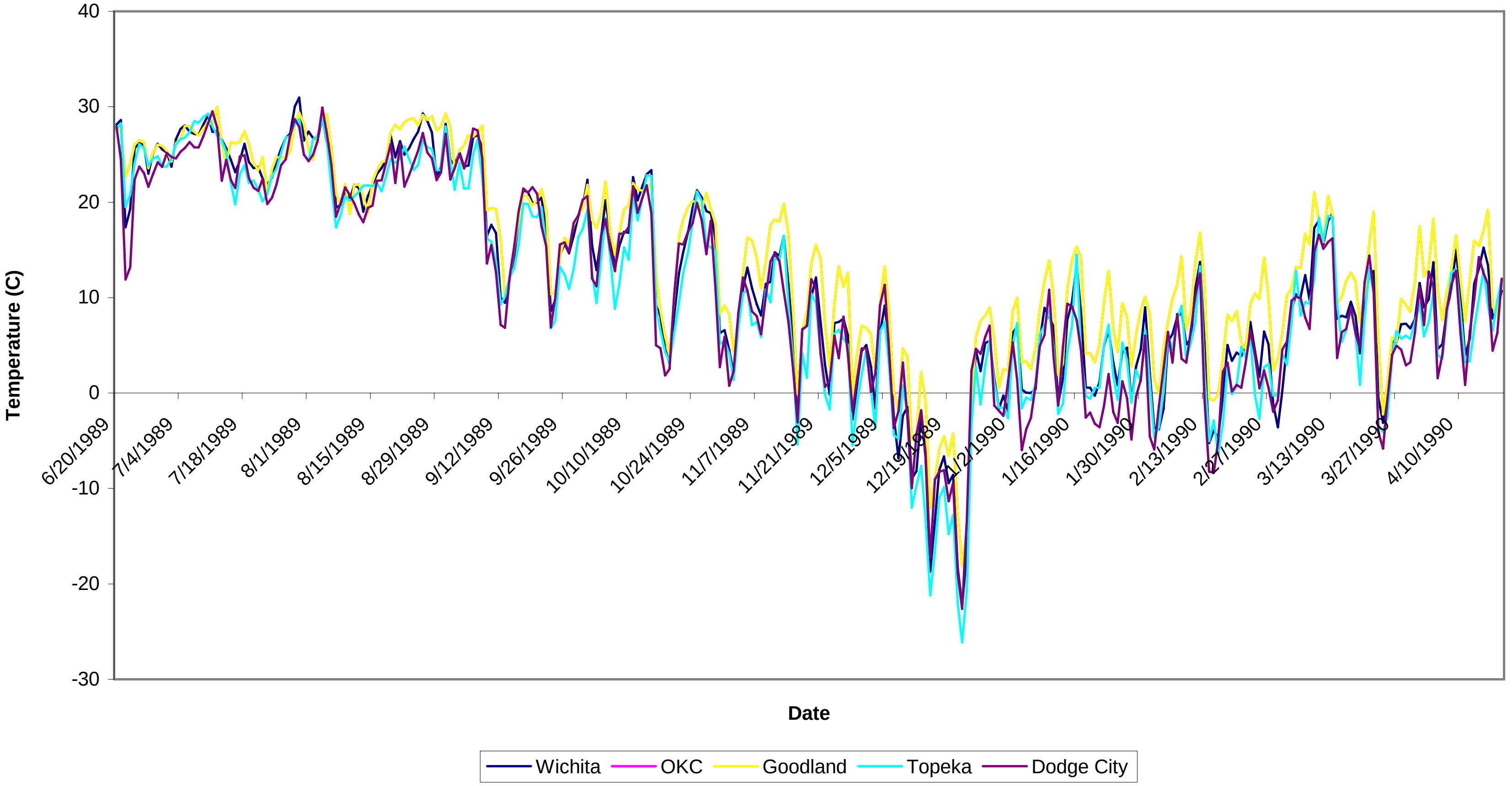

Figure 1. Daily Temperature Readings (°C) in Five Locations, 1989

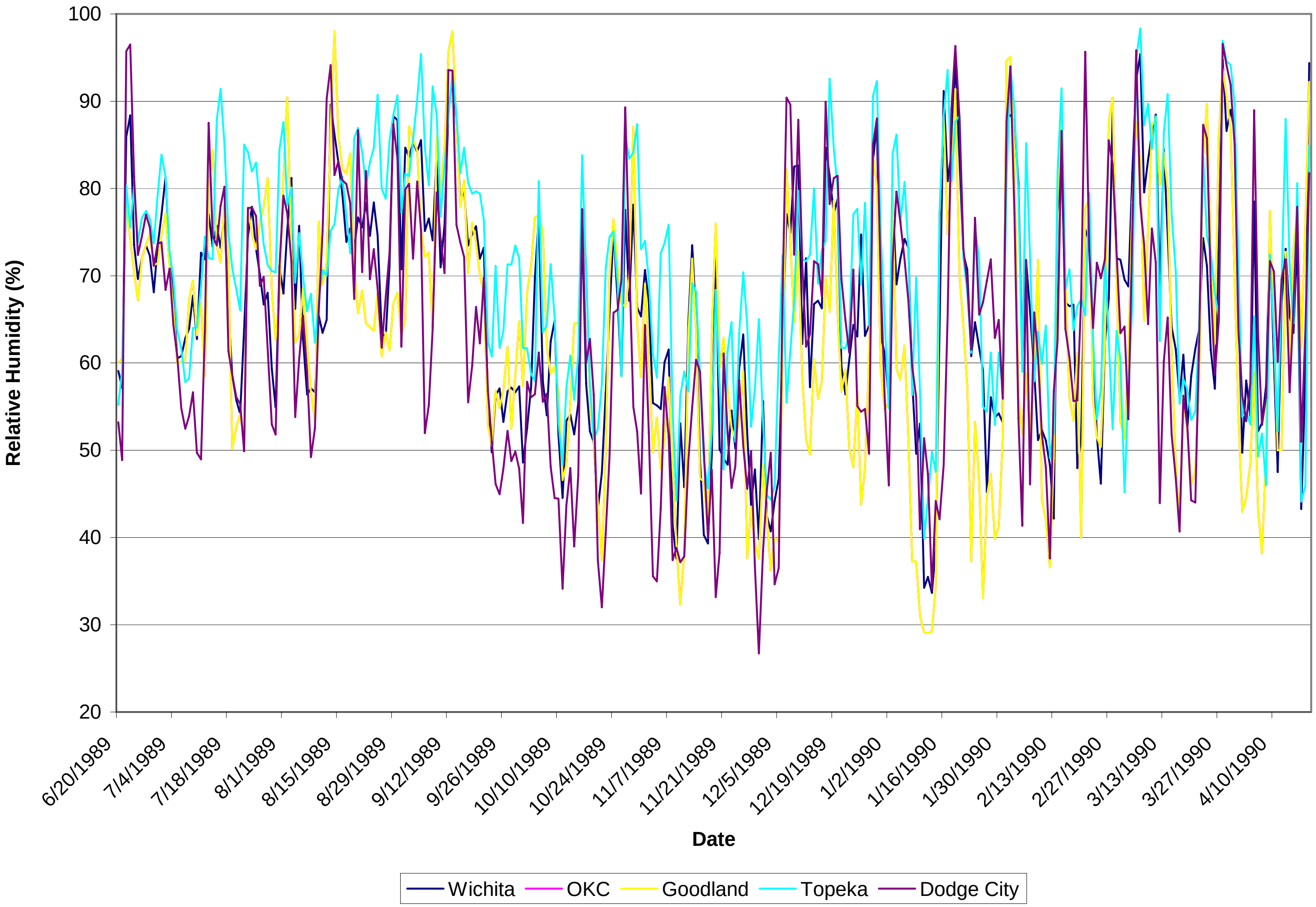

Figure 2. Daily Relative Humidity Readings in Five Locations, 1989

9

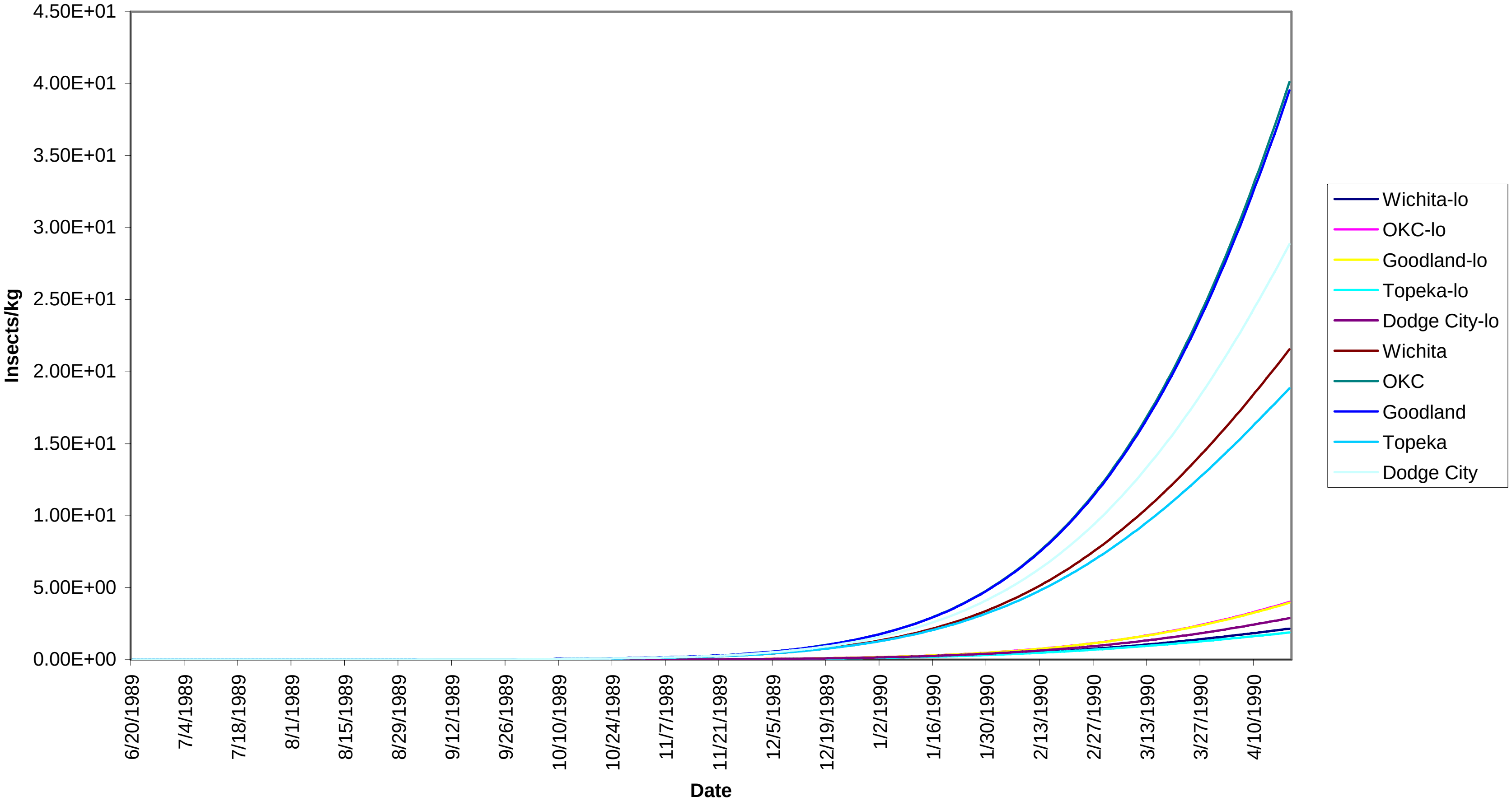

Figure 3. Population of Lesser Grain Borers in Five Locations, Low and Normal Immigration Rates, with No Treatment

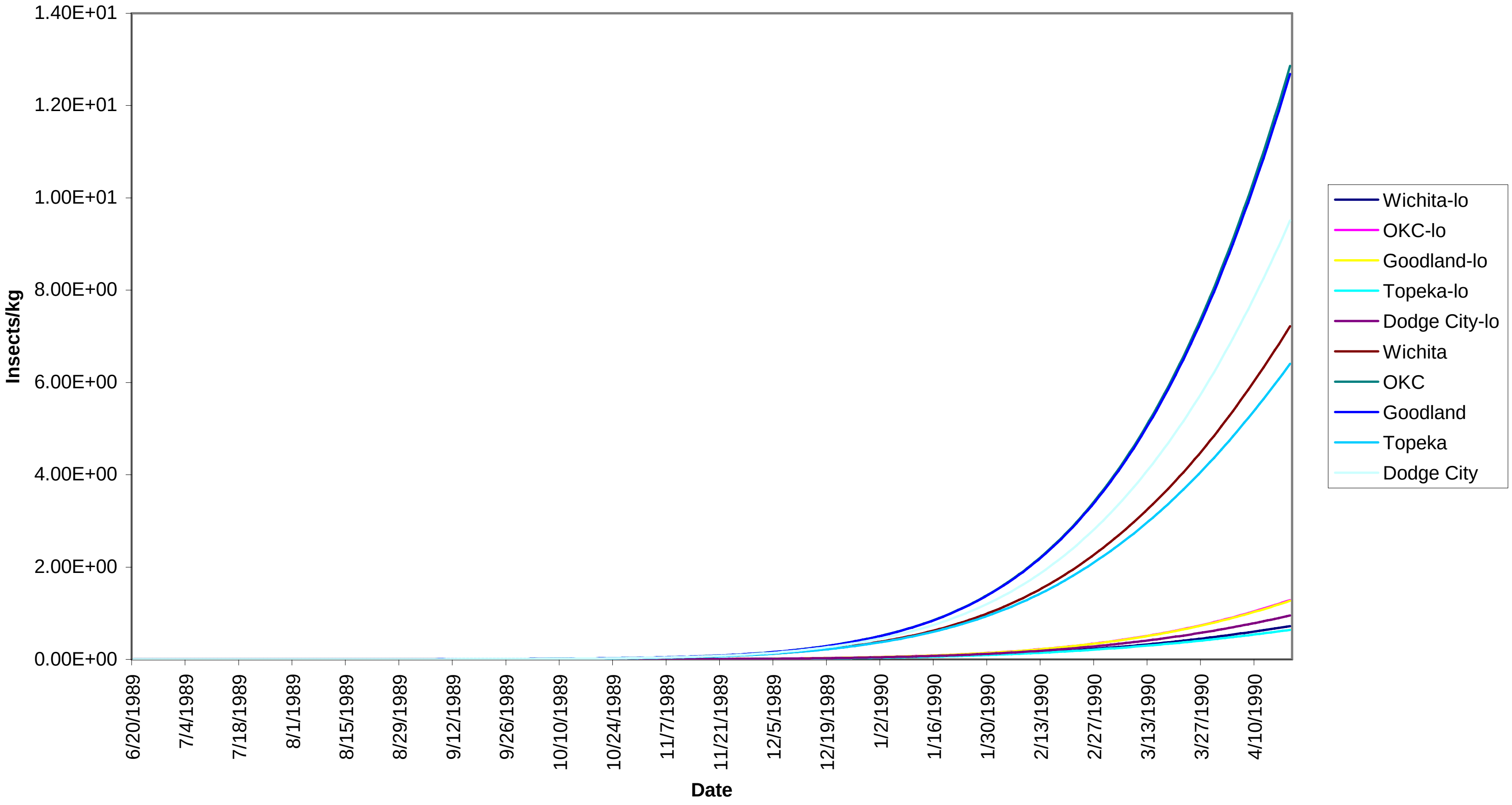

Figure 4. Insect-Damaged Kernels Resulting from Lesser Grain Borers in Five Locations, Low and Normal Immigration Rates, with No Treatment

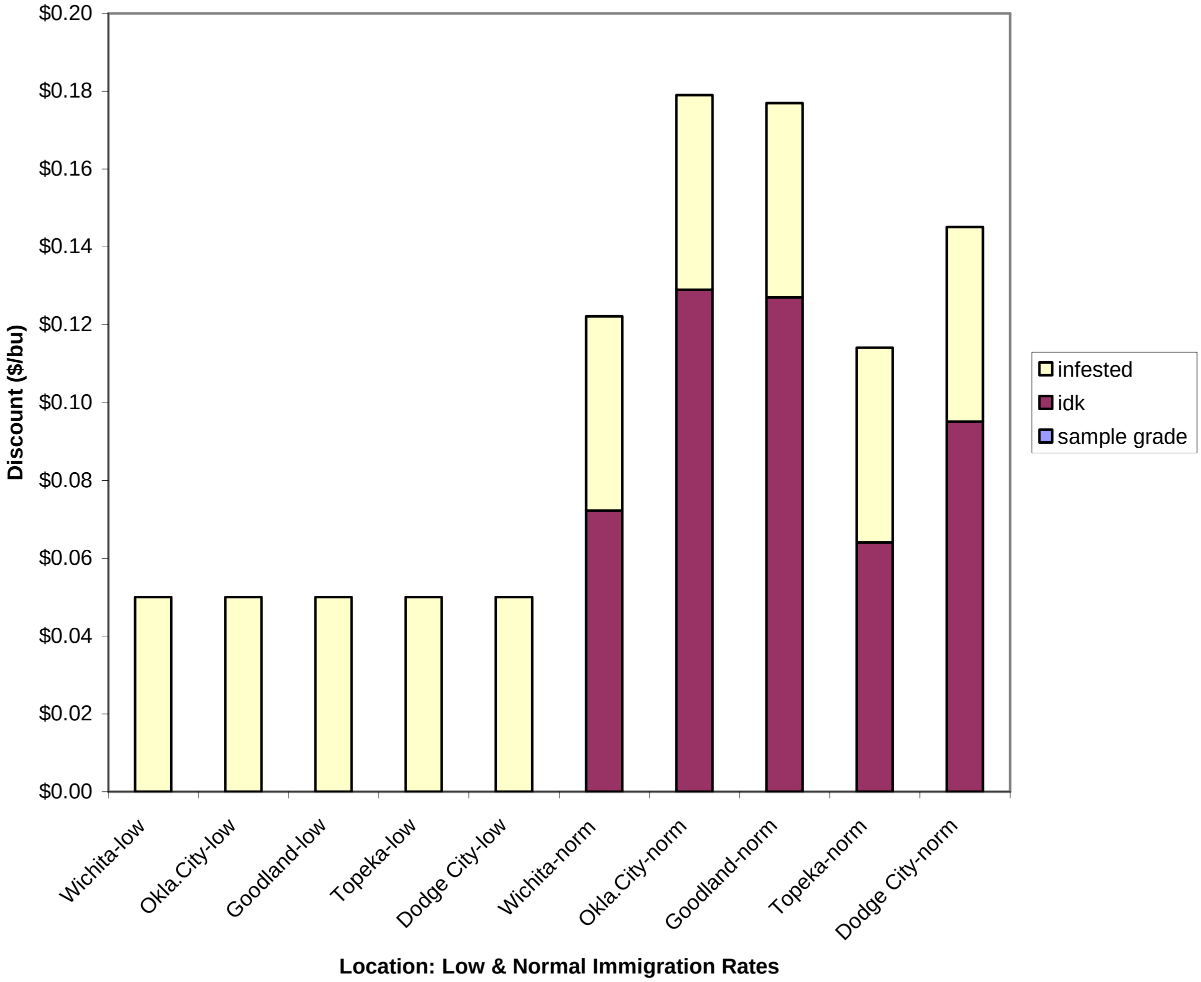

Figure 5. Cost of No Treatment, Storing until April 19.

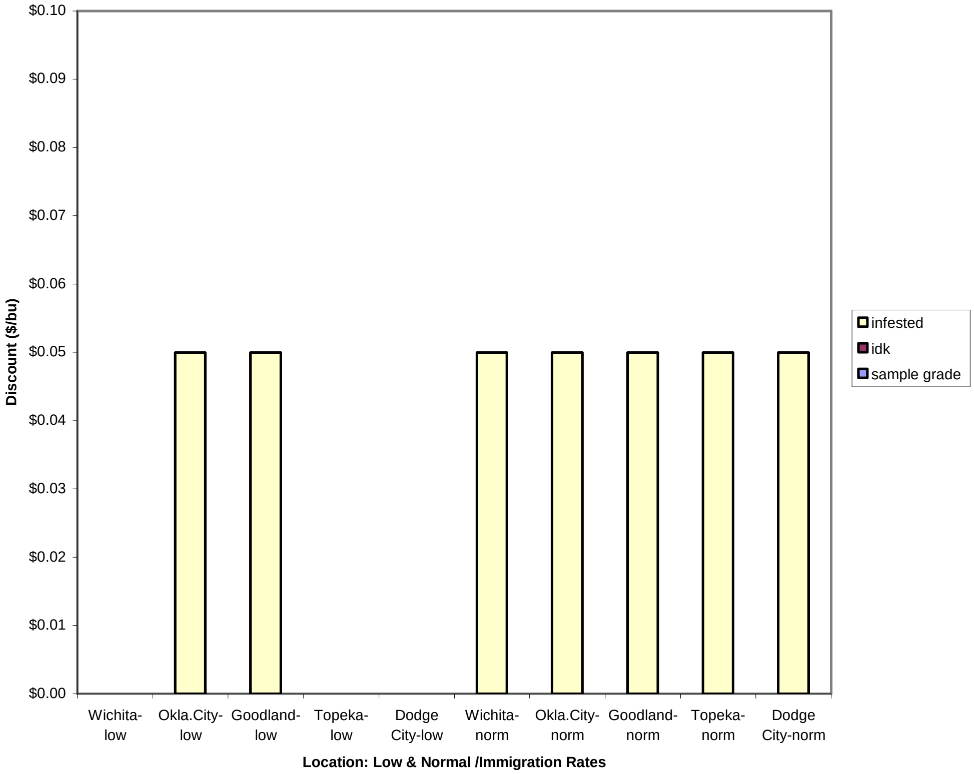

Figure 6. Cost of No Treatment: Storing Until February 28

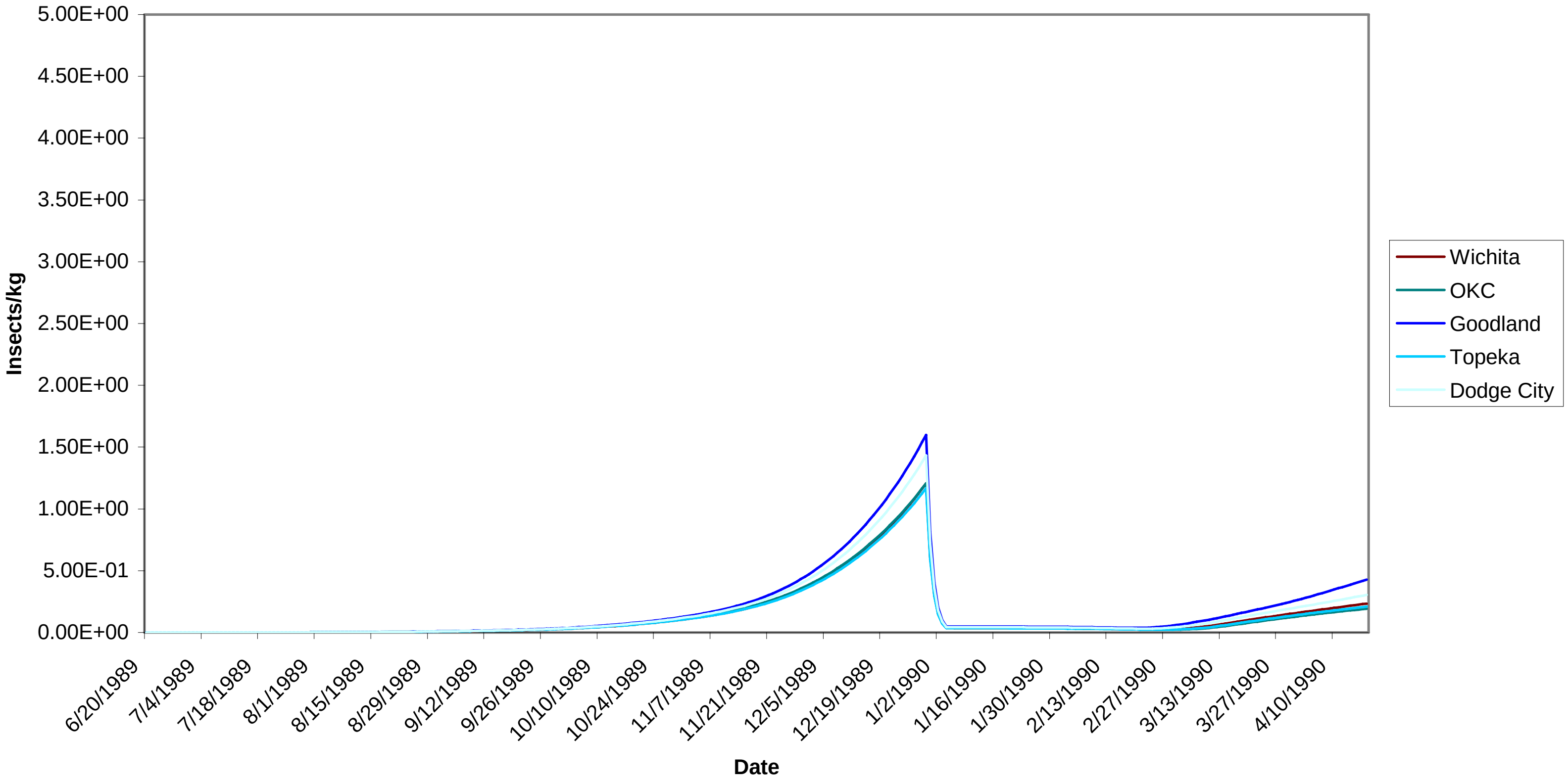

Figure 7. Population of Lesser Grain Borers in Five Locations, Normal Immigration Rate, Fumigation on December 31

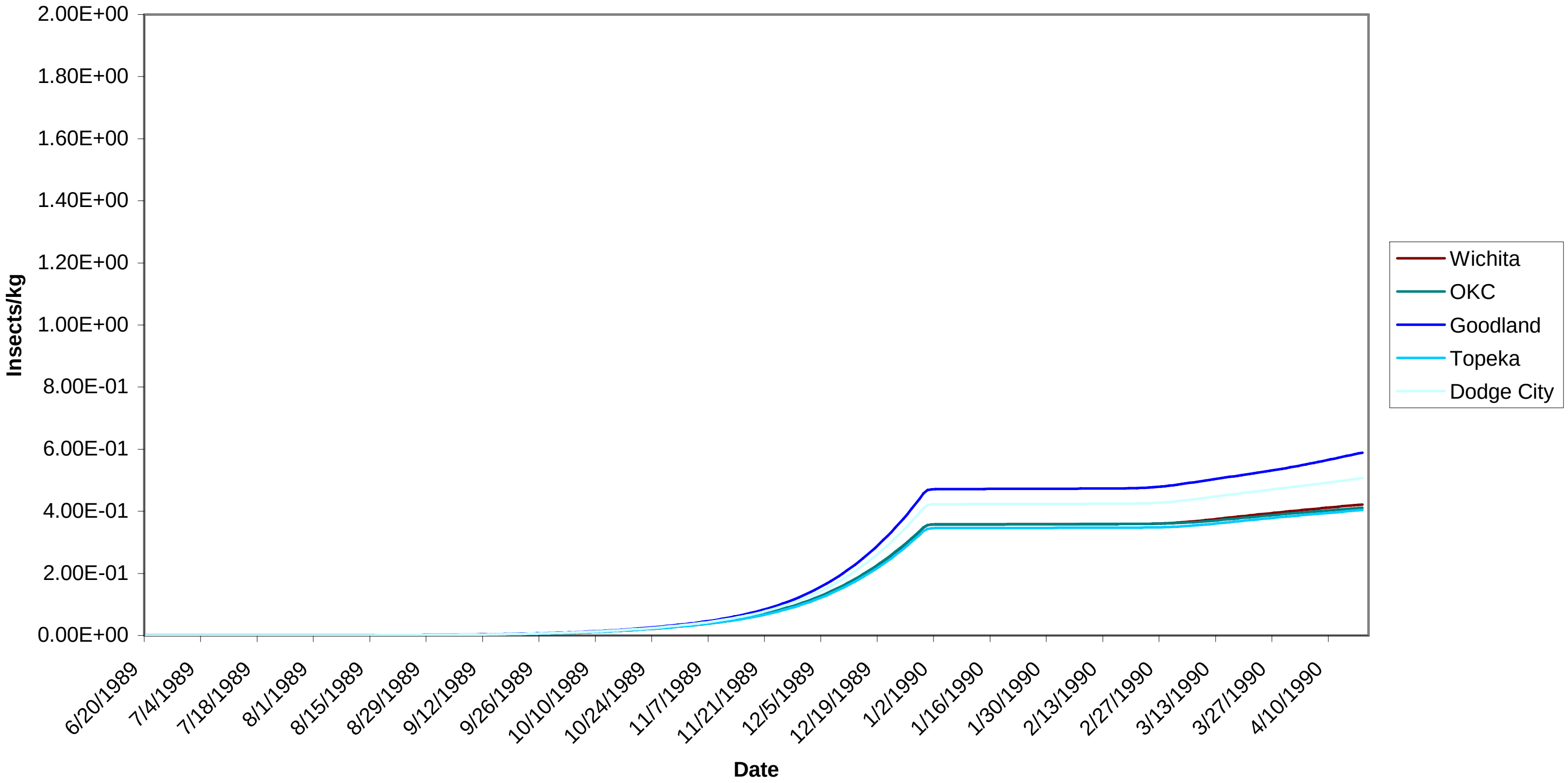

Figure 8. Insect-Damaged Kernels Resulting from Lesser Grain Borers in Five Locations, Low and Normal Immigration Rates, with No Treatment

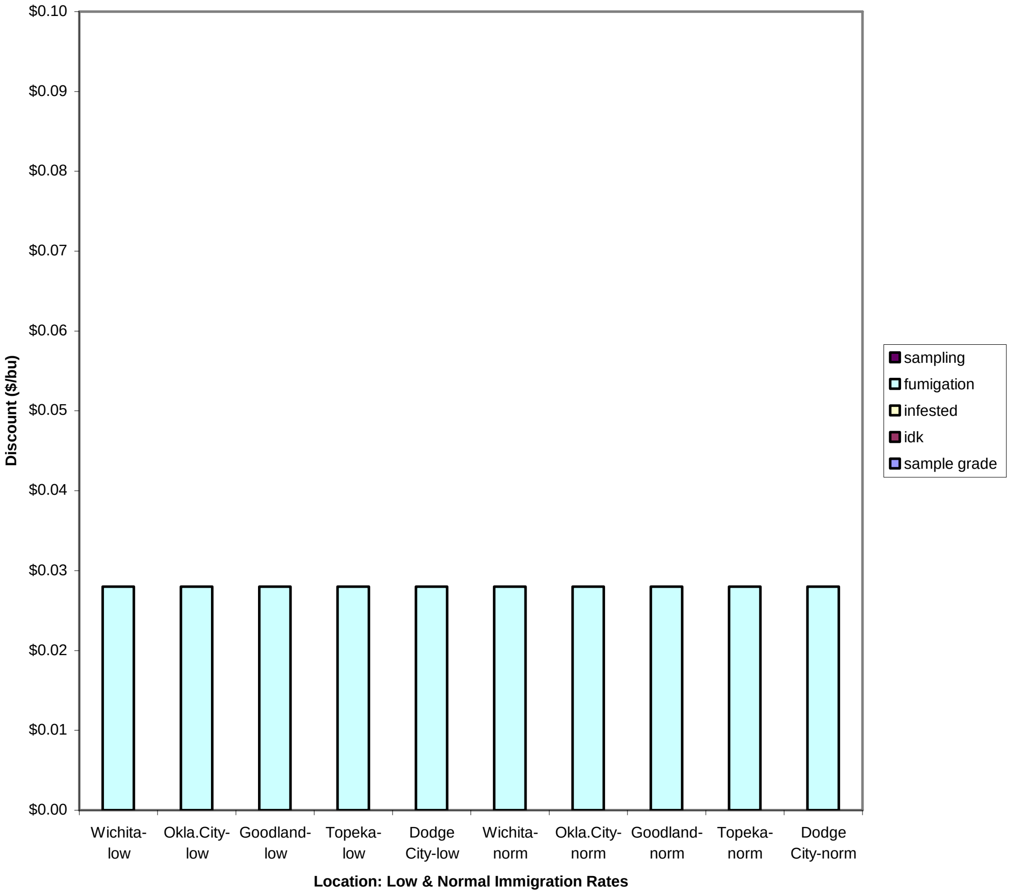

Figure 9. Cost of Calendar-Based Fumigation December 31 in 5 Locations, Low and Normal Immigration Rates

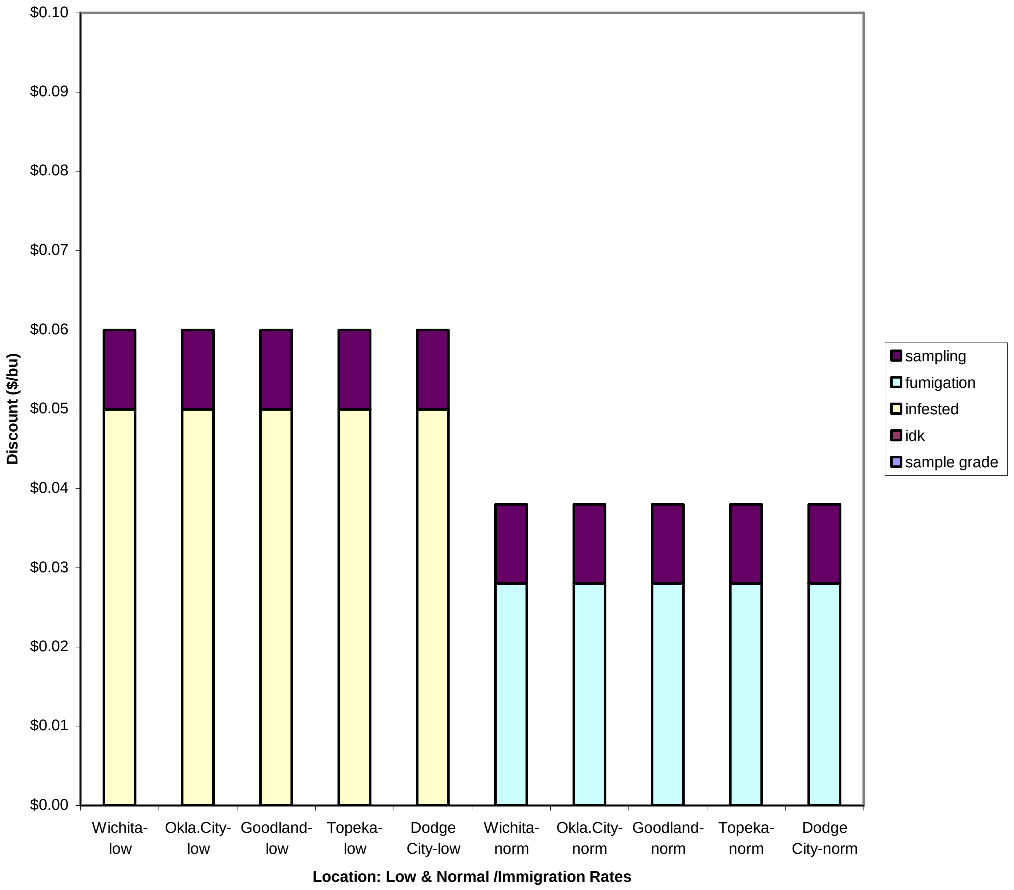

Figure 10. Cost of Sampling-Based Fumigation December 31 in 5 Locations, Low and Normal Immigration Rates, Storing until April 19

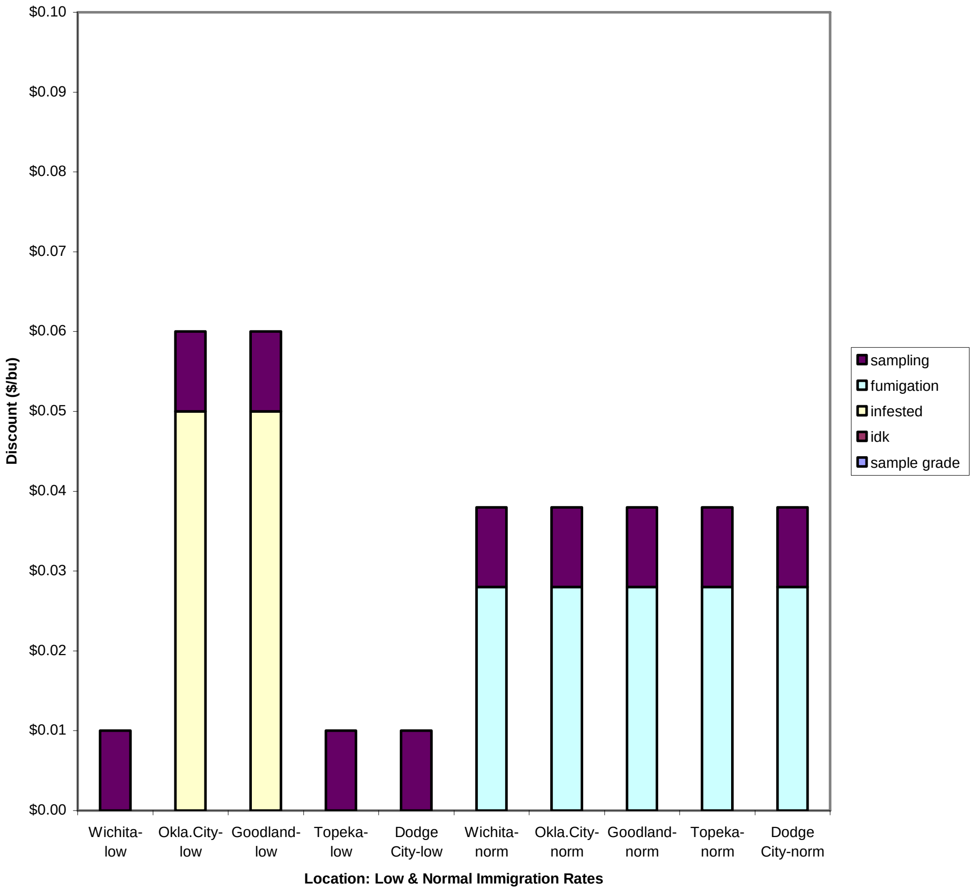

Figure 11. Cost of Sampling-Based Fumigation December 31 in 5 Locations, Low and Normal Immigration Rates, Storing until February 28

Table 2. Treatment and Insect Costs in Five Locations: Normal Immigration Rate

	Wichita	OKC	Goodland	Topeka	Dodge City	Avg.
Scenario 1: No treatment, Storing Until April 19						
sample grade	0	0	0	0	0	
idk	0.072	0.129	0.127	0.064	0.095	
infested	0.05	0.05	0.05	0.05	0.05	
Total Cost ($/bu)	**0.122**	**0.179**	**0.177**	**0.114**	**0.145**	**0.147**
Scenario 2: No treatment, Storing Until Feb 28						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0.05	0.05	0.05	0.05	0.05	
Total Cost ($/bu)	**0.050**	**0.050**	**0.050**	**0.050**	**0.050**	**0.050**
Scenario 3: Calendar-Based Fumigation Dec 31, Storing Until April 19						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0	0	0	0	0	
fumigation	0.028	0.028	0.028	0.028	0.028	
Total Cost ($/bu)	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**
Scenario 4: Sampling-Based Fumigation, Storing Until April 19						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0	0	0	0	0	
fumigation	0.028	0.028	0.028	0.028	0.028	
sampling	0.01	0.01	0.01	0.01	0.01	
Total Cost ($/bu)	**0.038**	**0.038**	**0.038**	**0.038**	**0.038**	**0.038**
Scenario 5: Sampling-Based Fumigation, Storing Until Feb 28						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0	0	0	0	0	
fumigation	0.028	0.028	0.028	0.028	0.028	
sampling	0.01	0.01	0.01	0.01	0.01	
Total Cost ($/bu)	**0.038**	**0.038**	**0.038**	**0.038**	**0.038**	**0.038**

Table 3. Treatment and Insect Costs in Five Locations: Low Immigration Rate

	Wichita	OKC	Goodland	Topeka	Dodge City	Avg.
Scenario 1: No treatment, Storing Until April 19						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0.05	0.05	0.05	0.05	0.05	
Total Cost ($/bu)	**0.050**	**0.050**	**0.050**	**0.050**	**0.050**	**0.050**
Scenario 2: No treatment, Storing Until Feb 28						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0	0.05	0.05	0	0	
Total Cost ($/bu)	**0.000**	**0.050**	**0.050**	**0.000**	**0.000**	**0.020**
Scenario 3: Calendar-Based Fumigation Dec 31, Storing Until April 19						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0	0	0	0	0	
fumigation	0.028	0.028	0.028	0.028	0.028	
Total Cost ($/bu)	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**
Scenario 4: Sampling-Based Fumigation, Storing Until April 19						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0.05	0.05	0.05	0.05	0.05	
fumigation	0	0	0	0	0	
sampling	0.01	0.01	0.01	0.01	0.01	
Total Cost ($/bu)	**0.060**	**0.060**	**0.060**	**0.060**	**0.060**	**0.060**
Scenario 5: Sampling-Based Fumigation, Storing Until Feb 28						
sample grade	0	0	0	0	0	
idk	0	0	0	0	0	
infested	0	0.05	0.05	0	0	
fumigation	0	0	0	0	0	
sampling	0.01	0.01	0.01	0.01	0.01	
Total Cost ($/bu)	**0.010**	**0.060**	**0.060**	**0.010**	**0.010**	**0.030**