UNIVERSITY OF FLORIDA
IFAS EXTENSION

CIR873

Pest Management Strategies for Storing Grains in Florida [1]

Michael Talbot and Phil Koehler[2]

The principle sources of loss in quality and quantity in grains during storage are fungi, insects, rodents, mites, respiration, and moisture migration. Although storage problems are common during bad harvest years, many also result from poor dry grain management practices. Employment of preharvest preventive management practices including bin sanitation, insect control, and aeration along with adequate observation will minimize dry grain storage problems. This paper will discuss procedures to ensure proper grain bin sanitation and pest control in order to reduce grain wastage and profit loss.

Insects

Stored grain of almost any kind is subject to attack by insects. The insects which attack stored grain are highly specialized to exploit the stores man has set aside for himself. Stored products insects are, in most cases, insects of small size with a high reproductive potential. Therefore, they are easily concealed in grain and grain shipments and have been carried to all parts of the world. Once established in a commodity they are usually difficult to control.

In general, stored products pests thrive in warm, humid environments. Grain with high moisture stored in warm conditions is usually most susceptible to insect infestations. Stored grain pests are important since they contaminate food, lower its nutritive value, and create conditions favorable for mold growth.

Pests which attack whole grain usually develop and feed inside the kernels of grain. They can be easily overlooked in grain shipments since they cannot be seen. These pests are not usually capable of existence as immature insects outside the grain. Examples of whole grain pests are the rice weevil, the granary weevil, the lesser grain borer, and the angoumois grain moth.

Other insects which attack grain are usually unable to penetrate whole grain. These insect pests however can attack grain after it has been either mechanically broken or attacked by whole grain insects. Examples of these secondary pests are the red and confused flour beetles, Indian meal moth, Mediterranean flour moth, and the sawtoothed grain beetle.

1. This document is CIR873, one of a series of the Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. Original publication date June, 1991. Reviewed July, 2002. Visit the EDIS Web Site at http://edis.ifas.ufl.edu.
2. Michael Talbot, assistant professor, Department of Agricultural and Biological Engineering, and Phil Koehler, professor, extension entomologist, Department of Entomology and Nematology, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.

Grain may become infested in a number of ways. One of the most common means of infestation starts in the field. In Florida, it is not uncommon for freshly harvested corn to have 10% of kernels infested with insects. Another common means of infestation is storing grain in or near infested storage facilities.

It is important to know the stored grain pests and inspect according to the length of time it takes an insect to complete a life cycle. Table 1 lists some stored grain insects and some biological data while Figure 1 illustrates several insects.

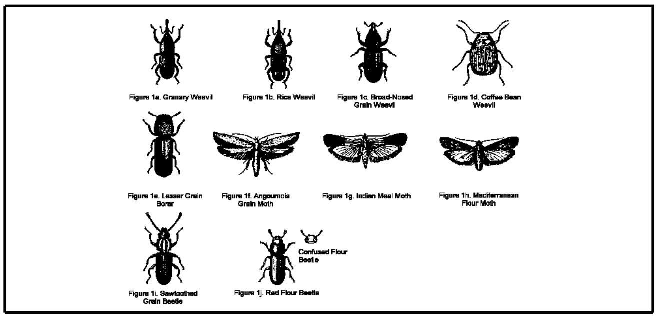

Figure 1 .

Molds (Pathogens)

Storage rots or moldy grain may develop in grain storage bins if the moisture content of the kernels is excessive and the air temperature is high enough to permit fungus growth. More than 150 different species of fungi have been reported on cereal grains. The major storage fungi are species of the common molds, *Aspergillus* and *Penicillium* . Some species of fungi such as *Alternaria* sp. and *Fusarium* sp. can cause infection in the field and can cause advanced decay in high moisture grains. Some of the fungi that grow in grains and other seeds before harvest or in storage produce toxins. One of the common storage fungi, *Aspergillus flavus* , produces several toxins called aflatoxins which cause problems when fed to animals.

Storage fungi cause loss of germination, dark germs (in wheat, designated germ damage or sick wheat), bin burning, mustiness, and heating. These are the final results of invasion of grain by storage fungi. Storage fungi are the cause, not the result, of spoilage.

Depending on the commodity, contamination by toxin is either a field problem, a storage problem, or a combination of the two. Since toxins are produced by fungi, they should be viewed as a potential danger anywhere fungi grow on materials which are used as food or feed. Fungal contamination is necessary for production of toxins, but toxicity is certainly not the inevitable result of all fungal invasion. Fungi are almost universally present on and in cereal grains, nuts and nearly all other plant materials, but toxicity seeing to be the exception rather than the rule.

Identification

It is sometimes difficult to identify the specific species of fungi which are causing a particular problem in a given lot of grain. A laboratory equipped with a compound microscope and culture facilities is necessary to confirm the identity of a fungus species. Many times, however, the significance of a fungus in a given bulk of grain can be judged by observing the color and shape of the mold growth, and by having a knowledge of the immediate history of the grain and future plans for the grain. A fungus that is common on grain in the field, for example, would be commonly found in freshly harvested grain. If corn or wheat seeds are covered with a black mold (likely *Alternaria* or *Cladisporium)* , they may be of low germination and would not be desirable for seed. Corn with extensive white mold growth is likely to be infected with *Diplodia* . If the grain is obviously infected with a white, pink, orange, or red fungus, a *Fusarium* sp. is most likely present. Some species of *Fusarium* are toxic and can cause problems when infected grain is fed to livestock. If a large amount of this mold is present and/or if feeding or reproductive problems in animals are associated with the feeding of a given bulk of grain, it should be tested for the presence of *Fusarium* toxins.

If grain is in storage and has been for some time, the appearance of a greenish fungi on the germ of the grain could mean that the grain is on the verge of severe deterioration. These fungi would most likely be species of *Aspergillus* or *Penicillium* .

Potential Damage

Germination Reduction

Under conditions that permit fungi to grow, the germs of seeds may be invaded almost exclusively by fungi. If the moisture content of the seeds is at or slightly above the lower limit that permits their growth, the germs can be invaded to the point of almost total decay. Frequently, no outward evidence of molding, even with microscopic examination and little or no invasion of the endosperm immediately adjacent to the germ, is observed. The first effect of this invasion is the weakening of the germ, followed by death. Some strains of *Aspergillus restrictus* , *A. candidus* , and *A. flavus* can cause severe damage and kill the germs quickly. Usually, weakening and death of the embryo by storage fungi precede the development of any discoloration. By the time discoloration is evident, the germs are dead.

Discoloration

Both field and storage fungi may cause the discoloration of whole seeds or portions of them, including the germs. It is not uncommon to find seeds with germs ranging from tan to black. Sometimes the fungi that cause this discoloration will be sporulating in the area between the germ and the pericarp. When the growth of the fungus is obvious to the naked eye, it will be graded as damaged kernel. This condition in corn is known as "flue-eye." Any discoloration due to molds will be graded as damaged according to the official U.S. standards for grain. It is not uncommon to find grain in hot spots that is brown or totally black due to the invasion of these micro-organisms.

Heating

Microbiological heating is common in many kinds of organic materials such as grain, feed, hay, sugar beet pulp, wood chips, baled cotton and wool, and manure piles. Storage fungi begin to grow because some of the grain is moist enough when stored or becomes moist through moisture transfer resulting from temperature differences within the grain mass. Usually, there is a succession of fungi as the moisture content and temperature increases. The fungi involved, *A. glaucus* , *A. candidus* , and *A. flavus* , can raise the temperature up to about 131°F and hold it there for weeks. The metabolic water produced by these fungi is sometimes dissipated by the heat of the hot spots and the moisture can accumulate in grain around the original hot spot. This is the factor that determines whether the heating will gradually subside or pass into the next stage, where a variety of thermophilic (heat-loving) fungi take over. These fungi may carry the temperatures up to 140 to 149°F and may be followed by thermophilic bacteria which can increase the temperature up to 167°F, the maximum temperature that can be obtained by micro-biological heating. Under certain conditions, purely chemical processes take over and carry the heating up to the point of spontaneous combustion.

It is not uncommon for grain to reach 122 to 131°F in a hot spot. It will be caked and black and appear to have been burned, even though it has not been exposed to temperatures required for ignition. This bin burning is common in soybeans and corn and may take two to three months to occur. Many times, heating will begin in the fines which accumulated in the spout line while grain was loaded into the bin. Some fines and accompanying weed seeds have a high moisture content and would, therefore, furnish enough moisture to start the growth of storage fungi in the heating process.

Mustiness, Caking, and Decay

Mustiness, caking, and decay are advanced stages of spoilage by fungi and are detectable by the unaided eye and also the nose. However, considerable fungal growth occurs in grain before it becomes apparent to the naked eye. Mustiness may develop where grain is still relatively sound, but usually some mold is visible on the kernels. The clumping or caking of kernels results from the mycelial growth that occurs in damp grain. The amount of caking will range from a slight adhesion observable when unloading a bin of grain to solid masses that do not break apart during handling. Bins with uneven internal temperatures can cause moisture migration and accumulation in the top. This may cause heavy mold growth and a crust to form over the grain mass. The crusted laver is usually only a few inches thick and may consist of rotted kernels and fungus tissue occupying all of the spaces between the kernels. Grain in this condition may be 30 to 35 percent moisture, while the grain immediately below can be 13.5 percent moisture. Caked and decayed grain, whether in a surface crust or in an entire bin of grain, represents the final stages of mold growth.

Mustiness, caking, and discoloration of kernels can cause severe losses. A small hot spot will do no more than plug up the unloading augers, causing time delays. At other times, caking and severe discoloration can reduce the grain value in a particular bin to the point of salvage value.

Rodents

For effective rodent management in and around grain storage facilities, the rodent must be identified so that effective measures can be instituted for control.

The majority of grain-handling facilities must contend with only two species of commensal rodents, the Norway rat (*Rattus norvegicus*) and the house mouse (*Mus musculus*). Both pests can cause tremendous damage to both the stored grain and the storage facilities. They cause a great deal of damage by their feeding and contaminate even more of the stored material with their droppings, urine, and hair.

Norway Rat

The Norway rat is a large, robust animal with a blunt nose, small eyes and small ears, and weighs about 11 ounces when fully grown. They normally achieve this weight and are sexually mature three months after birth. The Norway rat is typically 8 to 10 inches long with a tail that extends another 6 to 8 inches. The tail is hairless while the body is covered with a black or dark brown fur. The underbelly is usually lighter than the back.

The Norway rat has excellent senses that account for its survival in a human environment. Their eyesight is poor and they are color-blind but they have excellent senses of taste, smell, hearing, and touch. Norway rat pathways are usually close to walls where they can use their sensitive whiskers (vibrissi) as feelers to detect objects. Their acute sense of taste and smell allows them to detect even small concentrations of toxicant in baits.

The Norway rat is omnivorous. It will consume almost any food material including meats, but it prefers grain. The adult consumes about 1 ounce of food a day which averages out to approximately 23 pounds of food in a year. Simple arithmetic will show that even a small rodent population can account for a substantial loss in stored grain. This doesn't even take into account what the rodent will contaminate with its fecal material, urine, and hair.

The Norway rat is quite efficient at establishing and maintaining a healthy population. Its normal life span is only nine to twelve months due to natural predation and man-directed control programs. However, the female can produce up to seven litters a year with eight to twelve offspring per litter.

When developing an effective control program for the Norway rat, take into account its natural traits and features. This rat seldom climbs even though it is quite capable of doing so. It prefers ground level and will normally build its nests in burrows or in enclosed, sheltered areas. The Norway rat consumes water daily and is a good swimmer. Pay particular attention to areas where moisture is abundant because it prefers to nest close to an available water source.

The Norway rat is a shy animal and will not normally explore new areas or objects in its environment until it gets used to their presence. For example, when bait stations are introduced into an area for these rats, immediate bait acceptance should not be expected. The rodent must first become familiar with the station before it will enter and feed on the bait. The natural range of the Norway rat is 50 to 100 feet in any direction. They will range for food and water but will logically relocate their nest closer to food and water if it is available.

House Mouse

The house mouse is a small, slender animal which weighs about 1/2 ounce when fully grown. They normally achieve this weight and are sexually mature as early as 45 days. The house mouse is typically 2.5 to 3.5 inches long with a tail that extends another 3 to 4 inches. It has a pointed snout with large ears and small eyes. The hair is usually light brown to light grey and will appear lighter on the underbelly.

As with the Norway rat, the house mouse's senses are excellent. Their eyesight is poor and the rodent is colorblind but the senses of hearing, touch, taste, and smell are as acute as those of the rat. This rodent can also detect minute traces of toxicant and also must be offered palatable baits if effective control is expected.

The house mouse almost exclusively consumes cereal grains and will eat about 1/10 of an ounce per day. It is known for its nibbling habit of eating small quantities many times during the day. A single house mouse will eat approximately 2 pounds of food in a year but will contaminate a much greater amount with fecal pellets, urine, and hair.

The normal life span of a house mouse is the same as a Norway rat, nine to twelve months. The female can have up to eight litters a year with an average litter of five to six offspring per litter. With the gestation period being so short and the animal being sexually mature at such an early age, the house mouse has an even more dynamic population curve than does the Norway rat.

The house mouse is a good climber so control methods might be necessary on levels above ground. They are generally loners whereas rats most often live in larger groups. Nests for the house mouse can often be found in stored materials. Whole generations of mice can live within a pallet of stored materials if food is available. They do not need the large quantities of water that the Norway rat does and can usually obtain needed moisture from the foods they eat.

Whereas the Norway rat is shy, the house mouse is just the opposite. They will often investigate new and different objects in their environment. Bait stations will usually be entered in a short period of time because of this curiosity.

The natural range of the house mouse is small and they seldom travel more than 10 to 20 feet from their nest. This explains why they prefer nesting in stored materials (often food stuffs).

Integrated Pest Management

Integrated Pest Management (IPM) is a relatively new approach to an old problem: how to ensure protection of stored grain and maintain quality by controlling pest populations while minimizing effects on people and the environment. IPM attempts to make the most efficient use of the strategies available to control pest populations by taking action to prevent problems, suppress damage levels, and use chemical pesticides only where needed. Rather than seeking to eradicate all pests entirely, IPM strives to prevent their development or to suppress their population numbers below levels which would be economically damaging.

"Integrated" means that a broad, interdisciplinary approach is taken using scientific principles of grain protection in order to fuse into a single system a variety of methods and tactics.

"Pest" includes insects, mites, nematodes, pathogens, weeds, and vertebrates which adversely affect grain quality.

"Management" refers to the attempt to control pest populations in a planned, systematic way by keeping their numbers or damage within acceptable levels.

Effective IPM consists of four basic principles:

1. *Exclusion* seeks to prevent pests from entering the storage in the first place, thus stopping problems before they arise.
2. *Suppression* refers to the attempt to suppress pests below the level at which they would be economically damaging.
3. *Eradication* strives to eliminate entirely certain pests whose presence, however minimal, cannot be tolerated.
4. *Plant resistance* stresses the effort to develop grains that will be resistant to certain pests.

In order to carry out these four basic principles, the following steps are often taken.

1. The identification of key pests and beneficial organisms is a necessary first step. In addition, biological, physical, and environmental factors which affect these organisms must be ascertained.

2. Preventive cultural practices are selected to minimize pest population development. These practices include use of resistant grains, bin sanitation, proper grain drying, aeration, rotation of grain, and others.

3. Pest populations must be monitored by trained "scouts" who routinely sample grain storages and fill out an observation report.

4. A prediction of loss and risks is made by setting an economic threshold. Pests are controlled only when the pest population threatens acceptable levels of quality: remedial action is taken. The level at which the pest population or its damage endangers quality is often called the economic threshold. The economic threshold is set by predicting potential loss and risks at a given population density. This estimation takes into account weather data, condition of the stored grain, markets, risk-benefit, costs, and kinds of control available.

5. Am action decision must be made. In some cases pesticide application will be necessary to reduce the grain threat, while in other cases a decision will be made to wait and rely on closer monitoring.

6. Evaluation and follow-up must occur throughout all stages in order to make corrections, assess levels of success, and project future possibilities for improvement.

To be effective, IPM must make use of the following tools:

1. *Pesticides* . Some pesticides are applied preventively, such as empty bin treatments and grain surface treatments.

In an effective IPM program pesticides are applied on a prescription basis tailored to the particular pest and chosen to have minimum impact on people and the environment. They are applied only when a pest population has been diagnosed as large enough to threaten acceptable levels of quality. Pesticides are usually chosen only after all other feasible alternatives have been considered.

1. *Resistant crop varieties* are bred and selected when available in order to reduce pest problems in the field.

2. *Natural enemies* are used to regulate the pest population whenever possible.

3. *Pheromone (sex lure) and food-based traps* are used to lure and destroy male insects, thus helping monitoring procedures. Traps have control potential and have been used to keep a population within acceptable levels.

4. *Preventative measures* such as bin sanitation, empty bin pesticide treatments, surface residual pesticide treatments, and effective monitoring help avoid severe problems.

5. *Avoidance of peak pest* populations can be brought about by complete removal of old grain prior to storage of new grain, and aeration to reduce grain temperature and prevent moisture migration.

6. *Improved application by keeping equipment up to date and in excellent shape* can be achieved through reliance on accurate pressure, timing, agitation, and following proper operational procedures.

7. *Other assorted cultural practices* such as proper grain drying and turning grain during storage can influence pest populations.

Before-Storage Procedures

Cleanup

The most frequent source of insects infesting new grain is the previous year's old grain residue remaining in harvest and handling equipment, within the bin, under the bin's drying floor, and on the ground around the bin. Insects live from season to season around farm buildings and in accumulations of grain, feed, straw, hay, and litter. Newly harvested grain should never be placed on top of old grain. It is best to remove all the old grain and feed it, then sanitize and treat the empty bin before storing the new grain. If this is not possible the old grain must be treated before the new grain is added. In this case fumigation is best since a surface treatment will not be adequate.

All grain-handling equipment including augers, combines, trucks, wagons, and other farm equipment equipment should also be thoroughly cleaned and grain residues removed before harvest. These waste accumulations can be a source of infestation. A good time to do this is during maintenance of this equipment in preparation for harvesting.

Cleaning the bin means more than just removing the grain. All grain missed by the sweep auger must be removed. Bin walls, ledges, cracks, floor, and other areas, where old grain and dust can lodge, must be swept down. Bins equipped with drying floors require floor section removal to clean residue underneath. Wooden bins should be cleaned very carefully, because grain and dust tend to collect on walls and floors and encourage infestations. The sweepings along with the spilled grain and litter outside the bin should be removed and disposed of (buried or burned) far enough from the bin site to prevent an infestation of the newly stored grain. Grain bins should be cleaned thoroughly at least two weeks before the addition of new grain.

Market grain should be stored away from the farmstead if at all possible. If stored near the farm, grain should not be stored near feed rooms, stables, or animal feeders because places where livestock feed or where pet foods are stored can be serious sources of infestations. Grain and feed accumulations that are frequently overlooked include empty feed sacks, dusts created by the feed grinders, seed litter from the haymowers, feed left in animal selffeeders, and grain-based rodenticides.

Empty bins should be thoroughly cleaned and sprayed before new grain is placed in the bin. The aeration duct and the raised perforated floor that distribute the air may be infested and are difficult to reach with normal sprays.

Make Needed Bin Repairs

After the bin is cleaned, all leaks should be repaired. Screen or seal openings to keep out rodents and birds, and eliminate places that will harbor old grain (such as corners or leaks under bin floors). The structure should be made tight to prevent water and air leaks. Air vents should be sealable to facilitate later fumigation, if necessary. The bin should be equipped with adequate aeration fans and ducts that are maintained in good working order.

Mixing Old and New Grain

New grain should never be placed into a storage bin which contains old grain unless the old grain is completely free from insect infestation and mold contamination.

Pre-Storage Bin Sprays - Bin Wall, Ceiling and Floor Treatments

Bin sanitation is not complete until the inside and outside surfaces are sprayed with a residual insecticide. Surface sprays leave a thin layer of insecticide that kills insects which remain in the bin and those that crawl across the surface trying to get inside. As soon as the bin is cleaned, it can be treated with protective insecticides. Spraying without adequate cleaning will generally not be effective. Treatments should be applied 2 to 3 weeks before new grain is placed in the bin. Grain should not be added for at least 24 hours in order for the walls to dry thoroughly. The treatment will kill insects emerging from their hiding places (seams, cracks, crevices, corners, under floors and in aeration systems). Also, insects crawling or flying in from the outside will be killed. Any dead insects should be swept out before the grain is added. Malathion or chlorpyrifos-methyl used for this purpose in metal bins will remain effective for 4 to 8 weeks at 80°F. Methoxychlor may also be used. Residual bin sprays recommendations are listed in Table 2 .

Apply the spray (2 gallons per 1,000 square feet of surface area) to as many surfaces as possible, especially joints, seams, cracks, ledges, and corners (Figure 3). Spray the ceilings, walls and floors to the point of runoff. Use a coarse spray at a pressure of over 30 pounds per square inch and aim for the cracks and crevices. Spray beneath the bin, its supports, and a 6-foot border around the outside foundation. Treat the outside surface, especially cracks and ledges near the door and fans. In addition, pertinent areas should be treated after cleaning harvesting equipment, elevators, augers, trucks, or wagons.

Insecticides, formulations, concentrations, and rates of application approved for this and other uses are subject to change. Current insecticide recommendations should be obtained from the local county extension office and labeled directions should always be followed for approved chemicals.

Loading Grain for Storage

Bulk Treatment Equipment and Procedures

After the bin or storage area has been thoroughly cleaned and treated, the grain can be further protected against insect infestation by the application of an insecticide to the grain as it is loaded into the storage area. The use of an *approved* insecticide is an effective way to control stored grain insects, *providing* the grain being stored is not already heavily infested and the moisture content is not above 13%. High moisture grain attracts insects and enhances more rapid breeding than does dry grain. Grain protectants quickly lose their effectiveness on grain that is above 13% moisture content or at temperatures above 90°F.

Gravity flow or "drip-on" application equipment is shown in Figure 4 , Figure 5 , and Figure 6 . Pressure-type sprayers are illustrated in Figure 7 and Figure 8 , while power sprayers are shown in Figure 9 and Figure 10 . A special dust applicator used for small lots of grain is depicted in Figure 11 .

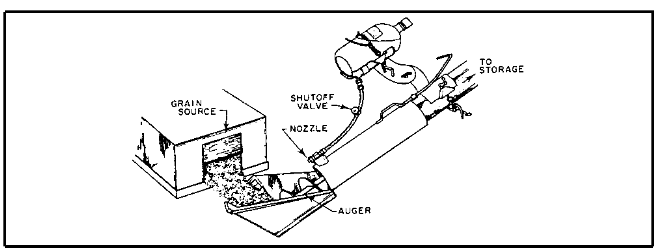

Figure 4 .

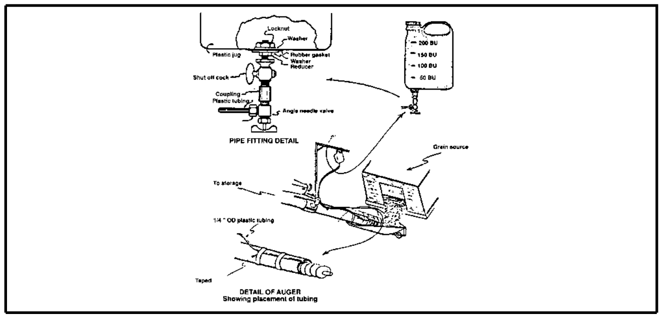

Figure 5 .

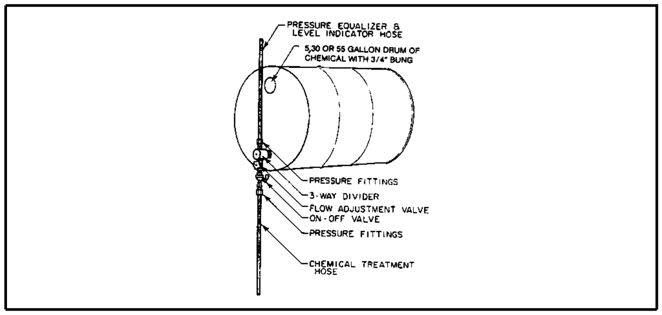

Figure 6 .

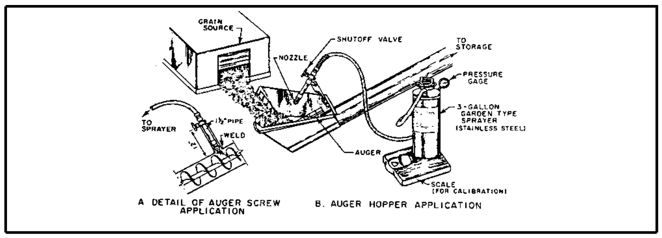

Figure 7 .

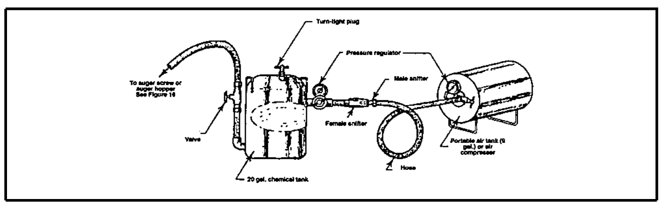

Figure 8 .

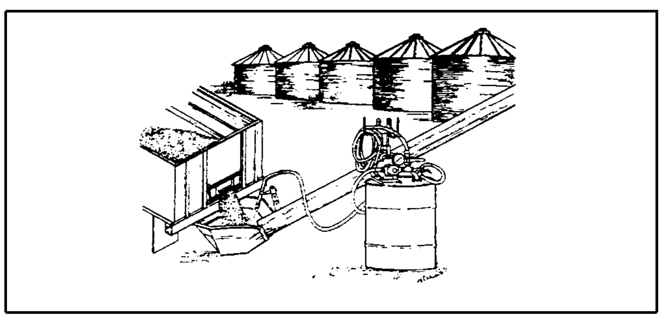

Figure 9 .

Point of Application

Protectants should be applied evenly to the grain as close to the point of final storage as practical.

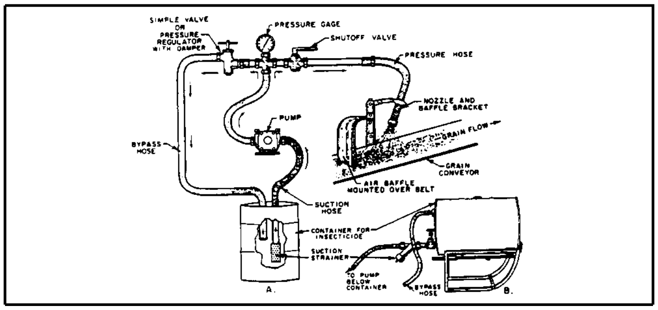

Figure 10 .

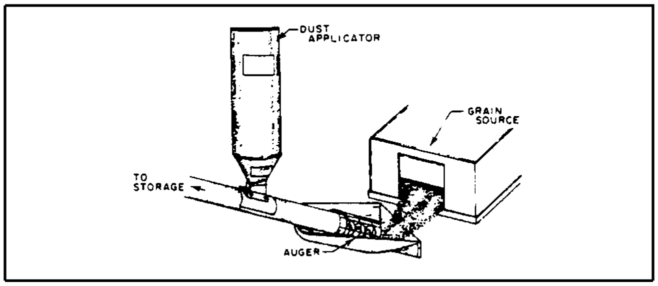

Figure 11 .

Protectants can be applied into an auger (Figure 7A) or into the grain stream as it falls into the hopper of the elevating equipment (Figure 7B and Figure 9). Protectant also may be applied as grain falls into the bin. Grain which is treated and then transferred long distances through numerous grain handling systems (such as pneumatic systems, belt augers, conveyors, or spouts and legs) before storage will have less insecticide residue when the grain is finally dropped into the bin. However, insecticide left in the handling system will help reduce insects in these areas.

Application Pressure

If other than a gravity-flow system is used, the spray pressure should be as low as possible; 10 to 20 p.s.i. (pounds per square inch) is preferred. With low spray pressures, larger spray droplets are produced. The larger droplets fall onto the grain and are less likely to drift into the air.

Moisture and Temperature of the Grain

Most failures with residual sprays occur because of excessive grain moisture and/or temperatures. For effectiveness for more than 2 weeks, grain should not be treated if it is above 13% moisture and the temperature is above 90°F. If warm grain is treated, it should be cooled with an aeration system as soon as it is practical. The operation of an aeration system will not remove the protectant from the grain. Treatment of grain at 14 to 16% moisture will be effective for short periods depending on the temperature.

Factors That Influence Effectiveness of Grain Protectants

The point of application, application pressure, and moisture and temperature of the grain influence the effectiveness of grain protectants as discussed above. Other factors include proper mixing and a fresh spray mixture.

Proper Mixing

Even application is important, and one disadvantage in using the emulsifiable formulations is that most of them must be agitated about once every half hour after mixing with water to avoid settling. The gravity flow or "drip on" applications (Figure 4 , Figure 5 , and Figure 6), the garden-type sprayers (Figure 7), and the pressurized spray tank (Figure 8) must be shaken to insure that the formulation is applied evenly. The power sprayers (Figure 9 and Figure 10) do not have to be shaken as the formulation agitates continuously.

Fresh Formulations

Only enough insecticide for one day's use should be mixed with cool water and the left over mixture should not be carried over for the next day's treatment. Concentrate, mixed spray, and dust should be kept cool and should not be stored in direct sunlight. Only fresh dust formulations should be used and carryover from one year to the next should be avoided. If the dust must be kept over, it should be refrigerated (away from food).

Equipment Required - Emulsifiable Concentrate

Any low-pressure sprayer that can be calibrated to deliver a known volume of liquid is suitable for applying liquid protectants. This includes compression sprayers (Figure 7 and Figure 8) and electric- and gasoline-engine-driven power sprayers (Figure 9 and Figure 10). The garden-type compression sprayer and the gravity feed "drip on" system are used to treat small lots of grain.

Power sprayers and metering-type sprayers are generally used to treat large lots of grain. In some areas, insurance terms require totally enclosed fancooled motors in grain elevators.

The correct size of orifice in the sprayer nozzle is important because orifice size and pressure are used to regulate the rate of insecticide flow. Most manufacturers of spray nozzles have charts that give the capacity in gallons per minute and the spray angle for each size of orifice.

A simple gravity or "drip on" applicator that does not use any moving parts may be purchased (Figure 4) or constructed (Figure 5). An applicator may be built by fitting two brass valves and polyethylene tubing in sequence to an opening in the bottom of a plastic container. These fittings are obtainable at plumbing supply shops. The upper shutoff cock on the jug (see "Pipe Fitting Detail," Figure 5) serves as the on-off valve while the lower needle valve regulates the amount of insecticide flowing through the plastic tubing. The needle valve is first calibrated to the desired flow for the rate-of-grain delivery into storage. It then can be kept at the same setting without the need for fine adjusting each time flow is turned on. The gravity feed applicator is used as grain is unloaded from a truck or auger into the hopper of a portable auger. The tubing is taped horizontally along the auger tube at the pick-up end, with the end of the tubing extending one-fourth inch beyond the end of the auger

tube so the insecticide flows directly into the grain. The plastic container can be suspended from the top of the grain bin or auger and must be agitated by hand at periodic intervals. The following supplies are needed to build the gravity feed 'drip on' applicator:

- 1 plastic container 128 to 384 oz.
- 1 lock nut 1/4" 18 pipe thread (PT)
- 2 washers 1/2"
- 1 rubber gasket 1/4"
- 1 pipe reducer 1/4" 18 PT x 1/8" 27 PT
- 1 shut-off cock 1/8" 27 PT x 1/8" 27 PT
- 1 pipe coupling 1/8" 27 PT x 1/8" 27 PT
- 1 angle needle valve 1/8" 27 PT x 1/4" in OD
- Polyethylene tubing 8'x 1/4" outside diameter

Recommended Treatment for Grain During Loading

Table 3 contains the recommended chemical treatment for grain during loading.

Proper Filling Procedures

The grain bin should not be overfilled (Figure 12 and Figure 13). Space (headroom) must be left on top of the grain for examination and sampling. After the bin is filled, the grain's surface should be leveled (Figure 14).

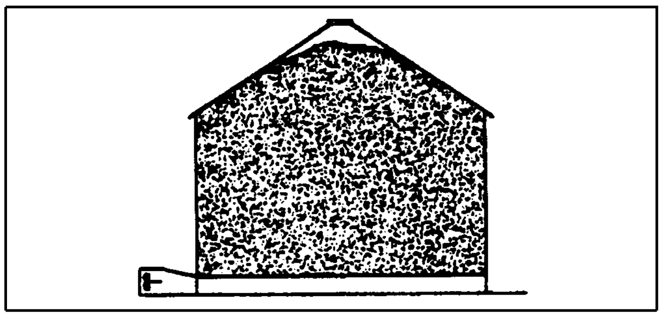

Figure 12 .

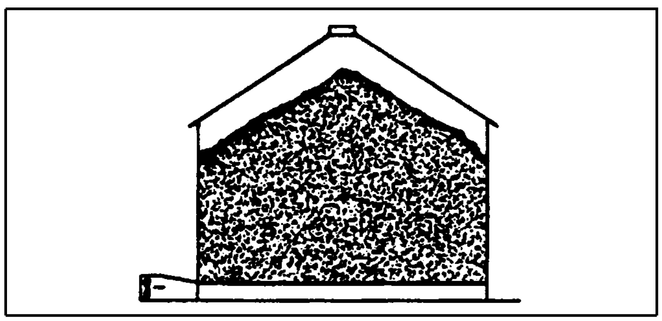

Figure 13 .

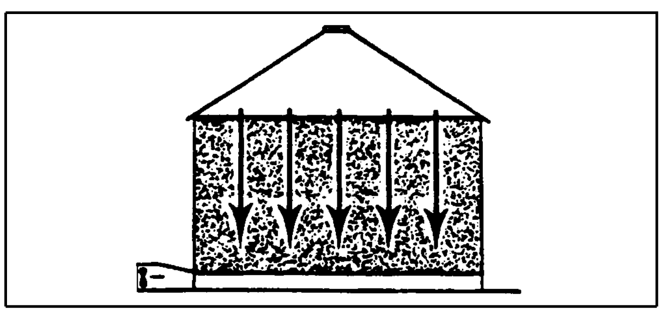

Figure 14 .

Application of insecticidal treatment, aeration, and fumigation cannot be effective on uneven grain surfaces (Figure 14). Moisture condensation and subsequent mold

and insect problems are more likely to develop in mounded grain. As with any other type of work, much can be learned by studying the mistakes that have caused other treatments to fail. In Figure 13 , the farmer has filled the grain bin to the top. It is impossible now to get inside and level the grain for proper treatment. Even if treatments are tried, application will be uneven and probably ineffective. Storing grain this high is not recommended by the manufacturer of the building and is strongly discouraged by fumigators. The best solution to this problem is to pull the grain down to the level of the sides (Figure 15). This will probably level the grain considerably but additional leveling will be worth the effort (Figure 15).

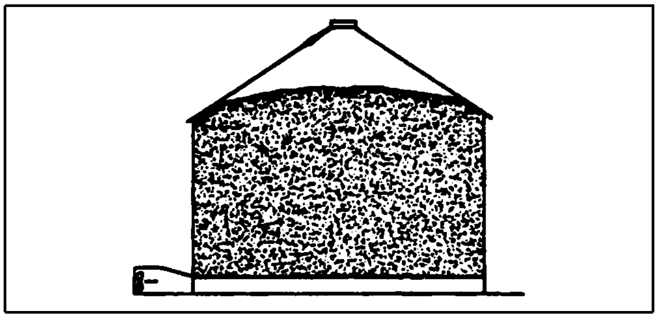

Figure 15 .

In-Storage Management

Surface Treatments

Surface treatments are applied (Table 4) to prevent insects such as moths from entering the grain from the outside. This should be done as soon as the bins are filled and the surface leveled. Treatments can be repeated if necessary. The surface treatment is not effective against an infestation several inches below the surface. Fumigation must be used when there is an existing infestation.

A surface treatment may also be applied when the grain is going to be stored through a warm season or after a general fumigation to help prevent insect reinfestation. The surface treatment will help control insects that enter the grain through roof openings and will kill insects found in the surface areas.

Effectiveness

Surface treatments alone generally will not keep the grain completely insect-free but they will aid in keeping insect populations lower during the storage period. Surface treatments are effective if the following limitations are understood:

1. Surface treatments will not control insects already in the storage bin; thus, the grain must not be infested prior to surface treatment.

2. The storage structure must be insect-tight below the treated 2 inches of grain.

3. The surface treatment should not be disturbed since it provides the protective barrier against insect infestations.

It should be noted that the malathion surface treatment will probably not control or prevent an infestation of the Indian Meal Moth or the Almond Moth because of resistance. Malathion-resistant beetles are also becoming a problem.

The same equipment used for the application of the wall sprays can be used to apply the surface spray. The surface treatment should be applied no more than three times during a storage year. Three applications during the year should only be made if the grain surface has been disturbed, or if temperatures are high and the risk of infestation is great.

Indian Meal Moth Control

Indian Meal Moths infest areas of grain and grain residues that are exposed to exterior areas of the grain mass such as the grain surface (Figure 16), aeration ducts, and materials beneath false floors. The worst infestations are found on the grain surface, but anywhere the moth larvae are found, they will leave a mass of webbing which constricts air flow and makes fumigation or surface treatments less effective. Damage by this insect to farm-stored grain is relatively low compared to the beetles or weevils. It is considered more of a pest rather than a serious economic insect except when they infest seed grains.

Bacillus thuringiensis (BT), a bacterium that controls moth larvae, has been approved for use in

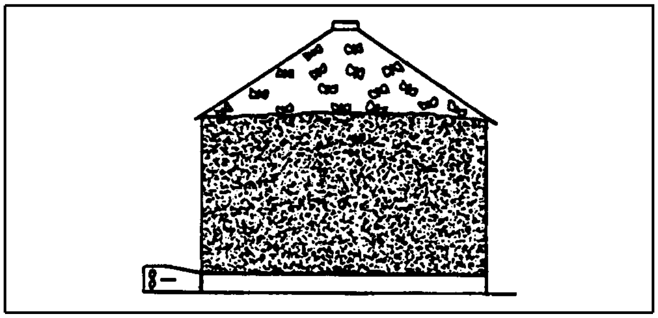

Figure 16 .

stored grains and soybeans. This material (see commercial label for dilution and application rate) is mixed with the surface 4 inches of grain (Figure 17) either by adding to the last grain as it is augered into the bin or by applying it to the grain surface after the grain has been loaded and leveled. This treatment will not control weevils or other beetles that infest grain. The *B. thuringiensis* formulation is exempt from tolerance restrictions.

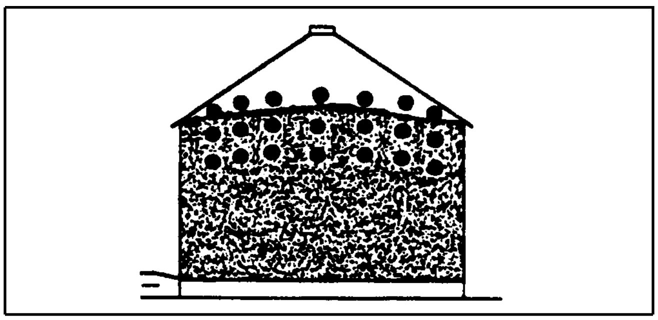

Figure 17 .

Monitoring

It is important to identify the insects that are in the grain or know which ones are likely to be in the grain so that scientific control can be based on the biology, behavior and habits of the insects.

For example, the Indian Meal Moth has been determined as the primary problem. This insect lives in the upper few inches of grain and the adult moths will often rest in the head space on the walls.

Grain treated with protectants should be inspected at monthly intervals to guard against the possibility of infestation. These inspections should not be limited to the surface of the grain, but should extend down into the grain. If treated grain becomes infested, it can be fumigated.

It is very important that stored grain be inspected often to determine its condition and the extent of pest damage. Early detection of problems and their elimination can prevent losses. Temperature, moisture levels, and the biological activity in stored grain change throughout the storage period. The grain should be inspected at 2- to 4-week intervals to monitor these conditions. Samples should be taken from top to bottom, to obtain at least 1 pint of grain per 1,000 bushels. Samples should be screened for insects and dockage. Moisture content and temperature should be measured throughout the bin to pinpoint spots where condensation or insects may be concentrated. During inspections, the presence of musty or spoiled odors, caking, crusting, moisture condensation, elevated temperatures, insects, or rodents are indications of problems that must be immediately solved to prevent grain loss. Additional information on methods for obtaining samples and for determining moisture content can be found in the extension publications entitled *Grain Sampling* and *Grain Moisture Determination.*

Aeration

Grain should be aerated to help maintain quality in storage. Aeration is low-volume ventilation (about 1/4 c.f.m. per bushel) to maintain uniform temperature throughout the grain mass, and to prevent moisture migration. Reduction and equalization of the temperature is vital to the prevention of insect and mold problems. Insects and mold develop more slowly (or not at all) at low temperatures. Moisture migration and condensation (which favor insects and mold) do not occur if uniform temperature is maintained. Aeration while turning, stirring, or otherwise physically disturbing the grain can aid in controlling crusting or caking that result from insect- or moisture-induced hot spots. For more information on aeration of grains, refer to the extension publication entitled *Management of Stored Grain with Aeration* .

Fumigation

If insect infestation occurs in spite of the precautionary measures discussed above, fumigation of the grain will be required. Fumigation is the most commonly used method of controlling insects that infest stored grain. It kills insects and eggs present at the time of fumigation, but does not protect the grain from reinfestation. In Florida, grain should be fumigated as it is being loaded or turned. The grain should be inspected at least once a month. Repeat fumigations may be necessary. The spring following harvest is a likely time for an additional fumigation.

Fumigants are dangerous and should be applied only by trained, experienced operators working in pairs. The Environmental Protection Agency has initiated a "Label Improvement Program for Fumigants" to help minimize occupational exposure to fumigants. Changes on the label to better define user information, warnings, and necessary precautionary measures will directly affect how fumigants are used and who uses them. Three features of the program are of prime importance:

1. The label will direct that two "trained persons" be present during the principal fumigation operation, especially if entry into the structure under treatment is required for application of the fumigant.

2. The use of approved respirator protection devices will be required during application of the fumigant when concentrations of the fumigant exceed prescribed levels or if the concentrations are unknown.

3. Specified direct-reading detector devices would be required to monitor fumigant concentrations to prescribed levels as a condition of reentry or transfer of treated grain.

Effective fumigation is possible when good storage practices are followed. For example. condensation and eventually caking and spoilage will occur, if farmers fail to level grain peaks, as outside temperatures drop during the fall and winter months. This same peaking will prevent even distribution of fumigants, allowing insects to survive in the areas that receive an insufficient amount of fumigant.

A fumigant is a tool that may be needed to help preserve the grain quality. A fumigant should be used only when needed since it is the most hazardous type of pesticide treatment that farmers can use. In addition, fumigation is expensive and provides no long-term residual protection.

Fumigation is needed when no other pesticide or control method can reach the insect infestation. If the insects are already inside the grain mass, no spray or dust can reach them.

In some parts of the country, field infestations can be heavy with considerable internal feeding by the time the grain is harvested and brought in for storage. In these cases, especially if the infesting insects develop within kernels, the grain should be fumigated at the time of storage. Later, if the infestation is discovered throughout the grain mass, control could be difficult. Only a properly applied fumigant gas will circulate to all points in the grain mass, allowing the control of the pests.

Insect infestations can also occur in "pockets" deep within the grain mass. Special fumigation techniques are available to provide control in this situation whereas insecticide sprays would not be effective.

Fumigation is not always practical. If grain is stored in the open, it would have to be covered with special gas-retaining tarps. This would also be true of most open slat cribs or even wooden buildings. This procedure is very expensive and time-consuming. While it is possible to find dosage recommendations for wooden buildings, the increased amount of fumigant required and the poor control often achieved makes this practice cost-prohibitive. Poor control often results in reinfestation just as large and damaging soon thereafter.

Grain fumigants are among the most important and useful agricultural chemicals available to the owner of stored grain. Fumigants act on all insect life stages. They control pests by diffusing through the space between grain kernels as well as through the kernel itself. Thus, fumigants are able to penetrate into places that are inaccessible to insecticide sprays or dusts.

Fumigants exert their effect on grain pests only during the time in which the gas is present in the insects' environment . After the fumigant diffuses out of the grain, no residual protection is left behind and the grain is again susceptible to reinfestation. The objective of fumigation, therefore, is to introduce a killing concentration of gas into all parts of the grain mass and to maintain that concentration long enough to kill all stages of insects present.

Fumigants may be applied directly into the fumigated space as gases from pressurized cylinders. Some gases appear as liquids under pressure but expand to a gaseous form when released. Fumigants can also be generated from solids that react with moisture and heat from the air to release the fumigant.

Regardless of formulation, all fumigants are poisons that are toxic to humans and other warm-blooded animals as well as to insects and other pests. Because fumigant chemicals are highly toxic and hazardous to use, they are classified as restricted-use pesticides. They should only be used by persons that have been trained to use them. Although special training and certification are required before these fumigants can be purchased, this training is seldom adequate to qualify the person to conduct a fumigation.

It is often safer, less expensive, and more effective for farmers to have their stored grain fumigated by a professionally licensed and certified fumigator. The most important factor to consider when deciding whether to hire a professional to do a fumigation is the personal risk involved in the handling and application of these highly toxic chemicals. A professional fumigator will have the knowledge and experience required to conduct effective treatment and will also have the special equipment needed to apply fumigants properly. In addition, professionals will have safety equipment such as gas masks or other respiratory protection which are expensive but necessary when applying any fumigant. However, professional fumigators are not always available to service farm-stored grains and many farmers still prefer to handle this phase of pest management themselves. Therefore, the following discussion is designed to help the farmer or new commercial fumigator with information needed to better understand the properties of grain fumigants, the factors that influence their effectiveness, and the methods used to apply and distribute them into bulk stored grain.

Preparing Bins

Attention to proper sealing of grain bins prior to fumigation will often make the difference between success or failure of the treatment. Many instances of poor control, charged against the fumigant, are due to bins that are not tight. A high degree of gastightness is essential to achieve the required combination of gas concentration and time of exposure necessary to kill grain pests.

Metal storage bins are not gastight since they were originally designed to hold and aerate grain. They can be used for fumigating if properly sealed. It is important to recognize that the bins will vary in tightness because of how well they are built. If the corrugated sections were caulked when put together and then bolted tight, they will be more effective when sealed. Loosely constructed wooden bins may have to be covered totally with a gastight tarpaulin to retain enough fumigant to be effective.

The goal of fumigating is to try to confine a gas for a sufficient length of time at a proper concentration to be lethal to the target pests. Sealing is extremely important and demands study and work but there are professional techniques that can make the job more effective (Figure 18).

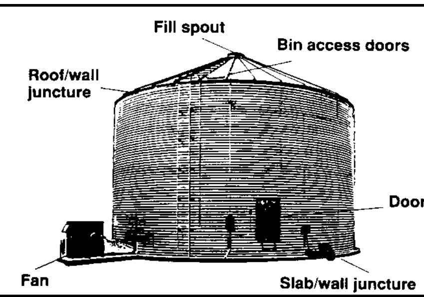

Figure 18 .

There are a number of places in a bin where gas can escape. The roof-wall juncture looks tight from the outside, but examination from the inside will show a gap around the perimeter in many bins. This gap is difficult to seal because it is usually dusty and may be damp. Cracks wider than 1 inch are even harder to seal. It is necessary to clean the dust from the surface before it can be taped or sealed with any other material.

Professionals will first clean the surface and then spray it with an adhesive dispensed from a pressurized can. The gap is then sealed with duct or furnace cloth tape since this is more effective here than masking tape. At least 2-inch and preferably 3-inch tape should be used when sealing these cracks.

Polyurethane foams can be used to seal this gap but they are expensive and difficult to remove if the gap is needed for extra grain aeration. Insects can burrow into the foams and destroy their effectiveness but they can provide a good seal for several years.

Another key area to seal is the gap between the bottom of the wall and the floor. Some manufacturers design the wall base to accept a special sealant that can give a long-term seal. Various sealing materials have been used including one made with polyurethane impregnated with asphalt. Plain asphalt has also been used but does not have as much elasticity.

The use of foam-in-place plastics applied after the bins were built seems to give a good seal initially, but still would be subject to problems discussed previously.

Roof ventilators can be covered with plastic bags. The bags are less likely to tear against sharp edges if a burlap bag is placed over the ventilator first. The plastic bag should be gathered in at the base and then taped in place. Extreme care should be exercised in this work to avoid falling.

Bin doors are not gastight when merely closed. They can be cleaned and sealed with masking tape, or if not used regularly, they can be sealed with foam-in-place plastic.

Aeration fans and their housing must be sealed to avoid gas loss. Normally, polyethylene glued to the air intake will be sufficient. However, the unit should be examined for other potential leaks.

Professional fumigators long ago found that it was difficult to get tape or plastic to stick to the dusty surfaces of grain bins. Cleaning is necessary and helpful but more was required. An expensive but useful tool is the pressurized can of tape primer. This can be obtained from the fumigant distributor or sometimes from an auto paint store. These materials give the surface a tacky texture and help hold the tape on much better. They can be applied to the adhesive surface of a piece of tape to improve its sticking power. Although taping of a damp surface is not recommended, it can sometimes be done with this material.

Another useful material is called Bondmaster. It is painted onto a surface and then the plastic tarp is pressed into the tacky area. This will normally hold the plastic on even in a high wind.

Bondmaster can be removed from the hands with mineral spirits since the application is a messy job that will usually leave some on the hands and maybe on the clothing. It can leave a stain on the building but the improved seal is probably worth the effort and mess.

Another alternative to taping the eaves is to cover the entire roof with a plastic sheet formed into a bonnet or cap which drapes over the top of the bin and extends down past the roof joint. An adhesive sprayed or painted in a horizontal band around the outside bin wall will provide a point of attachment for the plastic sheet. The bonnet can then be secured by rope using the corrugation grooves on the bin to reduce slippage. Obviously, this sealing method can only be partially completed before application of the fumigant in order to provide access to the grain surface.

The grain surface must be leveled and any crusted areas that have formed must be broken up. When grain is peaked, the action of fumigants is similar to rain on a hillside. The heavier-than-air gases simply slide around the peak, resulting in poor penetration and survival of pests in the peaked portion of the grain. Moldy or crusted areas near the grain surface are generally caused by moisture condensation when warmer air in the grain rises to the surface and encounters cold air above the grain. These areas are sometimes hidden from view just below the grain surface. Failure to locate and break up these areas will result in uneven penetration of grain fumigants and may lead to further deterioration of the grain from mold development and invasion of the grain by insects that feed on grain molds.

Methyl Bromide

Methyl Bromide is an economical fumigant available for control of stored grain insects. Methyl Bromide fumes are highly toxic to humans and animals. Methyl Bromide can affect the germination of grain and grass seeds, particularly at high moisture levels or high dosages. It should not be used to fumigate seed corn. Methyl Bromide will not corrode most metals. However, it can react with aluminum or magnesium in the absence of oxygen to form an explosive mixture. Therefore, aluminum or magnesium tubing should never be connected to a methyl bromide cylinder.

Instructions: For best results, Methyl Bromide should be recirculated through the grain in a closed aeration system (Table 5). Ventilating or aerating systems can be turned into recirculation systems by returning the air from the storage area to the blower. Usually savings of 50% on fumigant costs can be realized by the recirculation method.

Methyl Bromide gas is inserted into the air circulation system with little trouble. After 24 hours, Methyl Bromide can be removed from the storage area rapidly.

To apply Methyl Bromide without a recirculation system, a pan or other receptacle should be placed on the surface of the grain at the center of the bin (Table 6). Tubing from the receptacle should be stretched to the outside of the bin. An open crate or other frame should be placed over the receptacle and a plastic cover should be spread over the frame and grain surface. The door should be sealed and preparation to release Methyl Bromide should be made. A special applicator, Star Model 1.5 opener, should be used by following instructions.

Aluminum Phosphide

In recent years Aluminum Phosphide (Celphos, Delicia, or Phostoxin) has been found to be an effective fumigant for stored grain insects. The main advantage of Aluminum Phosphide is the ease of application.

- Instructions: Aluminum Phosphide is available as tablets, and the fumigant is released due to moisture in the air. Tablets should be kept away from liquid water. The container should always be opened in open air.

For treatment of grain pests in rice, wheat, barley, corn, oats, sorghum, millet and rye, the Aluminum Phosphide may be injected into grain with a probe or fed into the grain stream as it is flowing into the bin. Grain temperature must be 40°F for fumigation. Effective dosages are 6 tablets per ton of grain or 180 tablets per 1000 bushels. The exposure time required is 5 days (54 - 59°F), 4 days (60 - 68°F), or 3 days (warmer than 68°F).

Effectiveness

Temperature . Temperature influences the distribution of fumigants in grain and affects their ability to kill insects. At temperatures below 60°F, volatility of a fumigant is reduced significantly, sorption of fumigant vapors into the grain is increased, and distribution is less uniform throughout the grain mass. Gases move more slowly and insects breath less at colder temperatures. Thus, it takes longer for the fumigant vapors to reach insects in the grain, less gas is actually available for controlling the pests, and since the insects are less active, less gas enters their bodies.

Grain Moisture . The moisture content of grain also influences the penetration of fumigant gases by altering the rate of sorption. Dry grain of less than 10 percent moisture will extend the time required for solid fumigant decomposition.

Grain Type and Condition . Various grains have different characteristics that can affect fumigations. The surface area of individual grain kernels is an influencing factor in the dosage required to treat various commodities. For example, sorghum, because of its smaller size and more spherical shape, has higher total surface area than wheat. Increased surface means greater sorption loss, which reduces the amount of fumigants left in the space between the grain kernels and further reduces the amount of fumigant available to penetrate throughout the grain. To compensate for this increased loss, higher dosage rates are required in sorghum than in wheat, particularly when fumigants are used that are easily absorbed by the grain.

The type and amount of dockage in grain has a pronounced effect on the sorption and distribution of fumigants. When the grain mass contains large amounts of dockage such as crust, chaff, or broken kernels, the fumigant vapors are rapidly absorbed by this material and further penetration into the grain is impaired. Unfortunately, such areas are frequently sites that attract the greatest number of insects. When isolated "pockets" of dockage occur within a grain mass such as below grain spouts, fumigant vapors may pass around such pockets and follow the path of least resistance down through the intergranular area of the grain. Similar changes in fumigant distribution patterns may occur in grain that has settled or compacted unevenly during long storage periods or in storages vibrated by nearby traffic such as a railroad.

Insects . Grain insect pests and their various developmental stages (egg, larva, pupa and adult) vary in their susceptibility and resistance to fumigants. Beetles and other insects that develop on the outside of grain kernels are usually more susceptible to fumigants than certain moth and beetle species that develop inside grain kernels. The pupae and eggs that breath very little are the hardest developmental stages to kill while the young larvae are relatively susceptible.

Heavy infestations in which large amounts of dust, damaged grain, webbing, and cast skins have accumulated are more difficult to control because of the effect these materials have on the penetration and diffusion of grain fumigants.

Storage . A fumigant, whether applied initially as a gas, liquid, or solid, eventually moves through space, penetrates the grain, and is taken in by the insect in the form of a gas. The "gastightness" of the grain bin, therefore, greatly influences the retention of the fumigant. Metal bins with caulked or welded seams or concrete bins will still lose some gas but are generally better suited for fumigation than loosely constructed wooden bins.

Although there are often label recommendations for fumigation of grain in wooden bins, the high dosages and poor control usually achieved normally make this type of fumigation uneconomical.

Winds and Thermal or Heat Expansion . Winds and thermal or heat expansion are major factors influencing gas loss. Winds around a grain storage structure create pressure gradients across its surface resulting in rapid loss of fumigant concentrations at the grain surface and on the downwind side of the storage. The expansion of headspace air due to solar heating of roofs and walls followed by nighttime cooling can result in a "pumping" of the fumigant from the bin. Large flat storages that contain more grain surface than grain depth are particularly susceptible to gas loss due to wind and heat expansion. The greatest gas loss frequently occurs at the grain surface, a location that often contains the highest insect populations. Furthermore, when the grain surface is uneven with large peaks and valleys, the distribution of fumigants through the grain will also be uneven.

Air Movement . Successful fumigation of stored grain requires an understanding of air movement within the grain mass. It is easy to think that the air in between the kernels of grain in a bin is as immobile as the grain itself. This is not true and is one of the reasons that fumigation sometimes fails even when done by professional fumigators.

Air moves along the path of least resistance, with warm air moving upward and cold air moving downward. In a bin, there is usually air movement both up and down because of temperature difference between the well-insulated middle and the grain near the perimeter that is affected by the outside temperature. Air movement upwards can carry moisture that can condense on the surface and cause crusting. The resulting crust can also interfere with air and gas movement. Air will move easier through a grain mass composed of larger kernels, such as corn, and more slowly through those composed of smaller grains, such as grain sorghum. Air may move around a hot spot and carry a fumigant gas away from the critical area. Fumigant gases can penetrate these areas better than normal air but the air movement can affect how much gas reaches and stays at these critical areas.

Precautions in Fumigation

All precautions given on the label of the insecticide used should be followed precisely. All fumigants mentioned give off poisonous vapors. They have an anesthetic action, and a worker may be suddenly overcome without noticing adverse symptoms. Therefore, a worker should never fumigate grain without the assistance of another person, and should never stay inside the bin unless protected by a gas mask approved for the type of fumigant being used. If any fumigant is spilled on the skin, it should be washed off immediately with soap and water.

Rodent Control

Rodenticides

Food, water, and harborage are the three factors that must be controlled to minimum levels for any effective rodent control program to work. The basic requirement is to maintain consistent and diligent sanitation.

Good sanitation is the paramount factor in any list of guidelines or general principles for rodent control. Without adequate sanitation practices, rodent control becomes nothing more than chasing from one problem area to another.

While each grain storage area has its own unique geography and design layout, certain common features can be found at each. Generally, there are large areas for parking or open space adequate for vehicles to load or unload grain. Railroad sidings or tracks can be found at larger grain elevators. Storage sheds, maintenance areas, office buildings, and other structures make preplanning a must for effective control. Drainage ditches or runoff pathways are usually present. These areas and others will often determine where control devices or baits will be placed for maintenance control programs.

To establish a systematic plan for rodent control, a map or diagram should be drawn to facilitate planning. The development of the map can be used to determine prime areas of possible entry by the different rodent species. It can also be used to keep track of and to monitor bait stations, bait locations, or mechanical control devices.

There are numerous points of entry onto the facilities where field rodents or rodents brought in the grain shipments or other vehicles can enter. Sanitation, as mentioned earlier, will facilitate your rodent control program. All the potential harborage must be eliminated, including weeds growing along railroad sidings, ditches, and alongside buildings and other structures. Reduction also includes repairing structures where rodent populations can flourish. An open floor drain should be sealed by screening to prevent rodents from using the drain for harborage or pathways into the facility. "Build them out" is the best policy.

Water resources must be eliminated wherever possible. Drainage ditches and water runoff areas must flow quickly away from structures with no standing water allowed to accumulate. Norway rats, the single largest rodent pest for grain elevators, must consume water at least once a day. Control will be easier by removing any water sources or making the water available away from the structures. Controlling the available food sources around grain storage facilities is the most difficult of all the sanitation practices to be implemented. Spilled grain is an open invitation for rodent infestation, especially when it is left open and available. Cleanup must be instituted before nightfall when the rodents become more active and are searching for food materials.

Most experts will agree that sanitation is the key to any pest management program and can account for as much as 80 percent control of rodent populations when the rodents are properly built out of an area and the facility is kept clean. Assuming that sanitation is at an optimum, there is still 20 percent of the rodent population that must be controlled using either mechanical or chemical control.

Types

Two basic types of rodenticides are available to the pest control professional for use around grain storage. They are acute toxicants and chronic poisons.

Acute toxicants are designed for initial clean-out of heavy, well-established rodent infestations, situations where speed is of the essence or where results with standard anticoagulants have been poor.

Acute rodenticides were the mainstay of the pest control profession for many years prior to the development of anticoagulants. Most acute toxicants used were highly toxic to all life forms and seldom if ever had antidotes. Such compounds as Antu, DLP 787, Strychnine, Red Squill, 1080, and zinc phosphide were commonly used. Only zinc phosphide has survived the tests of time and safety and is still readily used in professional pest control and agricultural use.

Zinc phosphide is one of the oldest toxicants still used extensively in rodent control. It is most effective for use in cleanout situations and possesses many safety features. Zinc phosphide is a natural emetic, causing vomiting in non-target animals but not rodents since they cannot vomit. It is a stable compound and breaks down only in the presence of acidic moisture such as stomach acids. Its natural grey color and garlic odor make it unattractive to non-target species. Also, there is no true secondary poisoning associated with zinc phosphide, a potential problem for other acute toxicants.

Zinc phosphide differs from anticoagulant baits in that it produces toxic phosphine gas in the rodent's stomach. This gas produces mortality generally within four to six hours, making this compound ideal for initial cleanout of problem areas. Acute toxicants must be made palatable to ensure that a lethal dose is consumed in one feeding.

Acute products that use superior inert ingredients should be sought in order to achieve a good acceptance of the bait. Inferior baits may often be lower in cost but saving pennies on the bait may prove more expensive because of the need to remove the poorly accepted bait and to rework the site.

Chronic poisons or baits are most commonly known as anticoagulants. Since their introduction in the late 1940s and 1950s, anticoagulant baits have been the mainstay for most rodent control programs in all facets of pest control. There are inherent advantages associated with anticoagulants that have accounted for their widespread favor and usage.

In the most simple terms, anticoagulants inhibit the production of clotting agents within the rodent's blood. Without this blood clotting ability, the rodents die from internal hemorrhaging. Death usually occurs from five to fifteen days after consumption of the bait. The rodent must consume the bait over a number of days before a lethal dose is consumed. There is little possibility of bait shyness and an antidote, Vitamin K_1, is readily available in the event of an accidental poisoning.

Their safety features (delayed time to death and a readily available antidote) and general effectiveness have made the anticoagulants the leader in sales for rodent control. There exists a number of anticoagulants available for pest control. Such toxicants as Warfarin, Prolin, diphacinone, chlorophacinone, PIVAL, Isoval, Bromodialone, and brodifacoum are but a few. There is a wide variety of anticoagulant toxicants to choose from and manufacturers make claims of superior effectiveness or safety for each and every toxicant.

The existing anticoagulant toxicants can be categorized into three distinct families or generations of toxicants. The first generation of anticoagulants would be classified as coumarin-type anticoagulants. This family would include such compounds as Warfarin, Fumarin, and Prolin. They were the first anticoagulants to be developed and quickly found favor in the pest control profession because of their effectiveness and safety in comparison to other acute compounds being used. In relative toxicity, they are the "safest" compounds on the market. However, several days of consumption are generally needed before a lethal dose has been consumed and thus they are the slowest of the anticoagulants available today.

Development of stronger and possibly faster-acting anticoagulants was soon begun which accounts for the second-generation of anticoagulants. These are referred to as the indanione family of anticoagulants which includes PIVAL, Isoval, diphacinone, and chlorophacinone. They are from five to fifteen times more toxic than the coumarin family toxicants which accounts for their claimed increase in effectiveness.

However, it is the third generation of anticoagulants, the brominated hydroxycoumarins, which have made the biggest news in rodenticides. Whereas the coumarins and indandione anticoagulants have generally needed multiple feedings by the rodent to produce mortality, this third generation of anticoagulants can make the claim of being single-feeding anticoagulants.

A basic premise that must be remembered is that all three generations of anticoagulants work exactly the same within the rodent. Warfarin works exactly the same within the body as bromodialone or brodifacoum. The only difference is the relative toxicity of the product. For example, the technical ingredient brodifacoum is 184 times more toxic than the technical ingredient Warfarin. Its presumed effectiveness is directly related to toxicity.

Quite logically, as toxicity increases, relative safety decreases. When determining which toxicant will work best for a particular control situation, the safety parameters for a particular baiting program must be considered. A simple rule to follow is to use the least toxic material that will still do the job. For example, if in the past, Warfarin-based rodenticides have not worked up to par, consider a diphacinone-based material. If diphacinone has not worked, then take a step up to bromodialone.

Price is another consideration. The third generation anticoagulants cost considerably more than the older compounds. All effort toward control amounts to nothing if the toxic material is not eaten. The hard part of rodent control is getting the rodent to consume the lethal dose.

With such a wide range of toxicants on the market, it is difficult to determine which brand names to select. The Environmental Protection Agency has well over 100 different registrations on file for rodenticides. There are over 70 brand names alone that use the active ingredient Warfarin. As just mentioned, it is difficult to determine which product will work best. One point to remember which makes the choices that much more difficult is that products with the same active ingredient are not the same. As shown in Table 7 , products containing the same active ingredient get markedly different acceptance.

For baits to be effective, they must also be palatable to the rodent. In servicing grain storage operations, this becomes even more important when sanitation is not adequate. The rodenticide bait must be as palatable as the existing food, preferably more palatable. The key to this is to find a rodenticide bait that uses primarily human food grade materials. Baits containing human food grade materials will assuredly produce results superior to those baits using animal feeds.

Forms

There are basically six forms of rodenticide products that can be used effectively in and around grain handling facilities:

- paraffinized products,
- pelletized baits,
- meal formula baits,
- place pack baits,
- tracking powders,
- liquid rodenticides.

Each bait form has its own inherent advantages and disadvantages. Usually, each form of bait can be found containing either chronic toxicants (anticoagulants) or acute toxicants.

Paraffinized bait forms are designed primarily for maintenance baiting in high moisture areas. Their advantage can also be their disadvantage because the paraffin is introduced to the bait to make the product more weather resistant which reduces its acceptance when compared to a pellet or meal bait. When choosing a paraffinized rodenticide, products utilizing human food grade materials and inert ingredients should be sought. This will ensure the optimum acceptance for this type of bait.

Paraffinized bait can be used effectively for exterior baiting with bait placement into burrows or other inaccessible areas being best. If inaccessible areas cannot be found, this and other bait forms should be placed in tamper-resistant bait stations.

Pelletized rodenticides also have their advantages and disadvantages. The pelletized form is easy to work with in bulk containers. Pelletization is a crude form of encapsulation and helps to mask the taste of offending toxicants. The disadvantage to pelletized rodenticides is that they are easily carried from one location to another by the rodent. This is fine if you can guarantee the rodent will not contaminate other locations or stored materials with the bait. They might take the bait back to their nest and consume the product at a later time, an advantage. Problems occur when they store the bait in sensitive areas where the product should not be found.

Meal bait rodenticides have often been found to be the most palatable bait form. The open loose meal has air circulating around the bait and has proven quite attractive in many situations. However, the open form has a shorter life than other forms because it absorbs moisture and will turn moldy or rancid more quickly than pelletized or paraffinized baits.

There is seldom a problem with rodents moving the bait when using meal bait rodenticides. The rodent will not move meal products so special care must be made in placing the bait where the rodent will feel comfortable while feeding on it.

Place pack rodenticides have found increased favor in recent years. The product is labeled for safety purposes, the bait stays fresh until opened by the rodent and it is easily dispensed. Disadvantages to their use are the increased cost that the place pack material adds to the product, the difficulty that some rodents might have in opening them, and the lack of a full and comprehensive label upon some manufacturers' packaging.

Tracking powders, available as both acute or chronic products, have many applications in grain handling and storage areas. They can be dusted into wall voids, burrows, along runways, in enclosed spaces, and other areas. However, they do not stand up well to moisture (they cake and will not cling to the rodent). They are

often messy and cannot be used in areas where they can become airborne. Liquid rodenticides are often neglected because of the added equipment their use requires and their general reputation of being labor intensive to use. However, liquid baits work very well in areas such as grain elevators where natural food is plentiful and not easily eliminated.

Again, the key element to remember when choosing bait forms is palatability. The simple rodent control premise - "If they eat, they will die" - should be remembered. The difficult job is finding a rodenticide that is palatable enough to get maximum acceptance. The use of superior inert ingredients in the formulation should be sought. Human food grade materials are always more attractive than animal feeds. When considering baits, a low price should not be misleading. The most expensive component in effective rodent control is labor. The job should be done right the first time with a superior bait.

Mechanical Control and Exclusion

Snap traps, glueboards, and multiple-catch traps are the mainstay of mechanical control available for use in and around grain storage areas. They are often used as monitoring devices in areas where baits cannot be used for fear of contaminating the stored materials. They also are a last resort for areas where the rodents have become bait shy.

Mechanical devices can work very well if they are placed properly but their drawbacks can be many. With the exception of multiple-catch mouse traps, they are usually good only for one rodent and must be checked daily. Glueboards have the drawback of catching dust and dirt as effectively as rodents. When the board has been covered with dust or chaff, they lose their tackiness and are ineffective. Glueboards cannot be used effectively in areas where there is standing water. If the rodents' feet are wet or damp, the glue will not catch the rodents.

Exclusion or building out the rodents from the grain storage area will be a major tool in a sanitation program. Sealing off potential runway and harborage areas is a necessity.

Like insecticides, rodenticides are poisonous. They should be used only when needed, and they should be handled with extreme care. Directions and precautions on container labels should be carefully followed. For additional assistance with specific problems, consult the local extension office staff.

General Bin Safety

The number of human suffocations in grain storage systems is increasing. There appear to be at least five basic reasons:

- increased harvesting and handling of grains,
- larger on-farm storage facilities,
- faster grain handling capabilities,
- increased mechanization (operator working alone), and
- little knowledge of grain movement and safety precautions.

To avoid the mistake involving a life, know the dangers of flowing grain and practice safe work habits at all times.

Caution: There Are Several Reasons for Entering a Bin Filled with Grain

A successful manager of stored grain must check his investment closely and frequently. He may enter a grain bin to visually check the grain's condition, and may probe the bin to determine the grain's temperature and moisture content to ensure that there are no developing "hot spots."

Grain being removed from a bin equipped with a bottom unloading auger may fail to flow because of clogging or bridging. The manager may feel that the only option is to go inside the bin and remove the obstruction or break up the bridged grain.

When drying grain, check the incoming grain closely. The manager may feel that the wet holding bin is the best place to make observations.

Children may find that a storage bin filled with grain is an attractive place to play.

Caution: There Are Several Reasons for Not Coming out Alive

Flowing grain is dangerous. Why? To better comprehend the hazard, be familiar with the way in which most farm storage bins unload. Grain storage structures should be, and usually are, unloaded from the center. When a valve opened in the center of the bin or a bottom-unloading auger is started, grain flows from the top surface down a center core to the unloading port or

auger. This is called "enveloping flow" and is

. The grain across the bottom and around the sides of the bin does not move. The rate at which the grain is removed is what makes the enveloping flow so dangerous. A typical rate for a bin-unloading auger is 1,000 bushels per hour. This is equivalent to 1,250 cubic feet per hour or approximately 21 cubic feet per minute. A 6-foot-tall man (assuming an average body diameter of 15 inches) displaces about 7.5 cubic feet and this means that the entire body could be submerged in the envelope of grain in approximately 22 seconds. Even more importantly, an individual could be up to his knees in grain and totally helpless

). Also, it requires up to 2,000 pounds of force to pull a totally submerged man up through the grain. Flowing grain is like water in that it will exert pressure over the entire area of any object that is submerged in it. However, the amount of force required to pull someone up through grain is much greater than required in water because grain exerts no buoyant force and has much greater internal friction. People who have helped pull partially submerged children from grain have commented on how hard they had to pull and, frequently, that shoes were pulled off in the grain. This may mean that rescue efforts will fail unless the movement of grain is stopped.

Grain that bridges across a bin can be another hazard. Bridging grain may create air spaces in a partially unloaded bin (Figure 21). This situation presents several dangers. The first is that the person may break through the surface and be trapped instantly in the flowing grain (Figure 22). Another danger is that a large void may be created under the bridged grain by previous unloading so that a person who breaks through the crust may be carried under the grain and suffocate even though the unloading auger may not be in operation at the time (Figure 23). A third hazard is that, if the grain is wet enough to mold and bridge across a bin, there may be little oxygen present in the cavity because of microbial activity. Therefore, a person falling into this void may be forced to breathe toxic gases and microbial spores even if his head stays above the level of the surrounding grain.

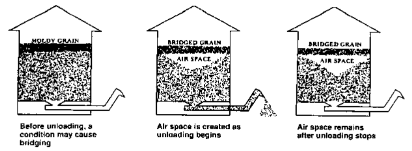

Figure 21 .

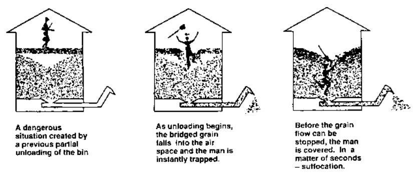

Figure 22 .

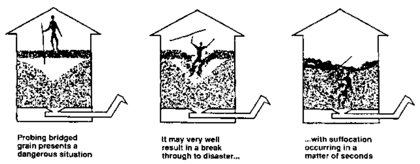

Figure 23 .

Safety hazards in grain bins are not limited to those with bottom-unloading augers. Gravity-unloaded bins may present a similar danger through bridging or unloading. A definite danger exists with wet holding bins that feed automatic-batch grain dryers. When the dryer completes its drying cycle and reloads, a person in the wet holding bin can be drawn below the surface of the grain in a matter of seconds (Figure 24).

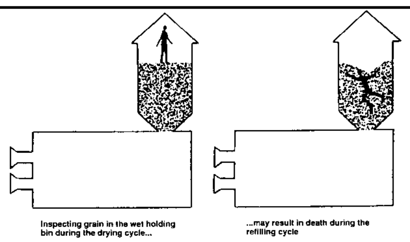

Figure 24 .

Summary

If additional land areas drain into a detention pond, it will need proportionally greater capacity. To minimize the detention pond size required, limit the drainage area to the production ponds and levees, and divert flood waters from surrounding land areas around the detention pond.

Table 1.

Table 1. List of stored grain pests and some biological data.

Grain Pest	Time Cycle Required for Complete Life Cycle	Remarks
Granary Weevil	4 weeks	Universal feeder on whole grains.
Rice Weevil	4 weeks	Universal feeder on whole grains. Most common stored whole grain pest in Florida.
Broad-Nosed Grain Weevil	4 weeks	Usually attacks soft or damaged grain.
Coffee Bean Weevil	4 weeks	Lays eggs in corn in field; infestations may continue for 3 months after storage.
Lesser Grain Borer	4 weeks	Universal feeder on whole grains.
Angoumois Grain Moth	5 weeks	Most important in stored corn.
Indian Meal Moth	6-8 weeks	Prefers coarse grades of processed grain.
Mediterranean Flour Moth	8-9 weeks	Prefers finer grades of processed grain.
Sawtoothed Grain Beetle	4 weeks	Prefers grain products.
Confused Flour Beetle	6 weeks	Attacks grain and grain products.
Red Flour Beetle	5 weeks	Attacks grain and grain products.

Table 2.

Table 2. List of residual pre-storage grain bin sprays.

Insecticide	Dilution	Direction
43.2% Chlorpyrifosmethyl EC	1/2 pt. per 6.5 gal. water	Treat empty bins prior to filling. After cleaning bins thoroughly, spray walls, floors and ceilings to the "point of run off" (2 gal/1000 sq. ft.). Apply the insecticide 2-3 weeks before harvest. Before storing the grain, sweep the bin to remove all dead insects.
57% Malathion EC (premium grade)	1 gal. per 25 gal. water	
25% Methoxychlor EC	1 gal. per 4 gal. water	
50% Methoxychlor WP	1 lb. per 3 gal. water	
.15% pyrethrins + 1.5% piperronyl butoxide	Ready-to use	

Table 3.

Table 3. Protect Grain When Loading Into Bins

Insecticide	Product	Directions
57% malathion EC	wheat, oats, rice	Mix 1 pint of'57% EC in 2-5 gallons of water per 1 000 bushels of grain. Spray grain evenly as it is loaded or turned into final storage. Complete coverage is essential.
1% malathion dust	corn, rye, barley, grain sorghum, field & garden seed	Apply uniformly at 60 lbs/1 000 bushels. Use only malathion labeled "premium grade" on grain. Grain treated with protectant can be fed safely to livestock at any time following treatment.
43.2% chlorpyrifosmethyl EC	wheat, oats, rice,sorghum, barley	Mix according to label directions. Apply 1-5 gal. per 1 000 bushels. Do not use on corn.
3% chlorpyrifosmethyl dust	wheat, oats, rice, sorghum, barley	Apply 11.5 lb/1 000 bushels of wheat, 9.2 lb/ 1000 bushels of oats or barley. Do not use on corn.
Bacillus thuringiensis (Dipel)	stored grains & soybeans (Indian meal moth, Almond moth)	Apply at rate of 3/4 lb per 100 bushels. Apply uniformly to grain stream.

Table 4.

Table 4. Surface treatments.

Insecticide	Product	Directions
57% malathion EC	stored grain and field and garden seed	Apply 1 pint in 2-4 gallons of water per 1000 sq. ft. of grain surface. Apply evenly over the grain surface immediately after grain is loaded into storage. Repeat if necessary.
1% malathion dust	stored grain and field and garden seed	Apply to grain surface at rate of 30 lb. per 1000 sq. ft.
43.2% chlorpyrifosmethyl EC	wheat, barley, oats, rice,sorghum	Apply 3 oz. (wheat), 2.4 oz. (barley), 1.6 oz (oats) in 2 gal. of water per 1000 sq. ft. of grain surface
3% chlorpyrifosmethyl dust	wheat,barley, oats, rice, sorghum	Use 7 lb per 1000 sq. ft. of grain surface.
Bacillus thuringiensis (Dipel)	stored grains & soybeans (Indian meal moth, Almond moth)	Apply 1 lb. ofBT in 10 gal. of water per 500 sq. ft. Mix into top 4 inches.

Table 5.

Table 5. Dosage of Methyl Bromide for recirculation systems.

Type of Grain	**Grain Temperature**	**Dosage (lbs/1000 cu ft)**
wheat, corn, rice	above 80¡F	1.5
wheat, corn, rice	60 - 80¡F	2.0
wheat, corn, rice	below 60¡F	2.5
grain sorghum	above 80¡F	3.0
grain sorghum	below 80¡F	4.0
Precautions: Do not breathe vapors. Read and follow all directions and precautions on the label and technical manuals.		

Table 6.

Table 6. Dosage of Methyl Bromide for non-recirculation systems (temperature must be above 60°F).

Volume (cu. ft.)	**Rate (lbs/1000 cu ft)**
less than 100,000	1.5 - 3
100,000 - 500,000	1.25 - 1.5
500,000 - 1,000,000	1.0- 1.25
More than 1,000,000	1.0
Precautions: Do not breathe vapors. Read and follow all directions and precautions on the label and technical manuals.	

Table 7.

Table 7. Bait acceptance test results for rodenticides.

	Acceptance Chronic Toxicants		**Mortality/ Acute Toxicants**	
	Rats	**Mice**	**Rats**	**Mice**
Brand A	48%	39%	100%	95%
Brand B	28%	17%	30%	20%
Brand C	19%	5%	50%	0%