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PEST MANAGEMENT

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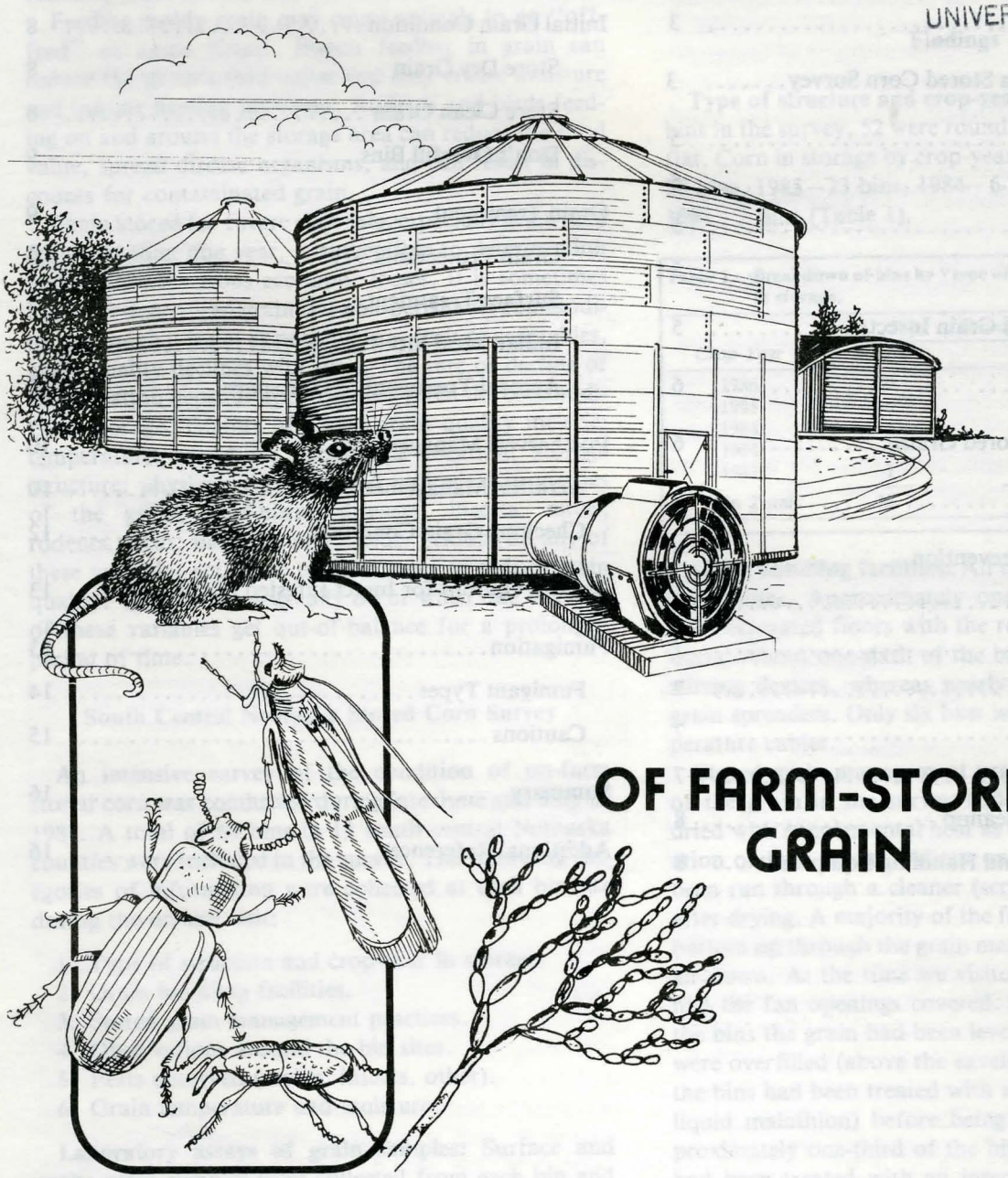

OF FARM-STORED GRAIN

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Pest Management of Farm-Stored Grain

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PEST MANAGEMENT OF FARM-STORED GRAIN

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Introduction

Grain may be stored on the farm for many reasons. It may be used as livestock feed. It may be stored in anticipation of higher prices. Regardless of storage reasons, grain quality must be maintained.

Feeding moldy grain may cause animals to go "off-feed" or cause illness. Insects feeding in grain can reduce the grain's feed value and may create moisture and initiate heating problems. Rodents and birds feeding on and around the storage area can reduce the food value, spread disease organisms, and can result in discounts for contaminated grain.

Grain stored for future cash sale, especially grain held for more than one year, is susceptible to deterioration and therefore serious economic losses. It is sometimes assumed that stored grain is a non-perishable commodity. Although it is not as perishable as fruit or vegetables, grain quality declines with time. The rate of decline or deterioration depends upon the care given the commodity in storage. Factors affecting grain quality include: temperature, moisture, geographic location, storage structure; physical, chemical and biological properties of the grain; seed-borne diseases, insects, mites, rodents, birds, bacteria, and molds. Seldom do any of these variables act alone or all at once to reduce grain quality. Quality losses usually occur when one or more of these variables get out-of-balance for a prolonged period of time.

South Central Nebraska Stored Corn Survey

An intensive survey of the condition of on-farm stored corn was conducted during late June and July of 1987. A total of 68 bins in 13 south central Nebraska counties were included in the survey. The following categories of information were collected at each bin site during the on-site visit:

1. Type of structure and crop-year in storage.
2. Grain handling facilities.
3. Stored grain management practices.
4. Observations around the bin sites.
5. Pests observed (molds, insects, other).
6. Grain temperature and moisture.

Laboratory assays of grain samples: Surface and probe grain samples were collected from each bin and taken back to the laboratory for further study. A portion of each sample was immediately frozen for future mold assay. The remainder of each sample was then incubated at room temperature for six weeks. At that time each sample was weighed, screened, and assayed for insects. Test weights were determined. Percentages of broken corn (% BC) and foreign material (% FM) were also determined using the new proposed grading system for corn (USDA, FGIS). The incidence of blue-eye was also recorded.

Findings

Type of structure and crop-year in storage: Of the 68 bins in the survey, 52 were round structures and 16 were flat. Corn in storage by crop-year was as follows: 1986 - 36 bins, 1985 - 23 bins, 1984 - 6 bins, 1983 - 1 bin, and 1981 - 2 bins (Table 1).

Table 1. Breakdown of bins by "type of structure" and "crop-year" in storage.

	Type of Storage		*Crop-Year*
Crop-Year	*Round*	*Flat*	*Total*
1986	30	6	36
1985	16	7	23
1984	4	2	6
1983	1	—	1
1981	1	1	2
Bin Total	52	16	68

Grain handling facilities: All of the bins had aeration capabilities. Approximately one-half of the bins had full-perforated floors with the rest having one or more ducts. About one-sixth of the bins were equipped with stirring devices, whereas nearly one-half of them had grain spreaders. Only six bins were equipped with temperature cables.

Stored grain management practices: A vast majority of the grain in the survey had been at least partially dried with supplemental heat as opposed to natural aeration or field drying. About one-half of the grain had been run through a cleaner (screened) either before or after drying. A majority of the fans pushed air from the bottom up through the grain mass as opposed to pulling air down. At the time we visited the bin sites only six had the fan openings covered. In about two-thirds of the bins the grain had been leveled. Several of the bins were overfilled (above the eaveline). About one-half of the bins had been treated with an insecticide (primarily liquid malathion) before being filled with grain. Approximately one-third of the bins contained grain that had been treated with an insecticide (primarily malathion or Dipel) either before or as it was being moved into the bins. An equal number of bins and grain treated on the surface after being placed in the bins.

Observations around the bin sites: In general, most of the farmer-cooperators appeared to be attempting to control the vegetation (grass, weeds) around their bin sites and not allowing trash to accumulate. Although many of them could have taken some more recent control measures (mowing and/or spraying) of the vegetation at the time of our visit, most were not beyond the point of rescue with just a small effort. However, 10 of the bin sites were deemed to be in need of immediate attention and would have required a major time effort to clean up and/or refurbish.

Pests observed (molds, insects, others): Moldy grain was observed in 33 of the 68 bins examined; however, disagreeable odors were detected in only 17 of these bins. Insects were observed in 56 of the bins; however, the range of infestation ranged from very low to very severe and needing immediate attention. Other pests observed included the following: birds only (6 bins), rodents only (3 bins), and both birds and rodents (2 bins). In addition to the above, five bins were also noted as having trash on the grain surface including cans, paper, mud, and sticks among other things.

Grain temperatures and moistures: Although temperature and moisture data were collected from several locations within each bin, the emphasis was placed on the center of the grain mass. Table 2 shows the average surface and 6 ft. depth temperature and ranges, and the average surface and 3 ft. increment moisture levels (down to 15 ft.) and ranges, taken from the centers of the bins. The surface temperatures and moistures were obtained from the top 5 inches.

Table 2. The average bin-center temperatures and moistures and ranges of all bins in the survey.

	Avg.	*Range*
	Temperature (F)	
Surface	82.4	70-94
6 ft	72.2	44-97
	Moisture (%)	
Surface	11.7	9-15.5
3 ft	14.1	11-17
6 ft	13.7	11-16.5
9 ft (65 bins)	13.6	10-17.2
12 ft (54 bins)	13.2	10.5-16
15 ft (30 bins)	12.9	10.8-14.8

The 6 ft. temperature was equal to or greater than 80° F in 13 bins, and in 11 of these bins the 6 ft. temperature was equal to or greater than the surface temperature (Table 3). The 3 ft. moisture level exceeded the surface moisture in 65 of the bins and also exceeded the 6 ft. moisture level in 38 bins. The 6 ft. moisture level exceeded the 3 ft. level in 18 bins (Table 3). In some cases the moisture at the 3 ft. depth exceeded the surface by as much as 6 percent.

Table 3. Temperature and moisture relationships at different depths within the centers of the bins.

	Depth Comparisons	*Number of Bins*
Temperature		
	6 ft ≥ 80 F	13
	6 ft ≥ Surface	11
Moisture		
	3 ft > Surface	65
	3 ft ≤ Surface	3
	3 ft > 6 ft	38
	3 ft = 6 ft	12
	3 ft < 6 ft	18

Laboratory assays of grain samples: The mold assays revealed that *Fusarium, Penicillium,* and *Aspergillus* species were the primary fungi associated with the mold-related storage problems in this survey.

The insect assays revealed that 79 percent of the samples were infested with one or more kinds of live stored-grain insects. The most commonly found insects were rusty grain beetles, *Cryptolestes ferrugineus,* and Indian meal moths, *Plodia interpunctella.* A considerable number of the samples were also infested with saw-toothed grain beetles, *Oryzaephilus surinamenis,* and red flour beetles, *Tribolium castaneum.* Few samples were infested with any of the primary grain-damaging insects such as weevils. However, the majority of the insects found are associated with cracked and broken grain, flour, meal, and moldy grain.

The kinds of fungi and insects found in this survey are those often associated with lower quality grain. The higher than expected incidences of blue-eye damage in this survey, along with the other grain quality findings (Table 4), adds further support to the proposition that much of the stored corn in this survey was not in the best of condition.

Table 4. The test weights, % BK, % FM, and % blue-eye in the grain samples collected in the survey by crop-year.

Crop-Year	*Test Wgt*	*% BK*	*% FM*	*% Samples Blue-eye*
1986	58.3	0.94	0.29	11.1
1985	57.2	1.12	0.39	34.8
1984	56.6	1.42	0.61	50.0

Conclusions

Some conclusions can be drawn from the information collected during this survey. It was obvious that some problems did exist in this on-farm stored corn. Of the 68 bins examined, 15 were identified as being in need of immediate emergency rescue measures. These were related primarily to mold development, insect infestations, and excessively high temperature and moisture conditions. Another 24 bins were identified as being in need of attention soon and/or requiring close monitoring. Most of these were associated with moderate insect infestations and/or high moisture levels and potential mold growth.

In many of the above cases the farmer-cooperators were unaware of the problems that existed in their bins. It was obvious that most of the bins in this survey were not being monitored on a regularly scheduled basis. In most cases scheduled monitoring would have identified these problems before they had become serious and preventive measurements could have been carried out to prevent storage losses.

Insects in Stored Grain

Stored grain insects may be divided into three types based on their location in the bin and the damage they cause: **surface-feeding caterpillars, external feeders** (feeding on the outside of kernels or on broken kernels in the grain mass), and **internal feeders** (feed and develop inside grain kernels).

Surface Feeders

The most common grain mass surface-feeding insect in Nebraska is the larvae of **Indian meal moths.** The moth has a wingspread of nearly three-fourths of an inch. It is easily distinguished from other grain moths by the markings on the front wings. They are reddish-brown on the outer two-thirds and silvery-gray on the body end. Each female moth lays 100 to 300 eggs over a three-week period. Fully grown larvae generally leave the food source and climb up walls to pupate and change into moths. The life cycle from egg to adult takes six to eight weeks during warm weather. There may be several generations per year. Full-grown larvae are about one-half inch long, creamy white in color, maybe with a pinkish or greenish cast.

Indian meal moth larvae will feed on almost any stored commodity including corn, small grains, and sorghum. Larvae are also a common "pantry pest" and will feed on processed food such as nuts, dried fruit, candy, baking products, and dry dogfood. Indian meal moth larvae feed on fines, broken or cracked kernels, and on the germ portion of whole kernels.

The infestation is usually in the top four to six inches of grain in the bin. Grain in bins with perforated drying floors may also be infested in the bottom four to six inches of grain with Indian meal moth larvae. The larvae produce a silk-like webbing which results in "caking" or "crusting" of the top 1-2 inches of surface grain (or on the bottom grain if infested from below). Their frass (excrement), cast skins (body shells), and silk contaminate the grain and impede airflow through the grain mass.

External Feeders

In stored grain, the external feeders are usually associated with fines, and cracked and broken grain. They include several species of grain beetles and flour beetles. They are quite often found in the home in processed cereal foods, flour, and meal.

Grain beetles deposit their eggs in the food source. Both the larvae and the adult beetles feed. Their feeding results in contamination from their frass, cast skins, and dead bodies.

The larvae and adults of the several species of flour beetles feed on grain dust, broken kernels, and flour.

The life cycle of grain and flour beetles ranges from four to six weeks during the warm season of the year.

Internal Feeders

The major internal grain feeders found in Nebraska stored grain include several weevils (rice, *Sitophilus oryzae,* maize, *Sitophilus zeamais,* and granary, *Sitophilus granarius*) and the lesser grain borer, *Rhyzopertha dominica.* Both the larvae and adults of weevils and lesser grain borers feed on whole, intact grain kernels. Most grains stored in Nebraska are susceptible to these insects.

The females deposit their eggs on or in the kernels. The larvae that hatch from the eggs feed and pupate inside the kernels where they cannot be seen. The new adults chew small, round holes in the kernel surface from which they emerge. The holes in the grain and the adults crawling on the grain are the only indication of their presence.

Weevil adults are small (about one-eighth inch long) snout beetles. Their eggs are laid inside the kernel. Lesser grain borer adults are about one-eighth inch long and their head is turned down. Their eggs are laid outside the kernel and the young larvae chew into the grain. The life cycle ranges from four to six weeks during warm weather.

Factors Favoring Stored Grain Insects

Combinations of temperature, grain moisture, and grain dockage and dust, combine to provide conditions suitable for the reproduction and survival of stored grain insects. The most favorable temperature for most stored grain insects is about 80° F. Above 95° F or below 60° F, reproduction and survival is greatly reduced.

The most favorable moisture range for stored grain insects is 12 to 15 percent (optimum 14-15 percent). The lowest moisture content for any survival and reproduction to occur is about nine percent. However, as temperature increases insects can reproduce in grain with a lower moisture content, and when moisture increases they can reproduce at lower temperatures. The life processes of the insects can increase the moisture content of "dry" grain.

Insect infestations are more likely in "dirty" grain than in clean grain. The presence of grain dust, cracked kernels, and dockage permits some grain insects to survive and reproduce at low moisture levels.

Molds in Stored Grain

Much of the basic and applied research on grain quality has been directed toward the control of moisture, temperature, and insects. Very little research, however, has been directed toward the control of molds, since only more recently have molds been recognized as a major cause of grain deterioration. Increased research on controlling molds to insure and maintain grain quality received a great impetus from the identification of mycotoxins (toxins produced by molds) in moldy agricultural commodities, including grain.

What are molds? Molds, or "fungi" as they are more properly called, are lower plants that lack chlorophyll; thus, they can't synthesize their own food. They usually reproduce by means of spores and, in addition, have some sort of sexual mechanism. They usually have a filamentous, thread-like body (mycelium) which branches. These threads or cells have true nuclei and the cell walls contain cellulose and/or chitin. Since molds live either saprophytically or parasitically and are found everywhere, they are responsible for much of the disintegration of organic matter, destroying food, fabrics, leather, wood, etc. Molds also cause the majority of our plant diseases (e.g., rusts, smuts, stalk rots, leaf blights) and many diseases of animals and man, including mycotoxicoses.

Molds that invade grain can be divided into two groups: field molds and storage molds.

Field molds invade grain before harvest, or after the grain is cut and swathed but before it is threshed. Field molds include primarily species of *Helminthosporium, Cladosporium, Alternaria,* and *Fusarium,* and require high grain moisture content (20-22%) to grow. Field molds seldom cause mycotoxin problems under Nebraska conditions.

Storage molds invade grain at moisture contents in equilibrium with relative humidities of 70-90 percent; thus, they are able to invade grain at lower moisture levels (as low as 14% for some species) than field molds. Species of *Aspergillus* and *Penicillium* are usually considered to be the principal storage molds and are often involved in mycotoxin problems; however, some species of *Fusarium* may also be involved.

Many molds are not capable of producing mycotoxins even though they may invade grain; and just because a given sample of grain is moldy, it is not necessarily toxic. Caution should be taken, however, anytime moldy grain is fed to animals or used for human consumption.

The following questions and answers on molds and mycotoxins will give some guidelines on basic practices which can be employed to reduce mold deterioration and potential mycotoxin problems.

What are mycotoxins? Mycotoxins are chemical compounds produced by certain species of molds which are toxic to animals. Diseases produced in animals or humans by the consumption of grain contaminated with mycotoxins are referred to as mycotoxicoses. Ergotism produced by the consumption of grain invaded by the ergot fungus is an example. Other examples of mycotoxins are the aflatoxins, a group of closely-related compounds produced by the common storage fungus, *Aspergillus flavus*. Aflatoxins are very toxic to many animal species. Aflatoxins have not been a major problem in Nebraska, although they have been found in grain in other areas of the U.S.

When can grain become contaminated by mycotoxins? Grain can be contaminated by mycotoxins in the field or in storage anytime conditions are favorable for mold growth.

What conditions are necessary for mycotoxin production? In general, high kernel moisture (16-25%) and warm temperatures (80-100° F.) associated with high relative humidities (80-100%) are favorable for mold growth. Extended periods of unfavorable harvesting weather or improper storage associated with the above conditions are thus conducive to mold growth.

What other factors may contribute to mycotoxin problems? Any type of stress in the field—such as root and stalk rots and other diseases, lodging, insect damage, and drought—may predispose the grain to mold invasion. In addition, damage at harvest time, such as cracking, may further predispose the grain to mold invasion.

Are all kinds of molds capable of producing mycotoxins? Fortunately, no. Many of the molds which may invade grain in Nebraska do not produce mycotoxins. There are, however, some molds which can produce mycotoxins if conditions are such that they can grow profusely on the grain. Improperly stored grain is the major cause of mycotoxin problems in Nebraska, whereas, field problem risks are relatively low.

What precautions can be taken to reduce the formation of mycotoxins? Emphasis should be placed on proper harvesting, handling, and storage. Harvesting crops promptly at maturity with properly adjusted and operated harvesting equipment is recommended to prevent mechanical damage. In addition, the main requirement for safe storage is to maintain moisture and temperature levels that prevent mold growth.

Controlling Molds in Stored Grain

Since moisture, temperature, and grain condition (e.g. mechanical damage, debris, insects) are the main factors associated with mold deterioration of on-farm stored grain, the following basic practices can help prevent mold related problems:

1. Adjust harvesting equipment for minimum cracking and maximum cleaning. Studies have shown that much of the mold growth and mycotoxin formation is associated with cracked kernels and debris. (This is especially important when harvesting lodged corn and sorghum.)

2. Dry all grain to a safe moisture level within 48 hours. If this is not possible, dry to 18-20 percent, then aerate. A **uniform moisture level** of 13 percent or below is considered safe for long-term storage of most grains.

3. Cool after drying as soon as possible then maintain uniform conditions throughout the bin with proper aeration management.

4. As an alternative to drying, high moisture corn or grain sorghum can be stored in airtight structures or bunkers. Organic acid preservatives such as propionic acid can also be used to store high moisture grain. This does limit end-use options, however.

5. Future alternatives or aids may include the application of fungicides before going into storage. Although none are available at the present time, several products are undergoing evaluation.

Vertebrate Pests

Rats and Mice may feed on grain, reducing the quality and quantity of the grain. Further contamination is caused by the presence of their fecal pellets and urine, which cannot be visually detected.

Birds, particularly house sparrows, pigeons, and European starlings, also reduce grain quality by feeding on it and leaving their droppings in the grain.

Specific directions on controlling vertebrate pests are in the NebGuides listed at the end of this publication.

Management for Pest Prevention

If stored grain is managed properly, pest problems should be minimal during the first year of storage under Nebraska conditions. Proper management requires that grain quality should be high when first placed into storage. Stored grain **quality never improves**—at best it can only be maintained. Once dry, high-quality grain has been placed into storage, controlling grain temperatures at the proper level is a major concern since grain temperature affects the rate of both mold and insect development. Recommended grain storage practices are discussed in the following sections.

This publication will describe pest management practices for farm-stored grain. References listed at the end of this publication contain additional information which detail different aspects of grain storage.

Preharvest Cleanup

Grain harvesting, handling and storage equipment must be cleaned before harvest to prevent insect and mold contamination of newly harvested grain. To do this:

Pest Proof Bins

Repair all leaks and holes in the bin so rain or snow can't get in and increase grain moisture. Unless roof vents have rain deflectors, keep them shut except when the fans are running. Screen roof vents to prevent birds from entering. Screen with holes three-fourths inch or smaller will keep out house sparrows. Keep the doors shut in flat storage buildings to keep birds and rodents out. To exclude both rodents and birds, leave no holes or gaps larger than one-fourth inch. All bins should have metal or concrete barriers around the exterior to prevent rodents from gnawing or burrowing in. Keep aeration fan openings tightly sealed when fans are not in use to prevent rodent entry.

Clean Outside Bins

Do not allow junk to accumulate, or weeds and grass to grow next to the bin. These hiding places for rodents make detection of their presence more difficult. Clean up spilled grain from loading and unloading areas so it won't attract insects, rodents, and birds.

Bins used for long-term storage should not be located near feed rooms, stables, or animal feeders. These areas often harbor insects and rodents which infest the long-term storage bins.

Where it is not possible to make grain storage structures rodent-proof, rodent damage to grain can be minimized by reducing the amount of shelter available to rodents as well as by use of rat and mouse baits (rodenticides) and burrow fumigants. Specific information on rodent control can be found in the NebGuides listed at the end of this publication.

Clean Inside Bins

Grain and grain debris may harbor insects and molds that will infest newly stored grain. For this reason, **never put new grain on top of old grain.**

Thoroughly clean the bin with brooms, hoes, shovels, and vacuum cleaners to remove all old grain, cracked kernels, and grain debris. Clean walls, ceilings, ledges, sills, and floors. Clean behind partitions, between walls, and clean out cracks and crevices. Remove and burn all sweepings and debris.

Spray Bins

After the bin is thoroughly cleaned, spray inside surfaces with a recommended grain protectant (Table 5) at least two weeks before storing grain. Always check the pesticide container label for dosage rates and restrictions for use on stored grain.

Spray surfaces to the point of run-off. One gallon of diluted spray will cover about 750 to 1,000 square feet of surface. Exact coverage depends on whether it is a wood, metal, or concrete surface. A dry, porous wood surface will require more spray than a metal surface.

Spray around all openings and into seams. Spray removable doors, behind partitions, and under perforated floors and aeration ducts. Before grain is put into the bin, sweep up and dispose of all dead insects.

Wear appropriate respirator to avoid breathing fumes, eye protection to prevent against splashing insecticide into eyes, and clothing which prevents skin contact.

Table 5. Recommended grain protectant uses. (Effective date—October 15, 1987)

Insecticide	*Empty Bin Spray*	*Grain Protectant*	*Topdress*
Actellic[1]	No	Yes/No	Yes/No
Bacillus thuringiensis[2]	No	No	Yes
malathion[3]	Yes	Yes	Yes
methoxychlor[4]	Yes	No	No
Reldan[5]	Yes	Yes/No	Yes/No

[1] **Actellic** *(pirimiphos-methyl)* is registered for use on stored shelled corn (field corn and popcorn) and grain sorghum. Topdress application directions are on Actellic Technical Information Bulletin No. 87-3. Do not make more than one application per crop (same grain). The treated grain may be sold or fed anytime after treating.

[2] *Bacillus thuringiensis* (Dipel, SOK-BT, Thuricide) is registered for use on stored grains and soybeans. The treated grain may be sold or fed anytime after treating.

[3] Premium grade **malathion** is registered for use as an empty bin spray or for use on stored barley, corn, grain sorghum, oats, rye, sunflowers, and wheat, but not on stored soybeans. Grain treated with malathion as recommended may be fed or sold anytime after treating.

[4] **Methoxychlor** is registered for use as an empty bin spray for use in storage bins that will contain barley, corn, oats, rye, sorghum, and wheat, but not soybeans. It is not registered for application onto any grain.

[5] **Reldan** (chlorpyrifos-methyl) is registered for use as an empty bin spray and for use on stored barley, oats, rice, sorghum, and wheat, but not on corn or soybeans. Topdress application directions are on the 3 percent Dust label and on Reldan 4E Technical Service Bulletin, TSB 187-5. Grain treated as recommended with Reldan may be fed or sold anytime after treating.

Aeration System Cleanup

Most modern grain storage bins are equipped with either subfloor aeration ducts or perforated floors. Grain dust and debris that accumulates under these floors provides an ideal place for flour beetles, dermestids, and Indian meal moth larvae to grow and infest the grain above. Mold spores may also originate from this area.

It is difficult to clean and spray under perforated floors without actually taking the floor up. Where the floor is not taken up, remove as much of the grain debris as possible, spray the floor with a bin spray as discussed above, then fumigate the empty bin with chloropicrin. Select a warm, calm day to apply the fumigant. Seal the fan and all lower openings. Post warning signs at points of entry. Apply the chloropicrin by pouring onto a tray or burlap, or pouring through the open roof hatch. Apply at the rate of one pound of chloropicrin per 1,000 cubic feet of airspace for the lower six feet of the bin. Allow the gas to remain in the bin for 48 to 72 hours, then unseal the fan opening, open the roof vents and aerate until the gas is exhausted. An approved gas mask or self-contained breathing apparatus is required to be worn if entering structures containing 0.1 parts per million (ppm) or more of chloropicrin. Therefore, the warning signs cannot be removed until the chloropicrin gas level is below the 0.1 ppm Threshold Value. Contact your fumigant dealer for information on gas-measuring devices.

Sweep up and remove any dead insects in the bin. The overall bin spray described in the preceding **Spray Bins** section is still needed in these bins. The fumigation is primarily to kill those insects in the hard-to-clean and hard-to-spray aeration ducts and under perforated floors. Fumigation may also help reduce the number of viable mold spores.

Clean Harvesting and Handling Equipment

Thoroughly clean combines and other harvesting equipment of old grain left in the machine from last use. Such grain may contain insects and molds that could start new infestations in the newly harvested grain. Also, clean grain wagons, trucks, augers, dryers, and other handling equipment.

Initial Grain Condition

Store Dry Grain

The moisture content at which grain should be stored to maintain quality depends on: 1) the type of grain, 2) how long the grain will be in storage, and 3) the temperature and moisture of the grain while in storage. Recommended moisture content for different kinds of grain stored in Nebraska is listed in Table 6. These recommendations assume that the grain is aerated to prevent heating. Reduce the recommended moisture content by one percent when storing lower-quality grain such as immature grain, cracked and damaged grain, and grain previously attacked by insects and/or molds. Grain obviously damaged by insects and/or molds should not be stored over the summer.

The moisture recommendations refer to the wettest grain in the bin—not the average moisture content. Hot-spot development often starts in pockets of high-moisture grain which can occur as the result of non-uniform drying, condensation, bin roof or sidewall leaks, insect activity, or moisture migration. Aeration can help disperse these moisture pockets and equalize moisture within the bin.

Table 6. Maximum recommended stored grain moisture content for aerated grain.

Storage Period	*Corn and Sorghum*	*Soybeans*	*Small Grain*
Marketed by June	15.5%	13.0%	----
Up to one year	14.0%	12.0%	13.0%
Over one year	13.0%	11.0%	13.0%

Store Clean Grain

Grain containing weed seeds, cracked kernels, and other foreign material tends to become infested with insects sooner than sound, clean grain. Broken kernels and fines are also more susceptible to invasion by storage molds than are whole kernels. These problems are compounded when fines are concentrated in one area of the bin and airflow patterns are disrupted. The least amount of air is being delivered to the grain which needs it most. Fines concentrations and non-uniform airflow also cause problems when fumigating because the fumigant is not uniformly distributed within the grain mass.

Effective fines management includes minimizing the amount of fines produced during harvesting, handling, and drying operations. Steps which can be taken to minimize grain damage levels include harvesting at lower moisture contents, maintaining proper combine adjustment, and drying with natural air instead of with heat. If the grain is fairly clean, grain spreaders help to uniformly distribute fines within the bin. If grain contains a lot of fines, it should be cleaned before being placed into storage. This is especially true if the grain is to be stored for more than one year.

Don't Overfill Bins

Although a few extra bushels of grain may be stored in a bin if it is peaked, these extra bushels of storage may prove to be costly.

Peaking the grain disrupts airflow patterns within the grain mass. Most of the air moves out toward the perimeter of the structure, rather than up through the peak. Moisture migration problems are more severe in peaked storages because the peak provides an area for the moisture to concentrate.

Grain fumigation is more difficult in peaked storages. Restricted air movement through the peak makes it difficult to recirculate fumigant in that area of the bin. Also, low spots collect most of the fumigant whereas high, peaked areas will not be fumigated.

Peaking the grain also makes bin inspection difficult, if not impossible. A minimum of 4 feet of headspace is required for most grain probes. Inspecting peaked storages can be hazardous. In very tight roof spaces grain can shift or slide pinning you against the bin roof. Similar grain shifts can block access doors, trapping you in the roof space.

Grain Treatment

Grain Protectants

Dry, clean, insect-free small grain, grain sorghum, or shelled corn, can be protected from most insect damage by using liquid or dust formulations of a grain protectant.

Table 7 gives suggestions for determining the need for applying grain protectants to stored grain.

Table 7. Need for grain protectants on stored grain.

Storage period	*Need for grain protectant*
Marketed or fed by following June	Do not treat
Marketed or fed June 1 - August 1	Topdress in spring
Marketed or fed later than August 1	Treat grain at harvest

Table 8. Recommended grain protectants.

Insecticide	*Rate*
Actellic[1] (5E)	9.3-12.2 oz per 1,071 bu. 8.6-11.5 fl. oz. per 1,000 bu. in 5 gal. water.
malathion[2] (57% EC, 2, 4, 6% dust)	1 pt. 57% EC per 2-5 gal. water per 1,000 bu; 30 lbs. 2% dust; 15 lbs, 4% dust; 10 lbs. 6% dust per 1,000 bu.
Reldan[3] (4E, 3% dust)	4E: amount in 5 gal. of water; per 1,000 bu. barley - 9.2 fl. oz. oats - 6.2 fl. oz. rice - 8.6 fl. oz. sorghum - 10.7 fl. oz. wheat - 11.5 fl. oz. 3% dust: Use 10 lbs on any of above listed grains per 1,000 bu.

[1] **Actellic** Do not make more than one application per crop. Do not store diluted Actellic in spray tank more than 48 hours before use. Use only on shelled corn (field corn, popcorn) or grain sorghum.

[2] Premium grade **malathion** is registered for use on stored barley, corn, grain sorghum, oats, rye, sunflowers, and wheat, but not on stored soybeans.

[3] **Reldan** is registered for use on stored barley, oats, rice, sorghum, and wheat, but not on corn or soybeans.

Apply the insecticide to the grain stream as it goes into storage. Treating wet grain or forcing heated air through grain treated with a grain protectant will reduce the effectiveness of the grain protectant.

If grain is harvested at storage moisture or is to be dried with natural air—

Liquid formulations may be applied with gravity-flow or "drip-on" applicators, or with low pressure (10-20 PSI) powered sprayers to the grain as it is dumped from the grain cart or truck into the auger. Mix only enough insecticide for one day's use.

Dust formulations may be applied to grain on grain carts or trucks by spreading the required amount evenly over the grain surface before unloading and "cutting" it into the grain with a shovel. The protectant will be mixed satisfactorily with the grain by the augering process.

If the grain will be dried with heated air—

Applicator devices are available commercially that may be installed in the grainhandling system to apply liquid or dust formulations to the grain after it is dried and cooled.

Do not get grain protectants in eyes. Wear goggles or face shield when handling. Wear an NIOSH/MSHA approved respirator when using grain protectants to avoid breathing vapors or spray mist. Wear rubber gloves when handling concentrate. Any precautions on pesticide container label supersede these precautions.

Surface Treatment or "Topdressing"

Once the bin has been filled and leveled, the grain surface may be treated with a liquid or dust grain protectant (Table 9). This top-dressing prevents most stored grain insects from entering the grain mass and from feeding on the surface grain. Each time the surface grain is disturbed, such as when probing for moisture, temperature, or insect samples, the barrier is broken. Retreat disturbed areas with a grain protectant.

Table 9. Recommended topdressing grain protectants.	
Insecticide	*Rate per 1,000 sq. ft.*
Actellic (5E)	For Indian meal moth, beetle, and weevil control on corn and grain sorghum. 3 fluid oz 5E in 2 gal water.
Bacillus thuringiensis	For Indian meal moth control. Several formulations available. Follow label directions for dosage.
malathion (57% EC, 2, 4, 6% dust)	For beetle and weevil control. Will not control Indian meal moths. 0.5 pt 57% EC in 6 qts water. 15 lbs 2% dust; 7.5 lbs 4% dust; 5 lbs 6% dust.
Reldan (3% dust, 4E)	For Indian meal moth, weevil, and beetle control. 7 lbs 3% dust. 4E; amount in 2 gal of water; wheat - 3.0 oz sorghum - 2.8 oz rice - 2.3 oz oats - 1.6 oz barley - 2.4 oz

The best results from topdressing are obtained when the insecticide is applied **before** the insect infestation becomes obvious. Treatments applied before June 1 will be better than those applied July 15. If there is a severe infestation of Indian meal moth larvae present, there will be a crust of webbing and trash on the grain surface. This crust must be removed and destroyed before the insecticide is applied.

The topdressing insecticides must be thoroughly mixed into the top 4 to 6 inches of grain for maximum effectiveness. Better results may be obtained by splitting the application. For example, calculate total amount of insecticide needed to treat the surface. Divide this into three parts. Apply the first third to the surface, rake in with a cob fork or similar tool, apply the second third and rake in. Finally, apply the last third and do not rake it in.

Indian Meal Moth

If Indian meal moth larvae have been a problem in a bin in the past, use a topdressing of *Bacillus thuringiensis* in addition to the malathion topdressing. Malathion will not control Indian meal moths. Since *Bacillus thuringiensis* does not control weevils and other beetles; Actellic, malathion, or Reldan will still be needed to control them. Actellic or Reldan should also give effective control of Indian meal moths if applied early before a serious infestation develops.

Another aid to control Indian meal moths is the use of Vapona® resin strips hung in the bin overspace. Vapona resin strips are thin, plastic strips impregnated with the insecticide *dichlorvos*. When these strips are hung in a closed area, they give off vapor that kills insects including the moth stage of Indian meal moths. To be successful with these strips, the area to be protected must be closed without ventilation because the air exchange will reduce the vapor concentration to the point that it will no longer kill insects. Vapona strips are more effective in round metal bins than in flat storage buildings due to the amount of airspace involved. Vapona is currently undergoing an Environmental Protection Agency Special Review. Some uses may be cancelled at some future date.

The strips will control Indian meal moths in tight storage areas if they are hung above the grain with one strip for each 1,000 cubic feet of airspace over the grain. The strips must be hung before moths begin to emerge in the spring. Strips will last up to four months. If strips are used, check grain regularly to detect a buildup of moths, indicating a deterioration of the strips. Replace strips with new ones if live moths are found.

Aerosol Treatment of Overspace

Many times Indian meal moths get out-of-hand in a bin before we realize it. The recommended grain protectants are more effective in controlling the young larvae than the one-half to full-grown larvae. It may take a month or more for a topdressing application to begin to show results. In the meantime, moths are abundant and laying eggs. In this case, particularly in machine-shed flatstorage structures, fogging or mist-blowing *dichlorvos* or *pyrethrin plus piperonyl butoxide* may be advisable to knock down the moth population (Table 10).

Table 10. Aerosol sprays for bin overspace.	
Insecticide	*Comments*
dichlorvos (Vapona; DDVP; 2, 2-dichlorovinyl dimethyl phosphate)	Follow label directions for dosage rate and use directions.
pyrethrin plus piperonyl butoxide	

Postharvest Management

Once dry, clean, good-quality grain is placed in storage, it must be aerated and inspected regularly so it remains pest-free and of high quality. To be most effective, aeration and inspection management should be directed toward avoiding problem situations rather than remedying problems after they occur.

Aeration Management

The primary purpose of aeration is to keep the grain at seasonably cool temperatures. Cooling the grain to 35° F before winter helps reduce air convection currents and prevent moisture migration. To prevent condensation problems when storing grain over the warm summer months, it is recommended that stored grain be warmed back up to 60° F. This seems to be the best compromise for a summer storage temperature which minimizes the chances of condensation while also being cool enough to retard insect and mold activity.

While there are a number of other fan operation schedules that can be used to maintain stored grain quality, the following management procedure is presented as one strategy which meets basic aeration requirements. Adapt it as necessary to meet your individual needs and conditions. The information in Table 11 can be used to estimate the length of time required to move a cooling or warming zone through the bin for your airflow design. This information is needed to apply the fan management procedure outlined below.

Table 11. Relationship between airflow rate and the approximate time required to move a cooling or warming zone through grain.

System Type	*Airflow Rate Cubic Feet Per Minute Per Bushel*	*Cooling or Warming Time, Hours*
Natural Air Drying	1	12 - 15
	3/4	16 - 20
Aeration	1/5	60 - 75
	1/10	120 - 150

Aeration Schedule Calendar

Fall

- Move at least one (preferably two) cooling zone(s) through the grain to remove field or dryer heat and help equalize moisture content.
- Thereafter, move one cooling zone per month through the grain until it is cooled to between 30° and 40° F.
- Check the grain temperature and condition every two weeks and as needed to monitor cooling zone progress.

The initial cooling is important. Do not skimp on fan operation. Turn the fans on as soon as grain covers the perforated floor or aeration ducts and operate them continuously until all the grain has been cooled to the prevailing outside temperature. Since cooling is the primary concern, especially if the grain has come from a dryer, do not turn the fans off during rainy or humid weather. Failing to get the grain properly cooled can cause more problems than the small amount of rewetting that occurs from running the fan on a humid day.

In Nebraska, average air temperatures drop at the rate of 2.5° to 3° F per week during the fall. Thus, moving a cooling zone through the grain once per month will keep grain temperatures within 10° F of the outside air temperature. Continuous fan operation is recommended to make these monthly temperature changes, but a carefully managed intermittent fan operation schedule can be used to move a cooling zone through the grain. However, intermittent fan operation may make it more difficult to keep track of the location of the cooling zone.

Whichever program is followed, keep grain temperature within 10° F of the average outside air temperature to minimize moisture migration and condensation problems.

Winter

- Check the grain temperature and condition at least once a month.
- Aerate as needed to maintain grain temperature between 30° and 40° F.

During the winter it is not necessary to think in terms of moving cooling zones through the grain. The aeration system needs to be operated only on a maintenance schedule to control localized temperature increases. In fact, it may not be necessary to run the fan at all during the winter if the grain remains dry and in good condition. One aeration strategy is to operate the fan for a few hours as part of a biweekly or monthly grain checking program. This allows the operator to check the exhaust air for "off-odors"—an indication that the grain requires immediate attention.

Avoid operating the fan on very cold or very warm days. This is especially true on days when the air temperature is warmer than the grain temperature since fan operation can result in moisture condensing and possibly freezing on the grain. Condensation problems can be prevented by operating the fan only when outside air temperatures are the same or cooler than grain temperatures.

Freezing grain is not generally recommended because of the increased likelihood of condensation problems if the grain is not properly warmed in the spring. However, freezing the grain becomes a secondary concern if the grain begins to heat or go out-of-condition. If a problem occurs, operate the fan continuously regardless of weather conditions until the problem is corrected.

Spring

- If the grain is not frozen and will be marketed or fed by June, aerate only as needed to control hot spots and heating problems.
- If the grain is frozen, move a warming zone completely through the grain as soon as temperatures are above freezing.
- If the grain is to be held until July or August, move one warming zone per month through the grain until it is uniformly warmed to 60° F.
- Check the grain temperature and condition every two weeks and as needed to monitor warming zone progress.

There is little reason to warm the grain if it is to be marketed or fed by June. One exception is that frozen grain should always be thawed before being handled in warm weather. Operate aeration fans continuously when thawing frozen grain to prevent freezing of condensed moisture on the grain.

Fans should also be operated continuously when warming grain to 60° F in preparation for summer storage. Although it would seem to make little sense to go to the trouble of warming grain in the spring after cooling it down in the fall, this is an important step for

summer storage. This temperature is cool enough to slow most insect and mold activity, yet is warm enough to minimize condensation if the aeration fans need to be operated to control localized heating in the bin. Since average outside temperatures change at the rate of 2.5° to 3° F per week, one warming zone per month should be sufficient to maintain uniform grain temperatures.

Summer

- Check the grain at least once every two weeks to monitor temperature, moisture, and insect activity.
- Consider operating the fan one night per week through June to help maintain grain temperature at 60° F.
- Otherwise, cover fan openings during June, July, and early August.

Not all of the grain going into the summer at 60° F will remain at that temperature. The grain along the bin sidewall and the grain surface will be gradually warmed over the course of the summer. Operating the fan on cool nights helps to bring these temperatures down. However, aeration is normally beneficial for only the early and late part of the summer because of high temperatures during July and August. Do not operate the fan during these months unless a problem situation develops.

Although aeration fans are not normally operated during this period, there are still some temperature control measures that can be effective. One is to ventilate the roof space to prevent high summertime temperature buildups. This can be accomplished to varying degrees by using equipment ranging from gravity vents to exhaust fans.

Perhaps more important than moving air through the roof space is keeping air from moving down through the grain. The best way to do this is to **cover the aeration fan openings when the fans are not in operation.** If the fans are not covered, the cooler air in the grain will move out of the bin through the fan and draw warmer air down into the grain. Such airflow can gradually warm all of the grain in the bin up to 70° to 80° F. These temperatures increase the risk of mold problems and provide a favorable environment for insect activity.

Checking Grain Condition

Inspect grain regularly for insect, mold, rodent, bird, and heating problems. Problems must be detected early if they are to be corrected before extensive damage occurs.

Grain checking is most important during the summer because grain is being held at higher temperatures and aeration conditions are less favorable than for the rest of the year. Grain temperature needs to be checked and recorded on a regular basis. Without temperature records it is difficult to tell whether warm grain temperatures are due to high outside air temperatures or by heating due to mold and/or insect activity. Insect activity is also at a peak during the summer and frequent checking is required if infestations are to be controlled before they develop into major problems.

Check the grain for heating and off-odors weekly. Use a sharp-pointed stick or rod and determine if hard, compacted areas are developing. During warmer months, take probe samples of the grain every 1 to 2 weeks. In the winter when the grain is cooler, take probe samples of the grain every 4 to 6 weeks. Buy or borrow a grain probe from your local grain buyer. Be aware of possible electrical hazards when using metal probes and ladders.

During cold weather insects will congregate near the center of the grain mass where it is warmest, so sample the center of the grain mass thoroughly during the winter. During warm weather infestations usually begin near the surface, so pay special attention to that area during the summer.

Follow a systematic procedure when taking probe samples. When first entering the bin, insert the probe horizontally 2 to 4 inches under the grain surface in the center of the bin before the grain surface is disturbed. Empty each sample into a grain sampling tray or section of eavestrough long enough to accommodate the grain probe. Sift the samples through a 10- to 12-mesh per inch screen and examine for insects.

Take additional surface samples around the sides of the bin. Look on the grain surface and bin walls for webbing and Indian meal moths. Then probe from the top to the bottom of the grain mass. Extensions may have to be attached to the probe so that it can penetrate to the bin floor. Deep bins may require the use of vacuum probes to get to the bottom.

In round bins, start the deep probes at the center, then probe around the wall. Insert the probe about one foot from the outer wall. Make surface and deep probes at the north, west, south, and east sides of the bin. Examine each sample for insects. In larger bins, samples may have to be taken at more locations, no farther apart than every 20 feet around the wall. Bins with diameter of more than 40 feet should also be sampled more than once near the center.

In flat storage bins, sample grain in the center and around the walls. Take samples no farther than 20 feet apart. Take surface probes first, then probe from the top to the bottom, examining each sample for insects.

Always retreat surface with a topdressing of grain protectant after taking the samples.

If you find signs of insect damage or insects in the probe samples and cannot identify the insects, ask your local extension agent or elevator manager for help in identifying them.

New methods of detecting stored grain insects are being developed. Chemical attractants and specially designed traps show promise in detecting early insect infestations. Most of them appear relatively easy to use and are economical. Your local grain buyer or chemical dealer can obtain them through their supply system.

Control Options for Insect-Infested Grain

What should be done if a farmer finds that he has insects in his stored grain? The first thing to determine is—what type of insects are causing the problem? Are they Indian meal moth larvae, external feeding beetles, or internal feeding insects? Secondly—is the grain going to be fed, sold, or kept?

If **Indian meal moth larvae** are the main problem, and **if the grain is going to be fed,** little needs to be done except get the bin emptied out as soon as possible. If the bin won't be emptied for a period of time, then the crust should be removed, *Bacillus thuringiensis* worked in as a topdressing, and an aerosol application of *dichlorvos* or *pyrethrin* applied to the overspace. When the bin is empty, do a thorough cleanup, use residual sprays, and fumigate the empty bin as described earlier. Use an appropriate grain protectant on any new grain placed in the bin.

If **Indian meal moth larvae** are the problem, and **if the grain is going to be sold,** removing the top 1 to 2 feet of grain will usually take off the Indian meal moth larvae. The infested grain can be fed. If feeding is not possible, then fumigating with aluminum phosphide would be an alternative. Seal the bin, probe in the fumigant, cover with plastic, leave sealed for 3 to 5 days, and properly air out the bin. Take air samples to make sure that the gas level is **below** the EPA exposure limit (Table 12). Then deliver the grain. The control obtained by treating the grain with a grain protectant while the grain is being loaded into a truck is too slow to be effective.

Table 12. Environmental Protection Agency exposure limits without approved respiratory protection for hydrogen phosphide gas released from aluminum phosphide during fumigation.

0.3 ppm	8-hour Time Weighted Average during application.
0.3 ppm	Exposure ceiling anytime after fumigation. Fumigation warning placards may be removed after gas level in grain is below 0.3 ppm.

If **Indian meal moth larvae** are the problem, and **if the grain is going to be kept in storage,** remove the crust layer, fumigate with aluminum phosphide. To determine whether aeration is complete, each fumigated site must be monitored and shown to contain 0.3 ppm or less hydrogen phosphide in the airspace around, and when feasible, in the mass of commodity. When air samples indicate that the gas level is below the EPA threshold level, and the bin is aired out, work in a topdressing of *Bacillus thuringiensis* into the top 4-6 inches of grain.

If **external feeding insects** are the problem, and **the grain is to be fed,** feed it out as soon as possible. When the bin is empty, clean it, apply residual sprays, and do an empty bin fumigation. Use a grain protectant on new grain going into the bin.

If **the grain is to be sold,** it can be fumigated several days before delivery. The grain could be treated with a grain protectant as it is being augered into the truck. Check with your grain buyer beforehand to be sure that they will accept grain that has an insecticide odor. To determine if the fumigant gas is aired out, each fumigated site must be monitored and shown to contain 0.3 ppm or less hydrogen phosphide in the airspace around, and when feasible, in the mass of commodity. Take air samples to determine that the gas level is below the EPA threshold level.

If **the grain is to be kept,** the best alternative is to fumigate. A second choice is to move the grain. Apply an appropriate grain protectant to the grain while it is being moved from the infested bin into a clean bin. The moving action itself will destroy many of the insects in the grain.

If **weevils or other internal feeding insects** are the problem in **grain that is to be fed,** feed it out, clean the bin, fumigate, etc. as described for Indian meal moths and external feeding insects.

If **the grain is to be sold or kept,** the only effective control is fumigation. Treating the grain with a protectant as it is being moved, may control the adults, but will have no effect on the eggs, larvae, or pupae inside the kernels.

Fumigation

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.

Fumigants affect grain pests only when the gas is present in the insect's environment. After the fumigant diffuses out of the grain, no residual protection is left behind and the grain is 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.

It is generally safer, less expensive, and more effective for farmers to have their stored grain fumigated by a trained, experienced and certified professional 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, experience, and the special, usually-expensive equipment needed to properly apply and monitor fumigants. In addition, professionals will have safety equipment such as gas masks or self-contained breathing apparatus which are expensive but required when applying any fumigant.

However, professional fumigators are not always available to service farmstored grains and many farmers prefer to handle this phase of stored grain management themselves. Specific directions for fumigating round bins with aluminum phosphide are discussed in

NebGuide 86-790 (Revised December 1987), *Fumigating Farm-Stored Grain with Aluminum Phosphide.* Copies of this NebGuide are available at your local extension office.

Flat storage structures and large round bins present special problems in keeping the fumigant in place long enough to cause an effective kill. Commercial applicators often recirculate the fumigant in these structures to distribute the fumigant more uniformly through the grain. They do this by attaching a return duct between the overhead space above the grain surface and the fan on the aeration duct. Depending on the direction of the air movement, the fumigant can be drawn or pushed through the grain and then directed back to the grain by a return duct. The fumigant is generally recirculated for a time estimated to produce two or more air changes within the stored commodity. Grain may be fumigated effectively at greater depths when bins are equipped with recirculating equipment. Some fumigators use large diameter plastic tubing to recirculate the air rather than the bin having a permanent recirculation setup.

Since all fumigants are Restricted-Use Pesticides, all fumigators must be certified by the Environmental Protection Agency to purchase and use them.

Fumigant Types

The principal type of fumigant now used for fumigation of farm-stored grain is solid formulations of aluminum phosphide. Limited amounts of chloropicrin and methyl bromide (a compressed gas) are also used in farm storage.

CHLOROPICRIN is a non-flammable liquid fumigant marketed in pressurized and nonpressurized containers. The label directions permitting use on stored grain were cancelled for most brands of chloropicrin in 1987 and is not recommended for that use now. It is very effective for use as an empty bin fumigant in cleaning out under perforated floors and aeration ducts. Chloropicrin is more than five times heavier than air; when applied to a grain bin it will settle to the bottom of the bin. The labeling permitting this use will probably be continued. Check labels on containers you will be using.

Chloropicrin is highly corrosive to most metals and may adversely affect the germination of most seeds. Chloropicrin is particularly effective against immature stages of grain pests and is especially toxic to the various stages of the Indian meal moth.

The irritating qualities of chloropicrin, even at low concentrations, provide warning and protection for the user against accidental exposure. However, the presumed warning qualities of chloropicrin should not be depended upon as the sole criterion of safety. Because of this, EPA has set an exposure limit of 0.1 ppm for chloropicrin.

CHLOROPICRIN SUMMARY

- EPA exposure limit of 0.1 ppm.
- Gas reading required on each fumigation.
- Use of proper gas mask or self-contained breathing apparatus required with gas concentrations above 0.1 ppm.
- Use directly on grain prohibited for most brands in 1987.
- Recommended for empty bin fumigation.

METHYL BROMIDE is a gaseous fumigant marketed as compressed, liquefied gas packed in special 1 or 1.5 pound cans or in cylinders of 50 to 1,500 pounds. The gas has virtually no odor at normal concentrations and no irritating qualities to indicate its presence. Methyl bromide with chloropicrin warning agent is no longer legal for use on stored grain. This makes the use of methyl bromide extremely hazardous for use by persons other than those trained and properly equipped with respiratory protection and monitoring devices.

Methyl bromide is nonflammable, penetrates grain well, and provides a very rapid kill of insect pests. It is over three times the weight of air, so recirculation or other techniques may be needed to ensure even distribution of the gas, particularly in large, deep storage structures. Recirculation is desirable for high-peaked flat grain storage.

Prolonged contact of liquid methyl bromide with the skin produces severe blisters similar to those caused by burns. Don't spill liquid methyl bromide on clothing or shoes. If spilled, remove the contaminated clothing quickly. Because the fumigant can become trapped between gloves or boots and the skin, don't wear gloves or rubber boots when working with methyl bromide.

The distribution problems and the extreme hazard of methyl bromide are reasons that this product should only be used by trained professional fumigators.

Methyl bromide can affect the germination of seeds such as grain sorghum and other grass seeds, and many other grains, particularly at high moisture levels or high dosages.

METHYL BROMIDE SUMMARY

- Primarily applied by professional fumigators.
- Good sealing is critical.
- Complete kill above 20 feet grain depth is unlikely without recirculation.
- Leveling of grain or probing into peaks is recommended.
- Seed grain should not be fumigated with methyl bromide.
- EPA exposure limit of 5.0 ppm.
- Gas reading required on each fumigation.
- Self contained breathing apparatus required on each fumigation.
- Methyl bromide with chloropicrin warning agent not to be used on stored grain after October 31, 1987.
- 100% methyl bromide may be used on stored grain.

ALUMINUM OR MAGNESIUM PHOSPHIDE are solid formulations of phosphine-producing fumigants. Aluminum phosphide has become one of the predominant fumigants used for the treatment of bulk-stored grain worldwide.

Phosphine has no adverse effects on seed germination when applied at normal dosage rates and is the choice of fumigants for seeds or malting barley. It is also widely used in the fumigation of processed foods since excessive fumigant residues have not been a problem with phosphine.

Phosphine can react with copper and copper-containing alloys such as brass, gold, and silver, resulting in corrosion and discoloration of exposed surfaces. This can result in damage to contact points, telephones, computers, and other electronic equipment. This problem is rare and apparently only occurs when there is a high concentration of phosphine in combination with high humidity and high temperature. But care still needs to be exercised in all fumigations. In the normal farm grain bin, there is little that could be harmed by phosphine, other than temperature cables.

Solid aluminum phosphide formulations, which release hydrogen phosphide (phosphine) gas when exposed to moisture and heat, are available in tablets, pellets, paper sackets, plates, and blister strips. Tablets or pellets are usually used in farm-stored grain. If the liberation of hydrogen phosphide occurs too rapidly in a confined area, an explosion or fire can occur. Therefore, **never put aluminum or magnesium phosphide in water!**

To control the rate of release, aluminum phosphide is formulated with other compounds which control the release rate and lowers the combustibility of the mixture. In some formulations, carbon dioxide is given off in the reaction to help retard this problem. Good practices in fumigation will result in concentrations that are probably no more than 1/25 of the amount that would result in a fire. Don't confine aluminum phosphide products that have been exposed to air in small volume containers. For example, partially spent aluminum phosphide dust may ignite or explode spontaneously if sealed in a plastic bag.

As shown in Table 13, the time required for release of hydrogen phosphide gas is much shorter on warm, humid days (or in warm, damp grain) and much longer on dry, cold days (or in cold, dry grain).

Table 13. Guide to determine the minimum length of exposure period[1] for aluminum phosphide.

Temperature to Which Fumigant and/or Insects are Exposed	*Pellets*	*Tablets*
Below 40° F	Do Not Fumigate	Do Not Fumigate
40° F - 53° F	8 days (192 hrs.)	10 days (240 hrs.)
54° F - 59° F	4 days (96 hrs.)	5 days (120 hrs.)
60° F - 68° F	3 days (72 hrs.)	4 days (96 hrs.)
Above 68° F	2 days (48 hrs.)	3 days (72 hrs.)

[1] As a "rule-of-thumb" a minimum of one day should be added to the exposure time listed above for each 10 feet the gas must penetrate downward. It is preferable to add 2 days for each 10 feet.

With grain temperature above 60° F, decomposition of tablets or pellets and release of gas should be nearly complete in three days. With temperature below 40° F and low grain moisture (below 10%), there may still be appreciable gas evolved for at least ten days.

Phosphine is only slightly heavier than air (20% heavier) but will diffuse rapidly through the grain mass because it is not strongly sorbed by grain. This combination of low sorption loss and good penetration means that bins treated with this fumigant must be gastight. This gas loss problem is partially solved because the leaked gas is being replaced, from the tablets or pellets, during the fumigation.

The formula for the various aluminum phosphine products varies somewhat between manufacturers, but the formulation is usually packaged in 3 gram tablets or 0.6 gram pellets for bulk grain fumigation. Aluminum phosphide tablets and pellets may be applied to the grain mass by probing them below the grain surface, added as the grain is turned, or applied to the aeration ducts below the grain. Tablets are usually used for fumigating farm storage and are probed into the grain. Each tablet produces 1 gram of phosphine and each pellet produces 0.2 grams of hydrogen phosphide.

Magnesium phosphide is a relatively new material that has been developed to release phosphine gas. It is formulated in cloth-covered plates (strips) which are sealed in plastic envelopes, and then packed in metal cans. These formulations dispense the same hydrogen phosphide gas (phosphine) but release it more rapidly. Present distribution is limited to professional fumigators.

PHOSPHINE SUMMARY

- Good sealing is critical.
- Important to keep bin sealed for 3 to 10 days (see Table 13).
- Probing fumigant into grain greatly improves the results.
- Recirculation or modified application techniques required for grain deeper than 30 feet.
- EPA exposure limit 0.3 ppm (See Table 12).
- Gas readings required in most fumigations.
- Full-face gas mask required between 0.3 to 15 ppm (or for escape situations).
- Self-contained breathing apparatus required above 15 ppm.
- Many label changes occurred with phosphine in 1987. Be sure you have the latest label and follow the directions.

Cautions

All fumigants are dangerous. Used properly they are an important tool in managing insect pests of stored grain. Follow the cautions listed on the container label and supplementary manuals and use only in strict accordance with label directions.

The type of respirator protection required varies with the kind of fumigant and the concentration of gas present. See the individual summaries of fumigants stated earlier in this publication for the EPA exposure limits and type of respiratory protection required.

Avoid spilling fumigant on the skin, clothing, or shoes. Remove fumigant-wetted clothing or shoes at once and wash the skin thoroughly with soap and water.

Never fumigate a bin by yourself. Have someone else around to help should you get into trouble. The helper must also be properly fitted with respiratory protection devices. Have a signal code devised so that you can communicate with each other. Make sure gas and electrical connections are turned off. Have the telephone numbers of the police and fire departments, hospital, physician and rescue squad available.

Do not drink alcoholic beverages for a day before, during, and one day after exposure to grain fumigants. Do not think that because you might have "gotten-away" with fumigations without these precautions before, that you can always get away with disregard for safety. Fumigants demand respect if you want to avoid injury or death.

Summary

Grain is food—protect it from insect, mold, rodent, and bird damage and contamination. Insect, mold, rodent, and bird damage can be reduced in stored grain by:

1. Cleaning bins, harvesting, and hauling equipment.
2. Cleaning outside of bins.
3. Spraying bin walls and floors.
4. Excluding birds and rodents.
5. Storing sound, dry, clean grain.
6. Cooling grain after drying.
7. Using grain protectants.
8. Topdressing grain surface.
9. Following recommended aeration schedule.
10. Inspecting grain regularly.
11. Fumigating, if needed.
12. Always read and follow label instructions when using pesticides.

Additional References

Several NebGuides with additional information on stored grain management are available at your local extension office.

G79-461 - Controlling Rats
G79-470 - Controlling House Mice
G80-516 - Burrowing Rodent Control with Gas Cartridges
G81-580 - Starlings and Their Control
G82-624 - Bait Stations for Controlling Rats and Mice
G83-656 - Rodent Proof Construction—Structural
G78-418 - Checking Condition of Stored Grains
G84-692 - Aeration of Stored Grain
G85-760 - Natural Air Corn Drying
G86-790 - Fumigating Farm-Stored Grain with Aluminum Phosphide (Revised December 1987)

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