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EC84-1534 Revised Pest Management of Farm-Stored Grain

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PEST MANAGEMENT

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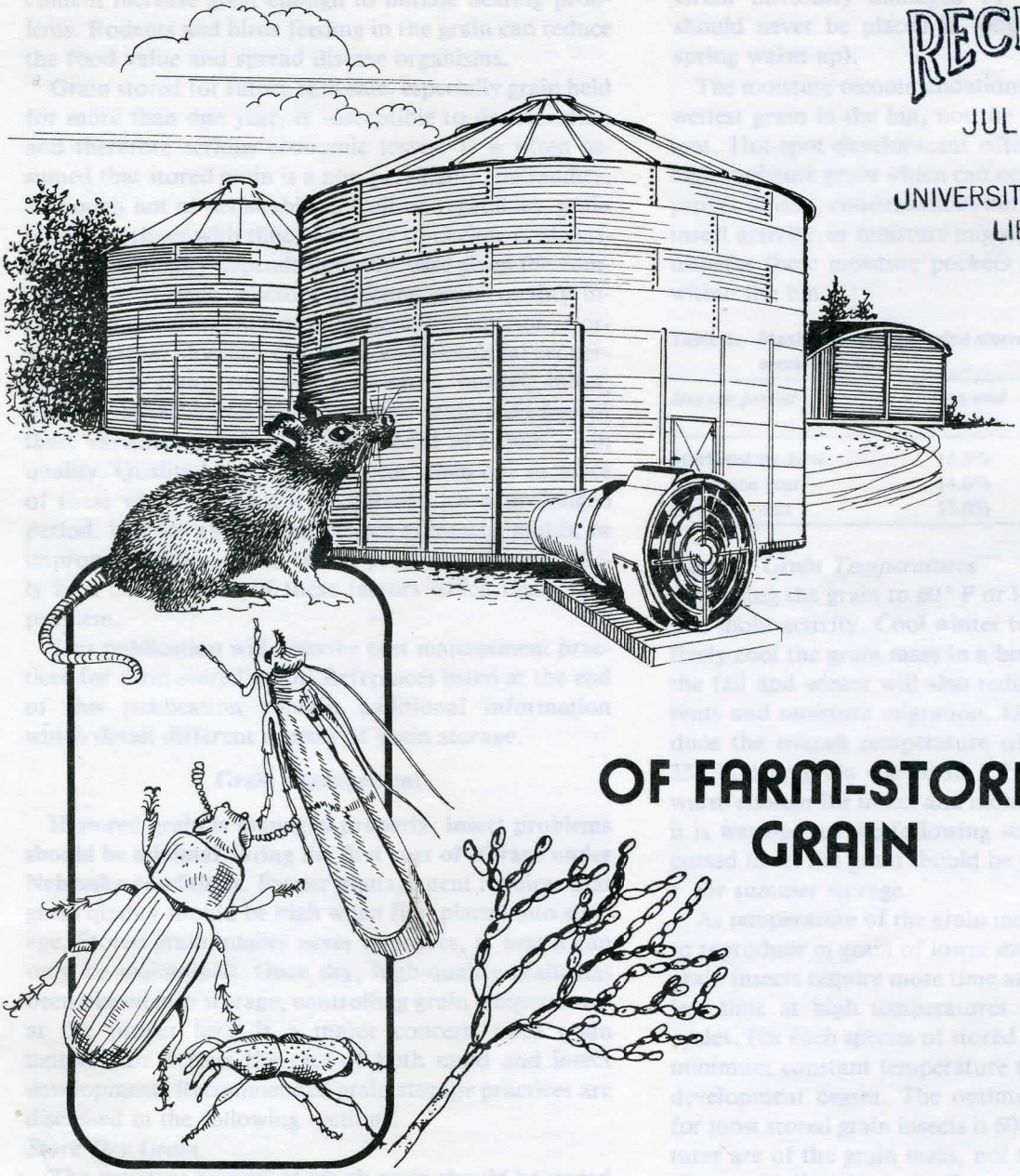

OF FARM-STORED GRAIN

Issued in furtherance of Cooperative Extension work, Acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture. Leo E. Lucas, Director of Cooperative Extension Service, University of Nebraska, Institute of Agriculture and Natural Resources.

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PEST MANAGEMENT OF FARM-STORED GRAIN

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Grain may be stored on the farm for many reasons such as to feed livestock or in the 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 cause a moisture content increase great enough to initiate heating problems. Rodents and birds feeding in the grain can reduce the food value and spread disease organisms.

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 often assumed that stored grain is a non-perishable commodity. Although not as perishable as fruit or vegetables, grain quality declines with time. The rate of decline or deterioration in quality 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. It is not a single factor such as insects, molds, or improper aeration which causes problems, but will likely be a combination of these factors which result in a problem.

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.

Grain Management

If stored grain is managed properly, insect 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.

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 of the grain while in storage. Recommended moisture content for different kinds of grain stored in Nebraska is listed in Table 1. These recommendations assume that the grain can be and is aerated to prevent overheating. Reduce the recommended moisture content by one percent when storing lower quality grain such an immature grain, cracked and damaged grain, and grain previously attacked by insects and/or molds. Grain obviously damaged by insects and/or molds should never be placed in long-term storage (beyond spring warm-up).

The moisture recommendations in Table 1 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 improper 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 1. 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%

Control Grain Temperatures

Cooling the grain to 60° F or lower will reduce insect and mold activity. Cool winter temperatures can effectively cool the grain mass in a bin. Cooling the grain in the fall and winter will also reduce air convection currents and moisture migration. Use aeration fans to reduce the overall temperature of the grain to around 35° F. Dry grain cooled to 35° F should not become warm enough for insect and mold damage to occur until it is warmed up the following summer. As will be discussed later, the grain should be warmed to around 60° F for summer storage.

As temperature of the grain increases, insects are able to reproduce in grain of lower moisture content. Stored grain insects require more time at low temperatures and less time at high temperatures to complete their life cycles. For each species of stored grain insects, there is a minimum constant temperature threshold below which development ceases. The optimum temperature range for most stored grain insects is 60-99° F. These temperatures are of the grain mass, not the temperature of the air surrounding the grain. Some stored grain insects can withstand temperatures below freezing for a few days.

Store Clean Grain

Grain containing weed seed, cracked kernels, and other foreign material tends to become infested with insects sooner than sound, clean grain. Mold growth and mycotoxin formation is associated with cracked kernels and debris. Air flow patterns, when aerating, may be adversely affected by cracked kernels, grain dust, and other foreign material. To obtain whole kernels, adjust the combine so that minimum cracking and maximum cleaning is obtained. Grain to be stored more than one year should be screened before storage. Small foreign material or "fines" will pack densely in a central core when grain is loaded into a bin. This packed column will inhibit air flow during aeration and fumigant movement during fumigation. Fines commonly have higher moisture content than the surrounding grain and are more susceptible to invasion by storage molds and many insects than are whole grains.

Don't Overfill Bins

Although a few extra bushels of grain may be stored in a bin if it is peaked up and not leveled, these few extra bushels of storage may prove to be very costly.

Peaking the grain changes the airflow characteristics within the grain mass. Most of the air moves around the perimeter of the structure rather than evenly throughout the grain. The center of the grain mass may develop serious moisture and temperature problems which result, at least in part, in condensation. Grain fumigation will be unsuccessful because of poor airflow. Also, low spots will collect most of the fumigant whereas high spots will not be fumigated.

Peaking the grain also makes bin inspection difficult, if not impossible. If the surface grain can't be inspected and probed, potential problems won't be detected until the grain quality has seriously deteriorated.

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. Screens with holes 3/4-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 and to reduce convection currents within the grain.

Clean Outside Bins

Do not allow junk to accumulate, or weeds and grass to grow next to the bin. The 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.

Clean Inside Bins

Grain and grain debris may harbor insects and molds that will infest the 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 2) at least two weeks before storing grain. Check the insecticide container label for dosage rates.

Use a compressed air sprayer or similar equipment and spray surfaces to the point of runoff. 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.

Table 2. Recommended grain protectants. (Effective date--December 6, 1985)

Insecticide	*Empty Bin Spray*	*Grain Protectant*	*Topdress*
Bacillus thuringiensis[1]	No	No	Yes
Malathion[2]	Yes	Yes	Yes
Methoxychlor[3]	Yes	No	No
Reldan[4]	Yes	Yes??	No

Follow container label instructions for dilution and application directions.

1 *Bacillus thuringiensis* is registered for use on stored grains and soybeans under various trade names. The treated grain may be sold or fed anytime after treating.

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

3 *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.

4 *Reldan* is registered for use as an empty bin spray or for use on stored barley, oats, rice, sorghum, and wheat, but not on corn or soybeans. 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. These are valuable additions to the bin for managing temperature and moisture; however, 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, if not impossible, to clean and spray under perforated floors or non-removable air ducts in many bins. In such cases, remove as much of the grain debris as possible, then fumigate the empty bin with chloropicrin (a RESTRICTED-USE PESTICIDE, to be applied only by certified applicators). Before applying the fumigant, seal around doors, foundation, and outside fan openings to prevent escape of the gas. Apply the required amount of chloropicrin from OUTSIDE the roof hatch. Place signs at all doors and hatchs indicating that the structure is being fumigated. Wait at least 48 hours then remove sealing material, turn on fans, and aerate until all gas is exhausted. Do not enter the bin until it has aired out. After it has aired out, sweep up and remove any dead insects before putting grain into 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, and 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 that might have been 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.

Grain Treatment

Grain Protectants

Dry, 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. See Table 2 for recommended grain protectants and limitations on their uses. Apply the insecticide to the grain stream as it comes out of the combine, if grain is dry, or as it is elevated into final storage if dried with heated air. Forcing heated air through grain treated with a grain protectant will reduce the effectiveness of the grain protectant. **When using heat to dry, apply the grain protectant after the grain has been dried and cooled.**

Protectants should be applied to the grain just before it reaches final storage.

If grain will 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. 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 commercially available that will apply protectants to the grain after it is dried and cooled.

Surface Treatment

Once the bin has been filled and leveled, the grain surface should be treated with a liquid or dust grain protectant (Table 2). This "topdressing" 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 or insect samples, the barrier is broken. Retreat disturbed areas with grain protectant.

Indian meal moths are one of the major insect pests in Nebraska farm-stored grain. The adult is a moth about one-third to one-half inch long. The wing tips are dark red or brown, with the basal one-third light gray. Full-grown larvae are about one-half inch long, dirty white in color, sometimes with a pinkish or greenish tinge, and a dark brown head.

Larvae prefer to feed on cracked or broken seeds, or weed seeds, but will feed on the germ of whole kernels. Larvae feed only in the upper portion of the grain mass unlike most other stored grain insects that will feed on the grain throughout the bin. The top 1-2 inches of the grain is often webbed together by Indian meal moth larvae. In a severe infestation, a crust of webbing and trash will be very obvious. This crust hinders fumigant penetration, protects the larvae from contacting the grain protectant "topdressing", and reduces the effectiveness of aeration fans. Remove the crust and damaged grain before treatment or before the grain bin is emptied.

If Indian meal moth larvae have been a problem in the past, use a topdress of *Bacillus thuringiensis* (Dipel®, SOK-BT®) in addition to malathion since Indian meal moths are resistant to malathion. If Reldan® is used as a grain protectant, a "topdress" of *Bacillus thuringiensis* is not needed. *Bacillus thuringiensis* does not control weevils and other beetles; therefore, malathion or Reldan is still recommended for use as a grain protectant and "topdress" in addition to "topdressing" with *Bacillus thuringiensis*. Follow pesticide container label instructions for dosage rates.

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. 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.

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 at least insects once each month for a buildup of insects. Replace strips with new ones if live insects are found.

Aerating and Checking Stored Grain

Once dry, clean, good-quality grain is placed in storage, it must be aerated and inspected regularly so it remains pestfree and of high quality.

Aeration

Develop and follow an aeration schedule in bins with false floors or aeration ducts. The purpose of aeration is to maintain uniform temperature and moisture conditions throughout the grain mass, prevent localized hotspot development, and cool existing or developing hotspots. Proper aeration is valuable in reducing insect and other pest problems in the grain.

There are a number of fan operation schedules that can be used to maintain stored grain quality. Following the management procedure outlined below will help assure that basic aeration requirements are met. Adapt it as necessary to meet your individual needs and conditions.

A well-defined temperature profile develops within the grain during the cooling/warming process. The actual cooling/warming takes place in a 1- to 2-foot thick cooling/warming zone which moves through the grain as it cools/warms. See Table 3 for the relationship between airflow rate and time on moving air through a grain mass.

Table 3. 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

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 of 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-spot" 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.

Grain checking is 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 high 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.

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 temperature 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 air flow 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. If problems are detected early enough, they can be controlled before extensive damage occurs.

Check the grain for heating and off-odors weekly. Use a sharp pointed stick or rod and determine if hard, compacted areas are developing. Probe samples of the grain do not have to be taken each week. In the winter, when the grain is cooler, take probe samples of the grain every 4 to 6 weeks. During warmer months, take probe samples of the grain every 1 to 2 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. Use the aeration system to minimize temperature variations within the bin. 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. 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.

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. Collect the sample and look for insects. Take additional surface samples around the sides of the bin. 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 extremely large bins, samples may have to be taken at more locations, no further 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 further 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 topdressing of grain protectant after disturbing the grain.

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.

When To Fumigate

If one granary weevil, one rice weevil, or one lesser grain borer, or as many as five insects of other species such as flour beetles and saw-toothed grain beetles are found per quart sample of grain, fumigation of the grain is necessary to prevent further insect damage. Fumigants will also kill rodents. Many times, however, the rodents will not be living in the bin, only visiting it to feed. Grain temperature should be above 65° F for the fumigant to be effective.

New methods of detecting stored grain insects by the use of specially-designed traps and chemical attractants are being developed. These traps show promise in detecting developing pest problems before they become serious problems. They appear to be easy to use and economical, and when available, will offer an alternative to the grain probing method.

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 insects' 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 often 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 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 stored grain management themselves. The following information can help the farmer or new commercial fumigator better understand the properties of grain fumigants and the factors that influence their effectiveness. Specific directions for fumigating round bins with aluminum phosphide are discussed in NebGuide 86-790, *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.

Applicators must be certified to apply fumigants, since fumigants are Restricted-Use Pesticides.

Fumigant Types

The principal type of fumigant currently legal 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 as a space, grain, and soil fumigant, as well as a warning agent for methyl bromide. Chloropicrin is more than five times heavier than air; when applied to a grain bin it will settle to the bottom. Chloropicrin is recommended as an empty-bin fumigant to kill the insects present beneath the perforated floors in bins so equipped. Chloropicrin vaporizes when exposed to air. This gas is heavily sorbed by grain and may require long periods of ventilation or aeration to remove the odor and resulting "tear gas" effect following fumigation. Chloropicrin is marketed in cans of 1 to 32 pounds and in cylinders of 70 to 375 pounds each.

Chloropicrin is highly corrosive to most metals and may adversely affect the germination of most seeds. It should not be used to fumigate seed grains. 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 very 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.

METHYL BROMIDE is a gaseous fumigant marketed as compressed, liquified gas packed in special 1 or 1.5 pound cans or in cylinders of 50, 100, or 200 pound capacity. As with other fumigants, the cost is lower when purchased in larger containers. However, farmers should not try to store fumigants but should buy only enough fumigant for each fumigation. Methyl bromide readily evolves into a gas when the container is opened if the temperature is above 39° F. The gas has virtually no odor at normal concentrations and no irritating qualities to indicate its presence. It is formulated as 100 percent methyl bromide and as a mixture with 1/2 to 2 percent chloropicrin added as a warning agent.

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.

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 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 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.

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. Phosphine is always a safer choice when seed germination is a factor.

Undesirable odors can result when certain materials are exposed to methyl bromide. Your pesticide dealer can furnish a list of potentially affected materials.

SOLID FORMULATIONS OF ALUMINUM OR MAGNESIUM PHOSPHIDE are phosphine-producing fumigants and have 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 the normal farm grain bin, there is little that could be harmed by phosphine.

Solid aluminum phosphide formulations, which release hydrogen phosphide (phosphine) gas when exposed to moisture and heat, are available in tablets, pellets, and powder—packed in paper sackets. 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 such as ammonium carbonate or aluminum sterate and calcium oxide which controls 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 1/50 of the amount that would result in a fire.

Manufacturers of aluminum phosphide fumigants indicate that there is a delay before phosphine is evolved in large quantities from commercial formulations. There is usually a 1 to 2 hour delay with pellets or a 2 to 4 hour delay with tablets before dangerous amounts of phosphine are released. The time required for release is much shorter on warm, humid days and much longer on dry, cold days. With grain temperature above 60° F, decomposition should be nearly complete in three days. With low temperature and low grain moisture (below 10%), there may still be appreciable gas evolved for at least five 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 the low sorption loss and the great penetration capacity of phosphine means that bins treated with this material must be fairly gastight. This gas loss problem is partially solved because the leaked gas can be replaced, from the tablets or pellets, constantly during the fumigation.

The formula for the various aluminum phosphine products varies somewhat between manufacturers, but this fumigant is usually packaged in 3 gram tablets or 0.6 gram pellets. Tablets are usually used for fumigating farm storage and are probed into the grain. Each tablet produces 1 gram of phosphine and each pellet 0.2 grams. Formulations packaged in sackets contain 34 grams of material and produce 11 grams of phosphine.

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 until more experience and data on the use of this material have been accumulated.

How Fumigants React With Grain

Understanding how fumigants react in grain and what influences their activity is an essential step in developing the "know-how" to effectively and safely use grain fumigants.

SORPTION — When a fumigant gas attaches itself to the surface of a grain kernel or penetrates into the kernel, it slows diffusion and disrupts penetration of the fumigant through the grain mass. However, some sorption must occur if the fumigant is to reach all stages of pest insects, especially those that develop within the kernel. Some fumigants when sorbed into a kernel react with materials in the grain to form other chemical compounds that may be permanent, thus forming residues. Fumigants containing bromide, such as methyl bromide, are particularly subject to this type of chemical reaction which has necessitated the establishment of residue limits or tolerances for the amount of bromide permitted in grain.

TEMPERATURE — Temperature influences the distribution of fumigants in grain and affects their ability to kill insects. At temperatures below 60° F, fumigant volatility 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 breathe less frequently at colder temperatures. Thus, it takes longer for the fumigant vapors to reach insects in grain, less gas is actually available for controlling the pest, and because the insects are less active, less gas enters their bodies. Desorption may take longer at cold temperatures because grain retains fumigants longer at low temperatures, thus requiring prolonged ventilation periods.

GRAIN MOISTURE — The moisture content of grain also influences the penetration of fumigant gases by altering the rate of sorption. In general, higher moisture grain requires an increase in dosage or an extended exposure to compensate for the reduced penetration and increased sorption. However, as previously mentioned, adequate moisture is necessary for needed to generate phosphine from solid formulations. Although most grain that will support insect development will also contain sufficient moisture to start the chemical reaction, 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 fumigation. 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 kernel size and more spherical shape, has more surface area than wheat kernels. Increased surface means greater sorption loss, which reduces the amount of fumigant 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 sorbed by the grain.

The type and amount of dockage in grain has a pronounced effect on fumigant sorption and distribution. When the grain mass contains large amounts of dockage such as crust, chaff, or broken kernels, the fumigant vapors are rapidly sorbed by these materials and further penetration into the grain and through the grain mass is impaired. Unfortunately, such areas frequently attract the greatest number of insects. When isolated "pockets" of dockage occur in 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 be obtained 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 outside grain kernels are usually more susceptible to fumigants than moth and beetle species that develop inside grain kernels. Pupae and eggs that breathe very little are the hardest developmental stages to kill, while the young larvae are relatively susceptible.

Heavy infestations in which large amount 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.

TYPE OF GRAIN STORAGE — A fumigant, whether applied first as gas, liquid, or solid, eventually moves through the spaces between the grains, penetrates the grain, and is taken in by the insect in the form of a gas. The "gas-tightness" 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.

The size and shape of the storage structure affect both distribution and retention of fumigants. The height of a storage bin often determines the type, application method, and fumigant used. Commercial applicators may use special techniques to achieve control that would be difficult for a farmer to apply.

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 head-space 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 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 professionally.

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 differences 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.

Gas movement in a grain mass is affected by other forces such as gravity, sorption, temperature, and moisture content, but an understanding of the air movement is the first step in understanding the many forces that determine gas dispersion.

Dosage and Time of Exposure

Because fumigants act in the gaseous state, the dosage needed to kill an insect is related to the concentration of gas surrounding the insect, the insect's respiration rate which is related partially to temperature, and the time of exposure of the insect to the specific concentration of fumigant. There is a general relationship for most fumigants between concentration and exposure time — high concentrations require shorter exposure time and low concentrations require longer exposure to achieve comparable kill. In phosphine fumigations, time of exposure is often more important than the concentration of gas. This situation is due in part to the increased time necessary for release of the gas from the solid material, and partially because the rate of uptake of phosphine by insects is somewhat time dependent.

Variations in recommended dosages are generally based on sorption differences of commodities and the relative gas-tightness of different storage structures. For example, dosage requirements for sorghum are generally higher than for less sorptive commodities such as wheat, and dosages in wooden bins are higher than in steel or concrete bins. Application rates for phosphine-producing fumigants are based primarily on the type of storage structure being treated and its gas-tightness. Because phosphine is less affected by sorption loss in grain, the rates of application for it in most commodities are virtually the same.

Dosage rates for methyl bromide are usually based on the amount of total space within a storage rather than the amount of grain present. Dosage rates are frequently in the range of 2 to 4 pounds per 1,000 cubic feet of space, which is equivalent to about 2.5 to 5 pounds per 1,000 bushels, depending on the amount of air space above the grain surface. In general, higher dosage rates of methyl bromide are required for cool grain, higher sorptive commodities, and less tight storage structures.

Dosage rates for chloropicrin are normally expressed in pounds of chloropicrin per 1,000 bushels of grain. For empty bin fumigation, it is expressed as pounds per 1,000 cubic feet of air space. Treatments below 70° F are not advised because of the high rate of sorption and poor penetration in cool grain.

Cautions

The sale and distribution of liquid fumigants (carbon disulfide, carbon tetrachloride, and ethylene dichloride) is prohibited after December 31, 1985. The application of these materials is prohibited after June 30, 1986.

All fumigants are dangerous if used improperly. Follow the cautions listed on the container label and use only in strict accordance with label directions.

Wear a gas mask with full face piece and proper canister or supplied air respirator approved by the U.S. Bureau of Mines and the National Institute of Occupational Safety and Health for use with the particular fumigant you will be using. Gas masks will not protect the user against heavy fumigant concentrations in bins where oxygen has been replaced by the fumigant. The effective life of a gas mask canister is limited. Keep an accurate account of the time that a canister is used and replace it according to instructions.

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 protective 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 to safety. Fumigants demand respect if you want to avoid injury or death.

Recommendation Changes

The insecticides and fumigants listed in this circular were registered for use in Nebraska as of December 6, 1985. Recommendations are subject to change as dictated by Federal and State regulations and/or receipt of new efficacy data. Check with your local extension agent for current status of these recommendations.

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.

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

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