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Economic Impact of the Chlorpyrifos-methyl Phase-out in U.S. Wheat Storage

Nathan Reigner
Janet Carpenter

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National Center for Food and Agricultural Policy
1616 P Street NW, First Floor
Washington, DC 20036
phone 202-328-5048
fax 202-328-5133
ncfap@ncfap.org
www.ncfap.org

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Executive Summary

Chlorpyrifos-methyl, an organophosphate, is an insecticide that is used primarily in stored wheat, with lesser use in other grains such as barley and sorghum. Because of the Environmental Protection Agency's (EPA) review process under the Food Quality Protection Act (FQPA); phase-out of chlorpyrifos-methyl began in 2001 with the termination of sales of dust formulations that were associated with greater worker risks. Sales of the liquid formulation will be allowed until the end of 2003, with use allowed until the end of 2004. Tolerances will not be revoked until 2008 to allow treated grain and processed food products to clear the market.

The FQPA review process disallowed several data "bridges" that were used in the original registration of chlorpyrifos-methyl, from chlorpyrifos-ethyl toxicity studies, creating numerous gaps in the toxicology profile. EPA requires additional studies for continued registration of chlorpyrifos-methyl. In light of these requirements, the manufacturer, Dow AgroSciences, has entered into the voluntary cancellation agreement described above.

Chlorpyrifos-methyl is the only effective grain protectant currently available for use on stored wheat. While malathion continues to be used, its efficacy has been severely diminished due to the development of insect resistance. Cancellation of chlorpyrifos-methyl eliminates the use of grain protectants as a pest management option. In grain growing regions where on-farm storage is prevalent, where pest pressure is high, or where facilities or environmental conditions are not amenable to aeration or fumigation, the impacts will be greatest. Increased reliance on on-farm storage due to trends towards identity preservation and rising transportation costs will increase the need for reliable pest control practices that are practical for use by growers in their varied storage facilities. In addition, seed producers will be particularly impacted as pest management is more valuable in this setting, and reliance on chlorpyrifos-methyl is highest. Further, tightening grain standards and increased competition from foreign producers will also increase the need for sound pest management throughout the grain storage and transportation system.

Several issues complicate estimating the potential losses of the phase-out of chlorpyrifos-methyl. The primary difficulty rests on a general lack of data on which to base loss estimates. USDA surveys pesticide usage in only commercial grain storage. As grain protectants such as chlorpyrifos-methyl are believed more commonly used in on-farm storage, the use of these materials is grossly underestimated. With roughly one-third of wheat in on-farm storage at any point in time, the omission of estimates of pesticide use in this setting is a potentially large gap. Few surveys have been conducted to estimate the use of pesticides in on-farm storage.

Data on losses in stored grain due to insect damage, and insect infestation, are similarly incomplete. Surveys of discounts received by growers have been only sporadically conducted. The prevalence of various insects in stored grain, which is not regularly sampled by farmers or even commercial grain managers, has also been surveyed for particular areas at certain moments in time. However, much of these data were collected in the 1980's.

Due to these data gaps, a rule of thumb has emerged, as many cite an estimate of 5 to 10% loss of total production to insect pests, at a value of $500 million. However, the basis for this estimate appears to be a 1965 USDA report. Many parameters of grain storage and pest management have changed in the past 35 years, which leads one to question the relevance of this estimate.

It is estimated that loss of chlorpyrifos-methyl would result in an $18.3 million loss, with approximately 72% of this loss experienced by farmers in their on-farm storage. This estimate is based on total usage of 67,700 lbs of chlorpyrifos-methyl on stored wheat annually, which accounts for 183 million bushels of treated wheat. It is assumed that all currently treated wheat will be subject to a $0.10/bushel discount. Taking into account the cost savings of not treating with chlorpyrifos-methyl at $0.02/bushel, the net loss is estimated at $14.64 million.

This estimate is based on chlorpyrifos-methyl usage data from 2000/2001, a year with relatively low levels of on-farm storage compared to levels typical over the last 15 years. Anticipated increased reliance on on-farm storage for reasons cited above would result in even higher losses than those estimated here.

To ensure the sustained stability and success of the U.S. wheat storage and marketing system, the needs of on farm and small bin storage must be met. The continued availability of safe and cost-effective stored grain insecticides is primary among these needs, requiring regulatory action to provide for the extended use of current insecticides and expedited registration of new products. A minor-use waiver for acute, subchronic, and developmental neurotoxicity studies must be granted for chlorpyrifos-methyl for use at 3 ppm, half the current rate. Use at this rate will mitigate any dietary concerns generated by anomalous food detects of chlorpyrifos-methyl while providing for the development and use of highly effective combination insect control products. Unfortunately, this transition to lower rates and greater efficacy cannot be made immediately. CODEX MRLs or equivalent interim measures must be established for all components of combination products for use in stored wheat. Until these MRLs are set, any combination product treated wheat is limited exclusively to domestic marketing. To maintain U.S. presence and competitiveness in international wheat trade, use of chlorpyrifos-methyl at 6 ppm must be continued until the CODEX MRLs for combination product components are available. Additionally, to provide growers with the greatest number of insect control options and to promote positive resistance management, Spinosad and Deltamethrin must be granted U.S. registration for use on stored wheat. With these regulatory actions:

- granting of a chlorpyrifos-methyl acute, subchronic, and developmental neurotoxicity minor use waiver at 3 ppm
- continuation of chlorpyrifos-methyl use at 6ppm until MRLs for combination

product components are established,

- establishment of international MRLs for Cyfluthrin and Spinosad for use on stored wheat and,
- domestic registration of Spinosad and Deltamethrin for use on stored wheat,

U.S. wheat storage managers, especially those on farm or using small bins, will have the most cost-effective, safest, and varied insect control options possible.

In recognition of the constraints placed upon crop protection companies by the small market and specialized use patterns of stored grain protectants, it is difficult for companies to develop and market new grain storage insecticides at costs practical for use by on-farm storage managers. With this understanding and the above-prescribed regulatory actions, the U.S. grain storage and marketing system is provided with the greatest opportunity to maintain its prominent and competitive place in international markets.

U.S. Wheat Industry

Wheat is the third largest crop in the U.S. in terms of acreage planted, with 60 million acres planted in 2002. [86] Total crop value for 2001 was $5.5 billion. [87] Wheat production is concentrated in the "bread basket" states. Kansas, North Dakota, Oklahoma and Texas are the largest wheat states, in terms of acreage planted. (Table 1 shows wheat acreage and production by state. Figure 4 shows acreage by state.) Total wheat acreage has declined steadily over the past five years. (See Figure 2)

The United States is the fourth-largest producer of wheat, harvesting 2.23 billion bushels in 2000, or 10% of total world production, in 2000/01. [87] Other major wheat producing countries include China (17% of world total in 2000/01), India (13%), France (6%), Russian Federation (6%), Canada (5%) and Australia (4%). [87]

Wheat is primarily used in food, with a much smaller portion of the crop used as livestock feed or seed. In 2001, 76% of domestic use was in food, 18% for feed and 7% for seed. [87]

Exports accounted for 44% of U.S. wheat usage in 2001. [87] Over 97% of wheat exports are raw wheat, with the remaining portion exported as flour. Of major importers of whole wheat grain, Egypt accounts for the largest share (16% in 2000/01), followed by Japan (11%), Mexico (7%), Philippines (7%), Nigeria (5%), Korea (5%) and Taiwan (4%). [87]

In recent years, foreign wheat producers have become more competitive in the world wheat market. Canada, Australia, the European Union, and Argentina are producing more, higher quality, and less expensive wheat than ever before. Though imports accounted for only 29% of supply in 2000/01, U.S. wheat grain imports increased by 1500% since the early 1980's. [20] During the same period, U.S. wheat grain exports have decreased by 33%. [20] (See Figures 2&5)

Since 1998-99, wheat prices have slumped to near 30-year lows, sustaining average prices between $2.48 and $2.80 per bushel. [20][87] Figure 1 shows wheat prices received by farmers since 1955-56.

There are two general types of wheat, winter and spring, reflecting the time of year the seed is planted. Normally, about 70 to 80% of U.S. production is winter wheat. [1] These two types of wheat may be further divided into six major classes: hard red winter, hard red spring, soft red winter, hard white, soft white and durum. Hard red winter wheat accounts for the largest acreage, 40% of total production in 2001. [88] Figure 3 shows U.S. wheat production by class.

The classes differ in protein and gluten content, which makes each class desirable for different uses. Hard wheat contains higher levels of gluten than soft wheat. Hard red wheat is primarily milled into flour used to produce breads. Soft red winter and white wheat are milled into flour for baking, cereals, and noodles while durum wheat is milled to produce semolina, the flour used to make pasta. [1]

Each class of wheat requires particular growing conditions, which has resulted in regional specialization. [1] Hard red winter wheat production is concentrated in the central plains and northern tier states, with some scattered production throughout the west. Hard red spring and durum wheat production is located almost exclusively in the northern tier. Soft red spring is grown mostly in the Mississippi and Ohio River valleys and along the central and southern Atlantic coast. White wheat production is concentrated in the Pacific Northwest with some additional growth in southern Michigan and western New York. [33]

A higher proportion of white wheat is exported than other classes of wheat. Nearly two-thirds of white wheat usage in 1999 was for export, compared to 46% for all wheat.

[88] Approximately half of white wheat exports were destined for Japan (18%), Korea (14%) and the Philippines (19%). [20]

Postharvest Storage

After harvest, wheat moves through a series of channels within the wheat marketing system. Once introduced into the wheat marketing system, the grain is used, exported, or stored. This system may include almost any combination of storage in on-farm facilities, commercial elevators, export terminals, mills or processor warehouses, and transportation by truck, rail or waterway. Figure 6 shows possible market channels after harvest.

In the major wheat production areas of the U.S., most farms have grain storage bins, and nearly every small town has a grain elevator. Often, wheat first enters the marketing system at a country elevator, where grain is collected from the surrounding farms. Wheat then moves to a terminal elevator, a regional load-out facility or a river terminal where it is blended with other wheat and shipped to an export terminal or major domestic use point. Grain typically moves from the harvester to a farm bin or country elevator by truck, but some is trucked directly to a terminal elevator. Grain is moved from country to terminal elevators mainly by truck and railcar. [3]

All wheat is stored for some period of time after harvest, the length of which is largely determined by market conditions, as growers and marketers strive to sell when prices are high. Wheat may remain in storage at any of these locations from a few days to several years, although multi-year storage is increasingly rare in the U.S. because the government programs that encouraged long-term storage have been discontinued. [3] In any crop year, some portion of supply may be comprised of wheat harvested in previous seasons. The average storage time for wheat is probably in the range of 6-9 months. [3]

As of September 1, 2000, when the amount of grain in storage is at a peak just after harvest, the U.S. wheat storage system held 2.35 billion bushels, with approximately 1/3 held on-farm and 2/3 at commercial elevators, export terminals, or processor warehouses. [21] Throughout the year, wheat stocks decrease as they are consumed or exported, being depleted to approximately one third of peak capacity before being replenished by the next harvest.

It is difficult to generalize about storage levels, as many factors contribute to variability in how much grain might be in storage at any point in time, including the impact of weather on annual production, the influence of farm programs on planting and marketing decisions, and fluctuations in domestic and international demand. Between 1960 and 2000, the maximum level of wheat in storage varied between a low of 2 billion bushels (1966) and a high of 4 billion bushels (1986). The variability has been somewhat less extreme since 1991, with a low of 2.7 billion bushels (1996) and a high of 3.3 billion bushels (1998). [87] Maximum annual storage of wheat, as comprised by beginning stocks and production, is shown in Figure 7.

The distribution of storage between on-farm and off-farm facilities also varies. On-farm storage grew between the early 1960s and the early 1980s, as the government attempted to decrease government-held grain stores. A federal program to encourage on-farm grain storage, the Farmer Owned Reserve (FOR), was established in 1977, after which time, on-farm storage grew substantially. The early to mid 1980s were a period of high levels of storage, both on and off the farm. In September 1987, there were about 3 billion bushels of wheat stored in the U.S., which was an all time high. The combination of drought in 1988 and a growth in exports drove stocks down until the late 1990s. In the late 1990s, off-farm grain storage reached near-peak levels. (See Figure 8) After the mid-1980s, there were fewer incentives under the FOR program to store grain on-farm and it was eliminated in the 1996 Federal Agricultural Improvement and Reform Act. [42]

Grain stores are either flat or upright. Upright stores are more than twice as tall as they are wide and are usually made of concrete, although some are made of metal sections bolted or welded together. Flat stores, either cylindrical bins or warehouse-type, may be built of metal or concrete. In general, concrete stores are better able than metal structures to exclude insects, to insulate grain from changes in ambient temperature, and to retain fumigant. [3]

Steel bins or tanks are the most common on-farm type of storage facility on U.S. wheat farms. In a 1996 survey of stored wheat management practices in key food-use wheat producing areas of the U.S., about 93% of farmers indicated they stored some wheat in the 1995-96 year in a steel facility. Flat and wooden storage was used by 3% of farmers, each, while the use of concrete storage facilities was reported by 1% of farmers. [42]

As wheat stocks pass through the storage and transportation system, the grain is subject to numerous stresses, such as elevations in temperature, changes in atmospheric moisture, mechanical damage from conveyance, mold growth and toxin deposition, and most significantly, insect infestation. The longer grain is held in storage, the greater the potential for damage, especially that caused by insect feed.

Storage Insects

Stored grain is constantly under threat of infestation by a number of insects. When improperly cared for, stored grain is susceptible to weevils, moths, grain borers, grain and flour beetles, and other insects. These insects are classified as either internal or external feeders. Internal feeders bore through the kernel's shell to feed on the contents and are the most damaging. External feeders feed primarily on broken kernels and the fine grain dust present in the bin. While the feeding patterns of external feeding pests are not as economically destructive as that of internal feeders, their mere presence in grain at inspection and sale is just as detrimental as the presence of internal feeders.

The most damaging insect pests of stored wheat in the U.S. are rice weevil and lesser grain borer, which are both internal feeders. Lesser grain borer is the most damaging pest of farm-stored wheat. Other insect species in the genera *Tribolium*, *Oryzaephilus*, *Cryptolestes*, *Ahasverus*, and *Typhaea* are commonly found in stored wheat but cause little damage to grain and contribute little to insect fragment count in flour. [3] Table 2 shows common and scientific names of common wheat infesting insects.

Insect infestation of stored grain varies both temporally and geographically. Insect populations on farms and at elevators reach their highest densities and are most noticeable in the autumn. [3] In southern parts of the U.S. wheat belt and the Pacific Northwest insects are a greater problem than in the northern portions of the wheat belt and thus receive greater attention. [3]

A 1980 survey provided the most comprehensive view geographically of insect infestations in farm-stored wheat in 17 states. Overall, 25% of samples were infested with an average insect density of 105 per 1000 g of wheat. Flat and rusty grain beetles were the predominant insects found, occurring in 13.8% of samples at an average density of 45 insects per 1000g of wheat. Sawtoothed grain beetle was the second most frequently identified insect, found in 7.9% of samples at 30 insects per 1000g of wheat. Only four other species or groups of species were found in more than 1% of the total samples: psocids (booklice), lesser grain borers, dermestid beetles and red and confused flour beetles. Among the 7 most heavily sampled states (North Dakota, Montana, Minnesota, South Dakota, Nebraska, Kansas, and Colorado), Minnesota had the highest incidence of insects (42.9%) and Montana the lowest (11.6%). [13] Table 3 shows the incidence and density of insects infesting wheat by state from the 1980 survey.

Other surveys have found higher levels of infestation. A survey of farm-stored wheat in central and south central Kansas at four times during the 1975-76 storage season found 79% of samples infested with Indian meal moth. [14] A subsequent survey of farm-stored wheat in Kansas in 1986-87 also showed high levels of insect infestation. [9]

Through the use of pitfall traps and grain sampling, it was estimated that 95% of the bins were infested during September and November when infestations were at their highest, mainly with flat and rusty grain beetles, red flour beetle and sawtoothed grain beetle. Sampling results from September indicated that flat and rusty grain beetles infested 61% of samples, while red flour beetle was found in 59% of samples. Other prevalent insects included lesser grain borer (34%) and sawtoothed grain beetle (31%).

A 1992 survey of elevator managers in the hard red wheat production system ranked six wheat-infesting insects as to their order of importance. Nationwide, granary weevil received the highest ranking, followed by "other," lesser grain borer, and Indian meal moth. [28] Elevator manager insect rankings from that survey are shown in Table 4.

A 1980 survey of farm-stored wheat in Minnesota indicated that 44.7% of samples were infested with insects in May-June and 50.0% of samples in August-September were infested. [48] Flat and rusty grain beetles were the most commonly found species, in 31.6% and 44.7% of samples in May-June and August-September, respectively. In terms of the number of storages in which grain infesting insects were found, 57.9% and 71.1% of storages were found infested in May-June and August-September, respectively.

On-farm stored wheat in north central Oklahoma was sampled monthly in 1982-85. Between 79.9% and 81.8% of samples were infested, across the 3 years. Lesser grain borer was the most prevalent primary insect species found in 29.0 to 37.5% of on-farm grain bins over the 3 years. Rice weevil was detected in 4.4 to 7.7% of bins. Flat and rusty grain beetles, Indian meal moth and Confused and red flour beetles were the most abundant secondary stored grain insect species, in each of the 3 years. [67]

On-farm and commercial storages were surveyed for insect infestation in Oklahoma from 1985 to 1988. [2] Lesser grain borer was found to be the most important insect pest by far, found in 23% to 62% of bins, over the 4 years, followed by flat and rusty grain beetles, confused and red flour beetles and Indian meal moth. (See Table 5.)

Insect infestations at port terminals were surveyed at 79 terminals in the U.S. and Canada in 1977-78. [47] One or more live-stored-product insect species were found in 17.9% of wheat samples. The most common insect pests were maize and rice weevils, infesting 7.7% of samples at an average density of 4.2 insects per 1000 g, followed by flat and rusty grain beetles in 7.5% of samples at 1.9 insects per 1000 g and lesser grain borer in 5.6% of samples at 4.3 insects per 1000 g. Indian meal moth was less prevalent, in 1.2 % of samples, but found at a much higher average density, of 21.5 insects per 1000 g.

Farm-stored grain in South Carolina was sampled for insects during 1979 and 1980. 96% of wheat samples were infested. [68]

Insect Damage in Stored Grain

Insect damage to stored wheat may be direct or indirect. The total quantity of grain may be reduced directly due to insect feeding. Indirect losses result from reduced grain quality. After harvest, losses in quantity and quality of grain, due to insects and other factors, can only increase, which underscores the importance of proper grain storage management.

Direct losses in the quantity of grain between harvest and eventual sale, are not generally measured. One estimate of direct losses to insects in wheat was made based on a survey of growers in 17 states conducted in 1980. It was estimated that insect infestations caused an average weight reduction of 0.8 pounds per bushel, 1.33% of the bushel mass, reducing the aggregate mass of that year's grain production by 4 million bushels or approximately 240 million lbs. [53]

More information is available on indirect losses due to decreased quality, as these are observable characteristics of the grain at the time of sale. Wheat quality is assessed by characteristics that may be grouped into two categories: composition and physical state. Grain composition, including protein, starch, oil, fiber, and mineral levels, is established while the grain is growing in the field. The physical characteristics of grain are divided into two types, purity and soundness. Grain purity is decreased by the presence of fungal toxin residues and foreign material including organic and inorganic matter. Grain soundness results from measures of grain moisture, kernel size, test weight, and defect and damage levels. [27]

Insect infestation reduces test weight, reduces nutrient content through the consumption of proteins and starch, causes the grain to have a foul odor and appearance, and increases the moisture and heat within the grain mass, compounding insect infestation and promoting fungal growth and subsequent mycotoxin deposition. When assessing wheat at the time of sale, the mere existence of insects in the grain mass, even if no grain is damaged, can be an equally important determinant of quality as damage or low-test weight. [11]

Quality Standards and Price Discounts

The importance of quality maintenance is reflected in the price assessment practices of the U.S. wheat marketing system. The value of wheat as it moves through the wheat marketing system is determined by its quality at the point of sale. Assessments of wheat composition and physical state determine price discounts and premiums.

The USDA Federal Grain Inspection Service (FGIS) administers a national inspection and weighing program with descriptive standards and terms to facilitate trade. The Commodity Credit Corporation (CCC), which acquires grain from commodity loan defaults, recently established minimum standards on grain cleanliness. In addition, domestic or foreign buyers may require that grain meet certain minimum levels of quality.

FGIS

The United States Grain Standards Act (USGSA) was enacted in 1916 to provide a uniform inspection and grading system to facilitate interstate and international commerce. Prior to passage of the USGSA, there had been as many as 73 separate and distinct sets of grades and grade rules, developed by state agencies and trade organizations. [27] The first federal wheat standards were established in 1917. [27]

USGSA requires the inspection and weighing of all export grain. Any U.S. grain sold by grade and shipped in foreign commerce must be officially inspected and officially weighed by FGIS with a few exceptions. Grain destined for domestic markets may be inspected by FGIS upon request. [69]

Under USGSA, there are five grades for wheat for human consumption and a "sample" grade, which is unfit for human consumption. Special grades supplement the primary grades. Tables 6 and 7 show USDA FGIS official and special grades and grade requirements for wheat. Each of the wheat grades is associated with specific tolerable levels of impurities, defects, and damage. The physical quality characteristics of grain, such as test weight, foreign material and damaged kernels, generally serve as the basis for the numerical grades. [27]

Other characteristics of grain may be sampled during inspection, and may affect the price received, but are not official criteria under current USGSA grading rules. Dockage, which is matter such as weed seeds, wheat stems, insect parts, dust and small parts of wheat or other grains, is one such characteristic. Dockage may be removed from a shipment by grain cleaning methods. Moisture and protein content may also be recorded during inspection, but are not grade-determining factors.

The USDA Grain Inspection Packers and Stockyard Administration (GIPSA) has proposed that dockage for all wheat exports be included as a grade factor. Currently, the percentage of dockage is recorded, but not figured into the wheat grade. Under the GIPSA proposal, it must contain no more than 0.3% for the top grade and 0.5% for the second grade level. The proposal was published in the *Federal Register* for public comment. [77]

FGIS regulations on insect infestation and insect-damaged kernels were implemented in May 1988. Wheat containing 32 or more insect damaged kernels (IDK) per 100 g sample is judged unfit for human consumption and designated "Sample Grade." Further, a special grade category, "Special Grade Infested," sometimes referred to as "Special Grade Weevily," indicates the presence of two or more insects known to be injurious to grain in a 1 kg sample. Any primary grade can be classified as infested.

CCC

In 2000, then–Secretary of Agriculture Glickman announced raising the standard for cleanliness of U.S. wheat exports destined for overseas food aid. Historically, CCC purchases for government donation programs had been at the 1.0% dockage level, which is the level often used in U.S. commercial purchases. In June 2000, Glickman announced a 0.8% dockage standard. Later that year, in October 2000, the maximum acceptable dockage level was lowered further to 0.7%. [77][79]

On February 5, 2002, USDA announced that it would lower the maximum acceptable dockage level to 0.6%, for the remainder of FY 2002. On March 5, 2002, USDA issued a *Federal Register* notice seeking public comment on whether the limit should be further reduced to 0.5% for FY 2003. [70]

Other Standards

Many elevators and processors employ stricter or more specialized quality standards to identify and acquire high quality wheat for specialty uses or export markets. Among the most common private standards applied by processors are revisions of allowable IDK levels, lowering the acceptable threshold from 32 IDK per 100g to 3-5 IDK per 100g, or requiring specific starch and protein levels.

Growers who wish to grow and market specialized qualities generally enter into contracts with processors. The contract establishes the volume of wheat to be produced, the specific qualities desired, and the price for the agreed upon quality. The farmer must then grow wheat with the characteristics desired and maintain these quality characteristics in storage after harvest until the time of sale.

Foreign buyers may also require that U.S. wheat meet minimum quality standards. In Japan, millers have long requested cleaner U.S. wheat, resulting in the Japanese Food Agency, which controls most imports in Japan, to gradually phase in tighter dockage specifications. [89] In 1994, the Japanese wheat purchasing agency implemented a program of bonuses and discounts to reduce the amount of dockage that is acceptable in wheat imported from the U.S. [3] Eventually, a standard was implemented lowering the allowable level of dockage to 0.5%. The standards were expected to be tightened to 0.3%. The U.S. may need to meet this level to remain competitive as Canadian wheat imports average 0.2% dockage. Taiwan also has voiced concerns about dockage levels in U.S. wheat, and in 1998 instituted a maximum dockage level of 0.5%. [89]

Blending

Blending is a practice that is used to create a uniform product from lots of varying quality or to meet specialized standards. Blending of grain over wide margins of quality to create a uniform product for sale is necessitated by the lack of any minimum receival standards. The U.S. system lacks uniformity in quality throughout the market channel. When grain reaches export, blending is used in an attempt to produce a uniform quality meeting the buyer's specifications. [27]

Specialized quality standards are met through different means by different type storage operations. Larger elevators often create lots with the special quality characteristics by purchasing only wheat with qualities approaching the specialized standard, and then blending these various qualities to achieve the exact standard desired. This method requires not only specific wheat qualities, but also the facilities and equipment to blend large quantities of grain.

Discounts

As the U.S. wheat marketing system has no minimum quality standards, growers and storage facility managers can market grain of any quality, the levels of which are reflected in prices. Producers can deliver any quality of grain and it will be accepted with appropriate discounts. The magnitude and prevalence of grain discounting by buyers for insect damage and infestation has been surveyed in various areas. Survey results are summarized in Table 8.

A 1986-87 survey of elevator managers in Kansas indicated $0.02/bushel discount for 0.1 to 1 insects per 1000 g sample, $0.021/bushel for insect density of 1.1 to 5.0 insects per 1000 g sample and $0.041/bushel for insect density greater than 5.0 insects per 1000 g sample. [11] A similar survey was conducted in Kansas in 1991, though this latter survey was expanded to include wheat growers. In the 1991 survey, the value of a price discount for live insects ranged from $0.02 to $0.05 per bushel with a mean of $0.043 per bushel. In the same study, elevator managers reported an average discount of $0.044 per bushel for live insects. [24] A 1980 survey of elevators in Minnesota indicated an average discount for insect infestation of $0.07/bushel with modes at $0.05 and $0.10/bushel. [48] A 1988 survey of South Dakota grain producers indicated an average charge for required fumigation of $0.05/bushel, an average discount for odors or insect damage of $0.07/bushel and an average discount for musty or mold damaged grain of $0.06/bushel. [50] A 1992 survey of elevator managers indicated an average discount for insect infested hard red wheat of $0.081/bushel. [28]

Wheat is usually sampled to determine grain quality when received at elevators or moved from one bin to another. Sampling is designed to provide grain quality information for segregation, blending and marketing. Routine grain sampling practices focus on factors other than the presence of insects, and sampling rates are much too low to routinely detect sparse insect populations. Because of the low grain-sampling rate, insect related quality factors are subjectively evaluated and inconsistently penalized. [3] Policies on discounts for insects or insect-related grade factors vary greatly from one elevator to another, and are applied less consistently than discounts for moisture, dockage, or test weight. [11]

One study of discounts assessed in relation to various quality characteristics found that lots whose samples were infested with insects were no more likely to receive a discount than lots with samples free of insects. Neither the presence nor the abundance of insect-damage kernels was significantly associated with a greater risk of price discount, which appeared to indicate a tolerance of live insects and their damage on the part of many elevator managers. However, when discounts were applied to wheat that was infested, the value of the discounts was significantly associated with the number of live insects and the number of insect-damaged kernels in the samples. [11]

Aggregate Loss Estimates

It is generally accepted that 5 to 10% of U.S. stored grain is lost to insect infestation each year, costing the grain industry $500 million annually. However, the basis of this widely cited estimate is unclear. Table 9 summarizes aggregate wheat and combined grain loss estimates.

The USDA Agricultural Research Service presented an early estimate of stored grain losses due to insects in 1965. [58] In that report, the average annual losses from 1951 to

1960 caused by insects in wheat were estimated at 3% of the total crop, not including costs of control or secondary losses. [58]

In a 1990 survey, extension entomologists were asked to estimate the total amount of damage caused by insects and molds to stored corn and wheat for their state. [17] Of the 15 states reporting, estimates ranged from none in Alaska and New Hampshire to $73 million in Minnesota and $76 million in Nebraska. A national estimate was derived for 1989 of $356 million. [17] A $50 million annual loss to insect and mold in stored grain in Oklahoma has been estimated. [26]

A Kansas State University extension publication cites industry estimates of 5 to 10% of stored corn and wheat lost to insects each year, amounting to diminished revenue from $1 billion to $3 billion. [59]

Damage caused by insects, molds, heat and sprouting was estimated to result in annual losses totaling more than $1 billion for U.S. grain. [60]

Total stored product insect control costs for stored grains in Georgia were estimated in 1993 at $3 million. [23] The proportion of these costs that could be attributed to wheat alone is $747,950.

The South Dakota Department of Agriculture estimated potential economic losses to wheat resulting from infestations of lesser grain borer. Of the 114 million bushels of wheat produced in South Dakota, it was estimated that 33% would be infested to economically damaging levels. The assumed average discount applied to infested wheat was $0.29/bushel, approximately 10% of market value, accounting for $10.9 million in potential lost wheat value for the state of South Dakota. [29]

Insect Pest Management

Farmers and elevator managers employ a variety of practices to protect grain from factors that could reduce the quality of stored grain. The most important factors affecting stored grain insect and mold population dynamics are: stored grain moisture content, temperature, the time grain is in a susceptible condition and accessibility to pests. [26] Recommended insect-control practices include sanitation, grain drying and cooling, monitoring and the use of pesticides. No one set of management practices can insure that wheat will remain sound and infestation free throughout the storage period. Climatic and storage infrastructure conditions are factors that influence which management tools are most effective.

Sanitation, Loading, Aeration and Monitoring (SLAM)

Sound grain storage practices rely on a combination of sanitation, loading, aeration, and monitoring (SLAM). Thoroughly cleaning all harvesting, loading, and storage equipment and facilities removes old, dirty grain and preexisting infestations, allowing the storage manager to begin with a clean, insect free storage space. Upon loading, wheat should be dried to about 12% moisture content, have the grain peak leveled after loading, and as much of the fine material within the mass as possible should be removed. These practices establish a consistent and manageable microclimate within the storage facility, minimizing the available amount of food and water to attract organism infestations.

Aerating, when done selectively, can manipulate and homogenize the temperature and moisture content within the grain mass, making the microclimate more hostile to insects and fungi. The desired microclimate manipulations are accomplished by circulating outside air through the grain mass. By replacing the warm air trapped within the grain storage with cooler outside air, the ambient temperature within the storage facility is lowered.

The use of aeration is limited by environmental conditions. A prerequisite for effective aeration is cool, dry air. In climates such as those in the southeast and southern plains where the air is warm and/or moist for much of the early fall, aeration can not be effectively employed as early in the storage season as is possible in northern climates, where cool, dry air is quick to replace summer heat.

To be employed effectively, aeration requires a combination of proper facilities, equipment and management. Storage facilities must be fitted with aeration fans and either exhaust or intake ports. While air can be forced through the mass with fans applying positive pressure, a greater volume of air can be transferred more rapidly using aeration fans to draw outside air into the mass through the application of negative pressure. Ideally, aeration fans are only operated while outside air is at its coolest and driest in comparison to that contained within the storage mass. Advanced aeration systems connect the fans to temperature and moisture monitors within and without the grain mass, which turn fans on and off according to comparative climate differences. Manual systems can be as effective as automated systems, thereby avoiding the associated capital costs, if the operator vigilantly monitors climatic conditions inside and outside the stored mass and turns the aeration system on and off accordingly. This method of operation is labor and knowledge intensive, and therefore is frequently abandoned in favor of less precise operation of aeration fans, consuming greater amounts of electricity and transferring air at less than optimal temperature and moisture levels.

The efficacy of aeration as an insect pest control technique has been demonstrated. In trials conducted on 5 farms in south-central Kansas, insect infestation in grain that was aerated early in the storage season was compared to infestation in grain that was not aerated until October/November. The grain cooled early in the storage season had significantly lower insect infestation than the grain with delayed aeration. [82]

When favorable environmental conditions exist, equipment is present, and it is operated properly, aeration can be an effective pest control option. However, if climatic conditions are not favorable, aeration equipment is not present or ill maintained, or not operated properly, aeration can have a negative impact upon the storage microclimate and consume significant amounts of electricity.

These sanitation and aeration practices to limit infestation should be supplemented by a regiment of monitoring temperature, moisture, and insect presence within the grain mass. By frequently monitoring the grain mass, storage managers can discover possible problems early in development and initiate corrective measures before a crisis occurs.

Insecticides

Augmenting the techniques of SLAM with the selective use of insecticides can maximize quality maintenance of stored wheat. Insecticides for storage management are used as prophylactic treatments and crisis management tools. Prophylactic chemical usage includes empty bin treatments, residual entire mass grain treatments, and residual top dress applications. Crisis management of insect infestations in stored grain is achieved through fumigation of the grain mass.

Prophylactic stored grain insecticides, often referred to as grain protectants, may be applied to empty bins or directly to the grain mass. Empty bin sprays are made to interior surfaces, openings, and surrounding areas of storage bins before loading. This type of application aims to surround the stored grain mass with a chemical barrier against insects moving into the bin from outside. Entire mass treatments and top-dress applications are made using insecticides with residual activity, in order to provide sustained protection over the storage period. Entire mass applications of grain protectants are designed to prevent insect infestations throughout the entire body of stored grain. The chemical protectant is applied to the stream of grain as it is conveyed out of the transport vehicle and into the storage bin so that all of the stored grain receives treatment. Top dress applications treat only the upper portion of the grain mass. Such applications can be made either to the flow of grain as the top of the bin is being loaded or to the top of the grain mass after loading is complete. The application timing is determined by the formulation of the protectant and ease of application. Top dress applications of grain protectants provide a barrier within the grain mass at the top of the bin, where infestations most frequently begin, without incurring the costs of treating the entire mass.

Grain protectants, as the name would imply, protect grain from infestation, but do not eliminate existing infestations. Fumigants are used for crisis management of developed insect infestation. Fumigants release toxic gas into the grain mass, killing any existing insect infestations. Fumigants can provide 100% mortality to existing insect infestations if used properly. Fumigants must be held at critical concentrations and above minimum temperatures within the bin, frequently for several days, in order to be effective. This often proves difficult in old or poorly maintained storage structures and can result in incomplete mortality. Fumigants provide no residual insect control.

Farmers relied upon liquid fumigants to control insects in stored grain from shortly after World War II until the mid-1980's. The main ingredient of the most widely used fumigants was carbon tetrachloride, which was banned in 1986 due to concerns over potential carcinogenicity. Ethylene dibromide had also been used as a stored grain fumigant, but was removed from the market in 1985 for similar reasons. Phosphine fumigants have been more widely relied upon since the removal of these other fumigants from the market. Malathion, a residual insecticide, has also been used since after World War II, though its efficacy has been diminished due to the development of resistance. Chlorpyrifos-methyl (Reldan) was registered in 1985 for direct application to stored wheat and other small grains as a protectant. [24][38][63]

Few protectants have been available for postharvest application because of the relatively small size of the stored-product market compared to markets for broad-spectrum field insecticides, strict regulation of pesticides on food and feed grains, and a lack of incentive for farmers to protect stored grains from insect damage. [62]

Among the insecticides available today for use in stored wheat, growers and elevator managers primarily use chlorpyrifos-methyl, malathion and cyfluthrin, as well as the phosphine fumigants. A chlorpyrifos-methyl/cyfluthrin combination product, used previously only with emergency exemption, has just recently been fully registered for use and will surely be adopted by storage managers.

Chlorpyrifos-methyl

Chlorpyrifos-methyl is a residual insecticide that is registered for use as either a bin-spray or a direct grain treatment. Originally marketed in both dust and emulsifiable concentrate formulations, only the emulsifiable concentrate is still available. Chlorpyrifos-methyl is labeled for the control of stored grain insect pests, including granary weevil, rice weevil, red flour beetle, confused flour beetle, saw-toothed grain beetle, Indian meal moth and Angoumois grain moth. [32] Although it was not registered until 1985, efficacy trials of chlorpyrifos-methyl, an organophosphate, began in the 1970's. A 1977 efficacy study found that residues from an initial application to hard winter wheat at 3 ppm in samples withdrawn at intervals during a 12-month storage period controlled rice weevils, granary weevils and maize weevils. Other insect pests required higher application rates. A dose as high as 8 ppm controlled 90% of lesser grain borers, 83% of confused flour beetles, and 98% of red flour beetles, 12 months after initial application. [15]

The efficacy of chlorpyrifos-methyl treatments varies depending on temperature and moisture content. [7] When applied at a calculated rate of 6.00 ppm, the actual rate of deposition is 4.39 ppm. [7] Chlorpyrifos-methyl residues further degrade at half-lives of 8.9 and 6.7 weeks on wheat stored at 30°C and 11.2% and 13.7% moisture content, respectively. [35] Corn treated at an application rate of 6 ppm of chlorpyrifos-methyl and held at various temperatures was sampled every 2 months over a 10-month storage period for survival of maize weevil. No weevils survived on corn stored at low temperatures until month 10. Weevil survival increased as moisture content increased in corn stored at 30.0 and 37.5 C. Population growth, the percentage of insect-damaged kernels, and dockage weight were all correlated with insect survival. [8] While this demonstration of chlorpyrifos-methyl efficacy does not reflect a registered or proposed use, it does provide an illustration of the product's efficacy under differing environmental conditions. The half-life of chlorpyrifos-methyl is shorter at higher temperatures and moisture contents. In areas where wheat is harvested and stored in mid-summer at temperatures above 30°C, the duration of chlorpyrifos-methyl efficacy may be dramatically reduced.

The efficacy of chlorpyrifos-methyl in combination with aeration has also been investigated. A 1995 study comparing aeration alone to chlorpyrifos-methyl followed by aeration in stored wheat in Georgia showed significantly more dockage and insect-damaged kernels in the untreated samples over a 9 month storage period. [16] Wheat samples treated with chlorpyrifos-methyl were examined from aerated and non-aerated batches over a 16-week period. No differences in either biological efficacy or the rate of chemical decomposition were detected between the aerated and non-aerated samples. [41]

Malathion

Malathion is among the oldest of the prophylactic chemical treatments still registered for use in stored wheat. Since its registration in 1958, it has been the most widely used residual insecticide for direct application to stored grain in the U.S. Malathion is an organophosphate that is labeled for use as an empty bin treatment and a grain protectant. It is sold in liquid and dust formulations. The development of resistance in target pest populations limits the utility of malathion as a grain protectant. [4][38][63]

Malathion's efficacy is also compromised by susceptibility to degradation induced by environmental factors. Malathion residues degrade quickly at rates that vary directly with temperature. [7] The mid-summer harvest of most wheat in the United States, and the subsequently high grain temperatures after harvest, catalyze temperature degradation when malathion is applied directly after harvest.

The cooperative extension service recently mounted an educational campaign against malathion use because of its near complete lack of efficacy as a residual insecticide. Insecticide resistance to stored grain insecticides is discussed in the next section.

Cyfluthrin

First registered in 1987, cyfluthrin (Tempo) was labeled for use with stored wheat only as an empty bin spray. On September 30, 2002, Cyfluthrin was registered for direct application to grain. Formulated as an emulsifiable concentrate or a wettable powder for structural use, stored grain usage is among several insecticide uses, including foliar application in crops. Unlike chlorpyrifos-methyl and malathion, cyfluthrin is a pyrethroid. Pyrethroids are synthetically produced analogs of natural insecticides, called pyrethrins, which are derived from plants. Pyrethroids are synthetically developed to enhance the photostability, insecticidal toxicity, and spectrum of coverage, of naturally produced pyrethrins. [37] The standard impact of pyrethroids is a "knockdown," or immobilization of the insect pest, which may be followed by recovery.

Efficacy tests of cyfluthrin on partially treated concrete surfaces were undertaken for confused flour beetle. Between 20 and 80% of the total area was treated, and beetles were exposed for 1 hour to each of the treated areas four times at monthly intervals. The percentage of beetles still mobile after exposure decreased as the percentage of treated area increased, with no significant difference with respect to time. Further, a delayed toxic effect was observed, as some beetles that remained mobile after exposure did not survive. [5]

In a study of the efficacy of cyfluthrin treatments of concrete surfaces on confused flour beetle at variable exposure intervals and application rates, all beetles were knocked down after 4 hours of exposure at all application rates. [56]

Although cyfluthrin was just recently registered as a direct applicant to grain, its efficacy for use as a protectant has been determined for some time. Efficacy of cyfluthrin on lesser grain borer and rice weevil in soft red winter wheat was evaluated in southern Georgia. At an application rate of 2ppm, cyfluthrin demonstrated greater than 88% mortality among lesser grain borer over a 10-month storage period with no definite pattern of variation between efficacy and length of storage. Control of rice weevil was equally effective, producing mortality rates of no less than 87% over a 10-month storage period. [6] When applied to corn at a rate of 2ppm, cyfluthrin exerted 100% mortality over maize weevil and 90% or greater mortality among red flour beetle over the course of a 10-month storage period. [36] To achieve required efficacy as a grain protectant, cyfluthrin is marketed only as a formulated product in combination with chlorpyrifos-methyl. There are no plans to market cyfluthrin as a "stand alone" grain protectant.

Storcide

Storicide is a new stored grain insecticide that combines chlorpyrifos-methyl at 3ppm with cyfluthrin at 2ppm. Through the combination of two insecticides with different chemical modes of action, Storcide is able to achieve efficacy among insect populations that may be resistant to any single insecticide. Although Storcide just recently received its section three registration in September 2002, it was previously used in South Dakota and the Pacific Northwest with section 18 emergency use exemptions issued for chlorpyrifos-methyl resistant Lesser Grain Borer infestations. During its use under section 18 exemptions, there were numerous anecdotal reports of its strong efficacy. In Laboratory tests conducted with Storcide, 100% mortality among Rice Weevil and Lesser Grain Borer was exhibited 48 weeks after treatment. [40]

Phosphine

The most widely used fumigant in wheat is phosphine gas. This fumigant is most commonly formulated as aluminum or magnesium phosphide tablets or pellets that are mixed with the grain flow during bin loading or turning, or probed into the grain mass after it is in storage.

When used properly, phosphine gas has historically resulted in 100% mortality of all stored product insects. When used improperly, in bins that are not completely sealed, in grain that is below 40°F, in concentrations below a critical level, or if the critical concentration level is not maintained for a sufficient length of time, phosphine's efficacy can decrease dramatically. Even when used properly and maximum efficacy is achieved, phosphine fumigation provides no residual insect control.

Phosphine is an extremely toxic, restricted use substance requiring the supervision of a trained and certified applicator for use. Phosphine's extreme toxicity also imposes other demands upon its use. Phosphine users are required to establish and follow a "Fumigation Management Plan," placard all facilities and vehicles being fumigated, provide local emergency management agencies with material safety data sheets and notify them when fumigating.

Methyl Bromide

Methyl bromide is another broad-spectrum fumigant that is infrequently used in stored grain. It is more expensive than phosphine and is problematic as improper application may kill the germ of the wheat, causing rancidity. Phase-out of methyl bromide began in 1999, due to concerns about its ozone-depleting qualities, and will be complete by 2005, with uses allowed after that time only by exemption.

Chloropicrin

Chloropicrin, commonly known as tear gas, is a fumigant that is also infrequently used in grain storage. It is sometimes combined with methyl bromide in order to widen the spectrum of control, as it is a particularly effective fungicide. It is also combined with methyl bromide at low concentrations as a marker, due to its pungent odor. Chloropicrin use in grain storage is restricted to use in empty bins.

Diatomaceous Earth

Diatomaceous earth (DE) is an alternative stored product insecticide whose action is mechanical, not chemo-toxic. Diatomaceous earth is a dust formulated from the fossilized remains of aquatic microbes. The silicate exoskeletons of these microbes are ground into a dust that acts as a desiccant, absorbing and abrading the moisture-retaining cuticle of stored product insects, causing them to dehydrate.

The potential for use of DE in stored grain is considered to be limited to surface treatments. Efficacy across species is variable. Further, application of the dust to grain can alter the physical properties of the grain, including bulk density and flow rate. Ideally, DE would be removed from grain after the storage period, which would increase costs. [83]

Methoprene

Methoprene is another alternative insect control substance that, unlike insecticides, does not kill insects.. Methoprene is an insect growth regulator that arrests insect development in the pupa stage, preventing adult emergence and subsequent reproduction. When used at the proper time in an infestation cycle, Methoprene can effectively arrest the development of entire pest generations. Without the development of successive generations of adults, the infestation will age and eventually die out. [90] Because Methoprene requires specifically timed application and does not immediately eliminate or prevent infestations; its proper use require a certain amount of training and tolerance for insect damage. Cost and efficacy concerns have severely limited adoption and use of the chemical in grain storage.

Other alternatives

Besides the discussed grain protectants and fumigants, there are a number of alternative insect control and quality management practices that are under investigation for use in U.S. stored grain. Among the discussed alternatives are synthetic chemicals including various synergised pyrethroid combinations, dichlorvos, biopesticides like *Bacillus thuringiensis* (*Bt*), insect growth regulators, neem oil, plant, fungal and bacterial derivatives, pheromones for trapping and reproductive interference, biological controls including pathogens, parasites (parasitic wasps), and predators, and environmental manipulations such as grain heating, chilling, irradiation, and CO_2 infusion. Some of these alternatives appear to be promising; especially the bacterial derivatives and some pyrethroid combinations, but will most likely cost substantially more than current insect controls. Two especially promising alternative grain protectants for use in wheat are Spinosad and Pirimiphos-methyl.

Spinosad

Spinosad is an emerging alternative product for the control of insects infesting stored grain. Spinosad, a bacterial derivative, is labeled for use on a multitude of crops and has received an experimental use permit for use as a stored grain protectant. As a bacterial derivative, Spinosad has a pesticidal profile very different from those of conventional grain protectants like organophosphates. While the product is highly toxic to insects, its mammalian toxicity is low. Spinosad has been approved for use in organic production regulated by the USDA's National organic program.

While Spinosad is still under development as a stored grain protectant, there is preliminary efficacy data indicating that Spinosad may be effective against some stored product insects. When tested against lesser grain borer and Indian meal moth larva on four classes of wheat, Spinosad treatments of 1 ppm resulted in total mortality, 84 to 100% progeny repression, and 66 to 100% reduction in kernel damage among lesser grain borer infested samples. The same dosage of Spinosad also resulted in 98 to 100% larval mortality and 95 to 100% kernel damage reduction in Indian meal moth infested samples. Efficacy among populations of rice weevils, sawtoothed grain beetles, and red flour beetle was lower at all dosages of Spinosad on all classes of wheat than the efficacy demonstrated against lesser grain borer and Indian meal moth. Rice weevils were generally more susceptible to Spinosad, especially at 1 ppm doses, than red flour beetles and sawtoothed grain beetles, and all species were most effectively controlled in Durum wheat. While efficacy against rice weevil after 14 days exposure to 1 ppm rates remained at or above 80% mortality in all classes of wheat, mortality under the same time and rate conditions never reached 80% among red flour or sawtoothed grain beetles and never rose above 14% in red wheat samples. [31]

Deltamethrin

Deltamethrin is a pyrethroid similar to Cyfluthrin. Its mode of action is the same as Cyfluthrin's, a rapid, paralyzing "knockdown" induced by a toxic effect to the central nervous system. Deltamethrin's toxic effect is more powerful than that of Cyfluthrin, often resulting in lethal knockdowns. [91] While not currently registered for use on stored wheat in the U.S., Deltamethrin has been proven an effective insecticide for use in stored wheat, especially when used in combination with Chlorpyrifos-methyl. An evaluation of Deltamethrin used in isolation at 0.5, 0.75, and 1.0 ppm and at 0.5 and 1.0 ppm in combination with 6.0 ppm Chlorpyrifos-methyl demonstrated its ability to control lesser grain borer and rice weevil infestations. After 10 months of storage, no insects survived in lots treated with any combination of Deltamethrin and Chlorpyrifos-methyl. During the same storage period, in lots treated with Deltamethrin only, lesser grain borer survival varied throughout the storage period, with maximum survival occurring at 10 months (48% survival), 10 months (35%), and 4 months (15%) in the 0.5, 0.75, and 1.0 ppm treatments respectively. Rice weevil survival in these same lots ranged from a maximum of 84.5% in 0.5 ppm treated wheat to 26.2% and 3.5% survival in 0.75 and 1.0 ppm treated wheat, respectively. [92] As is the case with cyfluthrin, there are no plans to market deltamethrin as a "stand alone" grain protectant.

Pirimiphos-methyl

Another possible alternative is pirimiphos-methyl, marketed under the name Actellic. Actellic, an organophosphate, is registered for use as a grain protectant on corn and sorghum. Although its efficacy pattern is similar to that of chlorpyrifos-methyl, it costs approximately twice as much. Recent efficacy studies illustrate pirimiphos-methyl's feasibility as an alternative to chlorpyrifos-methyl. Pirimiphos-methyl's lethality against red flour beetle, flat grain beetle, lesser grain borer and rice weevil was demonstrated in 1990 among populations sampled from Kansas. Among these populations, all red flour and flat grain beetles and lesser grain borers and 95% of the rice weevil populations were susceptible to pirimiphos-methyl. Similar mortality patterns were observed with comparable doses of chlorpyrifos-methyl, with the exception of slightly greater resistance among lesser grain borer (17%) and rice weevil (14%) populations. [71] The development of resistance to chlorpyrifos-methyl among lesser grain borer populations occurring throughout the 1990's was mirrored by resistance to pirimiphos-methyl. In 1996, lesser grain borer populations sampled from Kansas demonstrated 58.4% mortality to discriminating doses of pirimiphos-methyl while mortality resultant from chlorpyrifos-methyl was 38.8%. [85]

Resistance

The potential for insect populations to develop resistance to insect control practices is a recurring issue in the development and stewardship of effective pest control practices. Insect populations may exhibit resistance by different mechanisms: innate resistance, mutated development of resistance or cross-resistance due to exposure to similar practices.

Chlorpyrifos-methyl is related to relatively few instances of resistance, with the notable exception of lesser grain borer. Chlorpyrifos-methyl resistance among lesser grain borer was documented prior to its registration and use as a stored grain insecticide. [15] A 1990 study found that among 22 populations of lesser grain borer sampled from Oklahoma, all were less susceptible than laboratory control populations. Laboratory control populations exhibited 98% mortality, while field sampled populations exhibited mortality rates from 79% to as low as 1%. [10]

Observations of lesser grain borer resistance to chlorpyrifos-methyl are supported by a

1996 study of lesser grain borer populations from Kansas and Brazil. Populations from both areas exhibited resistance from 5.6 to 167.9 times higher than susceptible populations. Although Brazilian populations tended to be more resistant than U.S. populations, with 24.9% and 38.8% mean mortality respectively, both resistance patterns were statistically significant. The existence of resistant lesser grain borer in Brazil is unlikely to be due to the use of chlorpyrifos-methyl, as it is not a recommended or widely used grain protectant. Instead, Brazilian lesser grain borer resistance may have resulted from cross-resistance to another insecticide. [85]

Chlorpyrifos-methyl resistance in sawtoothed grain beetle has also been detected, in Minnesota barley storage. Of six populations sampled, four had mortality rates lower than susceptible laboratory controls. Resistant population mortality rates ranged from 40.0% to 8.3% and were statistically significant when compared to the 100% mortality rate of the control population. The barley from which the resistant populations were extracted had never been treated with chlorpyrifos-methyl. This may indicate that the resistance exhibited by sawtoothed grain beetles is the result of natural tolerance or cross-resistance to another pesticide and not selection by insecticide pressure. [12]

Insect resistance to malathion has long been recognized in several insect pests. As early as 1967, insect resistance to malathion was observed among stored grain insect pest populations. [38] Field strains of red flour beetle were found to be up to 11.3 times as resistant to malathion as susceptible laboratory strains, and that even field strains collected from sites where no malathion had been used were an average of 2.1 times more resistant than susceptible lab strains. This study concluded that the development of resistance was directly related to malathion use. [38] In 1997, the first definitive evidence of malathion resistance among confused flour beetle was published. After being administered a 2 mg/g dose of malathion, 10 field strains of confused flour beetle exhibited an average mortality of 76.1% compared with 100% mortality among susceptible strains of the same insect. Using the same doses, this study also demonstrated a 20.4% average mortality among 14 field strains of red flour beetle. [4] Similarly low mortality rates were found among U.S. and Brazilian populations of lesser grain borer in 1996. Seven U.S. populations of lesser grain borer had an average mortality rate of 31.6% after exposure to varying concentrations of malathion, while the mean mortality of Brazilian populations was 27.3%. [85]

Lack of efficacy of phosphine fumigants is most commonly the result of improper use; however, some recent research documents the development of insect resistance. A 1990 study found that 12 field strains of lesser grain borer infesting wheat exhibited a mean mortality rate of 71% when fumigated with phosphine. Of these twelve populations, eight had mortality rates at statistically significant lower levels than the 100% mortality found among laboratory strains. One of the resistant populations showed mortality as low as 8%. This same study also suggests that phosphine resistance may be beginning to develop among some populations of red flour beetle living in stored wheat. While the mortality rates are not as striking as those among lesser grain borer, one of the eight populations of red flour beetle tested with phosphine fumigant did exhibit a mortality that was lower and statistically significant when compared with the 100% mortality among the laboratory strain. [10]

The possibility of resistance to phosphine among wheat dwelling red flour beetle is strengthened by evidence of phosphine resistant red flour beetle dwelling in peanuts in the Southeastern United States. When administered a discriminating doses of phosphine, 8 out of 23 field strains of red flour beetle in peanuts exhibited resistance through mortality rates that were lower and statistically significant when compared to a laboratory susceptible strain. The resistant strains suffered a mean mortality rate of 91%. This study also revealed some phosphine resistance patterns among Indian meal moth. Of seven field strains tested with discriminating phosphine doses, four displayed significantly lower mortality rates than a laboratory susceptible population, indicating phosphine resistance. Among resistant Indian meal moths, the mean mortality rate was 83%. While such low levels of resistance may not be high enough to cause insect control failures, they do demonstrate that phosphine resistance definitely exists and will only increase in severity and scope as more phosphine is used. [44]

Strains of stored-product insect pests collected on farms and at country elevators throughout Kansas in 1987 were screened for resistance to chlorpyrifos-methyl, pirimiphos-methyl and malathion. *Tribolium castaneum* and *Cryptolestes* spp. were uniformly susceptible to both chlorpyrifos-methyl and pirimiphos-methyl, but all T. castaneum strains were strongly resistant to malathion. Of 22 strains of Oryzaephilus surinamensis tests, all but three were susceptible to chlorpyrifos-methyl, but only about one-third were susceptible to malathion. One of the chlorpyrifos-methyl -resistant strains was cross-resistant to pirimiphos-methyl. Of the 18 strains of *Rhyzopertha dominica* tested, all but three was susceptible to chlorpyrifos-methyl. These resistant strains were not cross-resistant to pirimiphos-methyl. The data indicate that Kansas populations of *O. surinamensis*, *T. castaneum*, *R. dominica* and *Cryptolestes spp.* are generally susceptible to chlorpyrifos-methyl and pirimiphos-methyl as of 1987. [62]

CODEX MRLs

CODEX Alimentarius is the commission charged with the development and maintenance of international food safety standards and the facilitation of fair international food trade. The commission was established and is operated as a joint venture between the Food and Agricultural and World Health Organizations of the United Nations. Among its duties is the establishment of tolerances for acceptable maximum residue limits (MRL) for pesticides in food products being traded internationally. Currently, chlorpyrifos-methyl and malathion are the only stored wheat protectants that have both U.S. registrations and CODEX MRLs. The lack of existing MRLs for other insecticidal products places restraints upon storage managers and wheat marketers. The limited number of CODEX MRLs for stored grain insecticides forces storage managers and wheat marketers to either confine their insecticide use to chlorpyrifos-methyl or malathion, or market their wheat for domestic use only. Until recently, this situation did not compromise U.S. wheat storage because chlorpyrifos-methyl was the most cost effective insecticide available.

However, because there is no MRL for cyfluthrin on internationally traded wheat, storage managers are not able to take advantage of the recent Storcide registration unless they are committed exclusively to domestic marketing. While Storcide provides is an effective insecticide, the opportunity for its use is limited by the current lack of CODEX maximum residue tolerances. Until an international MRL or interim measure is adopted for cyfluthrin on stored wheat, Storcide's real potential will not be realized.

On-farm vs. off-farm pest management

Storage conditions and pest management practices for grain held on the farm can be quite different those for wheat held in commercial storage. Farmers manage approximately one third of U.S. stored wheat. The variation among on-farm storage practices is greater than among commercial storage facilities.

Generally, farmers are more reliant on sanitation and the use of grain protectants than commercial storage managers, who tend to rely more on fumigation for controlling insect infestations. Variation in facilities, costs and management skill are all factors that contribute to these differences. Regardless of the differences between farm and commercial storage, emphasis on IPM techniques is essential for effective insect control.

The ease of use for any one particular insect control method is generally dependent upon the storage facilities available. The storage structures commonly used to store wheat on-farm are generally, in both form and condition, not conducive to effective and economic fumigation and farmers are frequently not licensed to use chemical fumigants. Empty bin residual sprays, which must be applied directly to the interior surfaces of the grain bin, are much easier to use in the smaller bins characteristic of farm storage than in large commercial bins. Application of a residual top dress, made after the bin is loaded, is also easier in smaller farm bins than large commercial bins.

Commercial storage facilities are best suited for the use of fumigants as the primary quality maintenance tool. Commercial facilities generally have professional staff that are trained and certified to apply restricted use fumigants, bins are properly sealed and prepared for fumigation and environmental monitoring, and they have the equipment and storage space to apply fumigants by introducing them while turning the grain.

The cost of using fumigants in on-farm storage is substantially higher than at commercial facilities, estimated to cost a minimum of $0.06 to $0.12 per bushel, in comparison to the cost of grain protectants which ranges from about $0.01 per bushel for malathion to approximately $0.02 per bushel for chlorpyrifos-methyl. A higher cost of fumigating on-farm grain storage results from the logistical challenges faced by on-farm storage systems. On-farm storage bins are often old or in ill repair, requiring extensive effort to properly seal the bin against fumigant leakage. Even new, good quality farm storage bins require some effort to ensure proper sealing. Most farm storage managers are not trained and certified to apply restricted use fumigants, requiring them to hire outside contractors to fumigate for them. Depending upon interpretation of new label restrictions, these contractors may be required to remain on-site during the entire multi-day period during which fumigants are held in farm bins, which would greatly increase fumigation costs.

Differences in marketing strategies between farmers and commercial elevator managers also drive differences in pest management. Farmers store wheat to increase market flexibility. For many wheat-producing areas, wheat prices are at seasonal lows at harvest time because of the abundance of newly available wheat. By storing wheat on-farm, farmers may wait to market their crop until prices begin to rise. In order to ensure maximum value for their wheat, farmers need to maintain quality during the entire storage period by minimizing insect infestation. The residual insect control provided by a single harvest time application of grain protectants frequently makes them a cost-effective quality maintenance tool for on-farm wheat marketing strategies.

Marketing strategies for commercial storage facilities are based upon moving wheat from the storage facility to processors and exporters. With frequent inflow of new grain and outflow of sold grain, commercial storage emphasizes shorter-term storage. The low tolerance of processors for live insects and insect damage favors the more complete efficacy that can be achieved with fumigants immediately before sale. The fumigation friendly infrastructure of commercial storage facilities combines marketing factors to favor fumigation as more a more cost effective insect control tool than residual insecticides for commercial storage.

Regional patterns in reliance on on-farm and off-farm storage have developed. In the central and southern plains, wheat is harvested relatively early before prices decline to seasonal lows. In this area, there is less reliance on on-farm storage. In contrast, wheat grown in the northern tier is generally stored on-farm. It is harvested well into the national harvest season when wheat prices are at annual lows. This combines with the ease of aeration resulting from early cool weather to provide economic incentive to store on-farm and wait for prices to rebound before marketing.

Pest Management Practice Use

Data on the use of pest management practices in stored grain are incomplete. The extent of use of non-chemical pest management practices has been surveyed occasionally in various areas. Pesticide use is estimated annually by USDA NASS, but these surveys include only commercial storage facilities. Information on on-farm pesticide use is sparse and irregularly collected. Surveys of on-farm pesticide use on stored-grain have been conducted only occasionally and often include only limited geographic areas. Pesticide industry sales data provide information on the total amount of pesticides sold, but do not accurately describe where the pesticides are being used.

Surveys have shown that farmers and elevator managers are using basic sanitation practices. U.S. farmers surveyed in 1996 indicated that 98% swept floors, 60% cleaned conveyors, 34% lifted aeration ducts and 24% blew down the walls. [42] A 1992 survey of elevator managers of hard red wheat showed that 95% would sweep prior to receiving grain, 6% would hose, 9% would blow and 15% would vacuum. [28]

Aeration is also widely used. Forty-three percent of U.S. farmers surveyed in 1996 indicated that between ¼ and ½ of all bins were equipped with aeration equipment. [42] A 1992 survey of elevator managers estimated the percentage of commercial storage facilities with aeration equipment, by storage type. That survey indicated that 81% of round steel facilities, 51% of concrete facilities and 69% of flat steel facilities were equipped for aeration. The proportion of facilities equipped with aeration systems varied across the wheat area. Areas with the greatest aeration present were Texas, Kansas, Nebraska, Indiana, and Oklahoma. The higher proportion of facilities equipped with aeration in the southern areas can be explained by the critical need to manage temperatures to reduce insect and mold populations. [28]

USDA NASS data on the postharvest use of pesticides in stored wheat at commercial facilities show that fumigation is the most widely used, with 18% commercially-stored wheat in surveyed states treated with aluminum phosphide alone. [49] All other pesticides are used on less than 3% of total commercially stored grain. Chlorpyrifos-methyl is the next most widely used pesticide, used on 2.09%, followed by malathion, which was used on 1.05%. State level data show that chlorpyrifos-methyl use is more common in the Pacific Northwest than in other areas of the country. Washington, Idaho and Oregon estimates show between 4 and 6% of commercially stored wheat treated with chlorpyrifos-methyl. Fumigation was more prevalent in the southern plains states. According to USDA NASS survey, more than 25% of commercially stored wheat in Oklahoma, Texas, Kansas and Missouri was fumigated with phosphine. Table 10 shows USDA NASS postharvest wheat pesticide use for 2000.

An Oregon state extension survey of pesticide use at commercial storage elevators conducted in 1994 estimated that between 60% and 100% of wheat was treated with chlorpyrifos-methyl in different regions of the state. [46] Table 11 shows estimated grain protectant use by region in Oregon.

Other surveys do not estimate the volume of grain treated with pesticides, instead reporting simply the number of managers who use a particular practice. While these surveys are useful in describing the extent of adoption of various practices by stored grain managers, they are less useful in determining the amount of grain that is treated with pesticides, as it is unknown what portion of grain is being treated. A 1992 survey of elevator managers for hard red wheat in 11 states estimated the reliance by managers on various pesticides. Between 12 and 39% of elevator managers reported treating stored wheat with malathion, across the surveyed states. [28] Chlorpyrifos-methyl use was reported by between 4 and 49% of managers. Table 12 shows results from the 1992 survey.

A survey of southern plains elevator managers conducted during the 1996-97 storage year, indicated that 19% of managers used chlorpyrifos-methyl in steel bins, and 12% of managers used chlorpyrifos-methyl in concrete bins. Malathion use was more common, reported by 34% of managers for use in steel bins and 17% for use in concrete bins. [45]

In a 2001 survey of four elevators in Washington State, only one reported the use of chlorpyrifos-methyl in the past two years. Further, the manager reported that chlorpyrifos-methyl was used due to the lack of aeration. [34] Tennessee elevator managers surveyed in 1994 reported widespread reliance on malathion, with 72% of managers reporting malathion use as a bin spray, 38% as an entire mass treatment and 37% as a top-dress. Chlorpyrifos-methyl was the next most widely reported pesticide used, by 14% of managers as a bin spray, 19% as an entire mass treatment and 37% as a top-dress. [30] Results of the Tennessee survey are shown in Table 13.

Two surveys addressed on-farm use of pesticides in stored wheat. A survey of Alabama farmers was conducted in 2001. Malathion was the most widely used insecticide, as an empty bin treatment, grain protectant or top-dress. Malathion usage results are presented in Table 14. Fumigation with phosphine was also widely reported. Seventy-seven percent of growers reported fumigating with phosphine. [22]

A 1987 Oklahoma survey includes both on- and off-farm pesticide usage. In that survey, malathion was the most commonly reported insecticide as a bin spray and grain protectant. Grain protectants were generally used more widely on-farm than off-farm. Conversely, fumigation was more commonly reported by commercial elevator operators than by farmers. [2] Results of the Oklahoma survey are shown in Table 15.

It is generally accepted that chlorpyrifos-methyl use is more prevalent in on-farm storage than at commercial elevators. Therefore, the USDA NASS survey data of insecticide use in commercial storage facilities greatly understates the total usage of chlorpyrifos-methyl and other grain protectants that are more likely to be used by farmers. Gustafson sales data indicate total annual sales of approximately 81,000 lbs. of chlorpyrifos-methyl for use on all labeled stored grains. [72] It is believed that approximately 80% of this usage is on stored wheat, or approximately 67,700 lbs. [25] USDA NASS estimates only 18,900 lbs of chlorpyrifos-methyl use in commercial storage, or 28%. [49] Gustafson has also estimated the total amount of wheat in the Pacific Northwest that is treated with chlorpyrifos-methyl to be approximately 73 million bushels. At an application rate of 6 ppm, the Pacific Northwest would account for 39% of chlorpyrifos-methyl use on wheat.

Gustafson sales data for chlorpyrifos-methyl are also calculated by state. However, these data indicate sales from distribution centers that may serve regional markets. Therefore, we have aggregated the state level sales data to the regional level. Further, these data are for total chlorpyrifos-methyl sales. Assuming that 80% of total sales in any region are used for wheat, regional estimates of chlorpyrifos-methyl use can be derived. Those estimates are shown in Table 16.

The available data suggest some regional patterns in pest management practices between the three major wheat-producing regions of the U.S.: the Central and Southern Plains, the Northern tier and the Pacific Northwest. Stored grain managers in the Central and Southern Plains, where there is a large commercial storage capacity and less reliance on on-farm storage, primarily fumigate to control insect infestations. In the Northern Tier, naturally low harvest and winter temperatures favors reliance on aeration as primary insect control practice. Farmers and elevator managers in the Pacific Northwest treat a comparatively high percentage of its wheat with residual grain protectants.

Pest Management in Wheat for Seed

The maintenance of quality during storage is especially important for those growers who produce wheat for seed. Foundation seed growers first produce seed. The plants grown from foundation seed are used to mass-produce seed for distribution to farmers. This seed production system is organized and overseen by state crop improvement associations and universities. Although farmers frequently save some of their own harvest to provide seed for planting the following season, they must periodically refresh their seed stocks, often with new, improved, or purified wheat varieties from the foundation seed system. [64]

Those who grow and store wheat for seed rather than processing, especially those involved in the production of foundation seed, must pay special consideration to the maintenance of quality, including the suppression of insect infestations. A wheat kernel's value as seed is dependent upon its viability to produce a healthy wheat plant. The viability of a seed is quickly destroyed by damage to the germ, the part of the seed that grows into a new plant. Seed germs are made unviable by direct insect feeding or by excessive heat, which can be generated by insect and mold infestations. To avoid germ damage, it is imperative that insect infestations be minimized. [66]

The maintenance of quality within seed stocks is further complicated by the conditions under which seed is commonly stored. Seed is frequently stored in small lots, in bags ready for sale to farmers or in 50- or 100-bushel bins. Storage containers such as these prohibit the practical application of fumigants for insect control. Fumigating bagged seed or seed stored in small bins requires sealing, applying, monitoring, and airing out each lot individually. Seed is sometimes bagged and distributed to the point of sale early in the storage season. Even though the seed leaves the producers' facilities, its quality must remain high until it is purchased and planted. To ensure quality maintenance after the seed is distributed, residual insect control is needed. [66]

The difficulty of fumigation in small lot seed storage combined with the need for residual insect control to protect sensitive seed germs throughout the storage season has lead the wheat seed industry to become particularly reliant upon grain protectants. The seed industry currently treats a large portion of its wheat with chlorpyrifos-methyl. Chlorpyrifos-methyl is the product of choice among wheat seed storage managers because of its broad-spectrum insect control, its residual toxicity, and its food additive tolerance. Using a product registered for food to protect seed gives seed storage managers the ability to release their wheat into the food processing system. While seed storage managers enjoy the flexibility chlorpyrifos-methyl's food additive tolerance gives them, chlorpyrifos-ethyl (Lorsban) is an effective and economical alternative. Chlorpyrifos-ethyl provides comparable efficacy to chlorpyrifos-methyl, resulting from the similar chemical structures and action, at approximately half the cost. This low cost alternative can provide the quality protection in stored wheat seed required by the industry, but compromises the ability of seed producers to sell leftover or damaged seed into the processing market. [65]

The rigorous insect control necessary to ensure viable wheat seed is justified by the added value of seed wheat in comparison to processing wheat. High quality wheat seed generally sells at two to five times the price of wheat for processing. This higher value allows seed producers to invest more heavily in infestation suppression and prevention. [66]

Trends in grain storage

Many factors influence the structure of the U.S. grain storage and marketing system. Changes in storage type and capacity, federal programs, transportation infrastructure, demands for segregation, changing cleanliness standards, increasing pest management costs and increased foreign competition all contribute to an evolving system with differing implications for pest management needs. The U.S. stored grain marketing system is adapted to current conditions. However, the system is shifting to accommodate trends in these influences that impose greater pressures on grain storage, at once making storage quality maintenance more important and more complex.

Grain storage capacity increased greatly in the 1970's, as the government supported construction of storage structures, both on and off the farm, through low interest loan programs. U.S. grain storage capacity continued to increase through much of the 1980s, peaking in 1987. For the next decade, capacity steadily declined, but has risen slightly in the past few years. A large proportion of the storage facilities in use were therefore constructed in the 1970's. The useful life of steel storage bins, common in on-farm storage, constructed in that period was typically 20-30 years. Therefore, much of the on-farm grain storage capacity constructed up through 1980 is past, at, or near the end of its useful life. [19]

Most grain elevators currently being used in the U.S. were built in the 1950's and 1960's. The cost of constructing upright concrete bins has increased more rapidly than that of metal storage bins, much of the new elevator space are metal bins. These bins are usually larger and are more likely to have aeration equipment than concrete bins, but they have less thermal insulating capacity, are more accessible to insects, and are more difficult to seal for fumigation. [33]

Four primary federal programs influence wheat planting and marketing decisions: the

Farm Storage Facility Loan (FSFL) program, the commodity loan program, the Farmer Owned Reserve (FOR) program and the conservation reserve program.

The Commodity Credit Corporation (CCC) has made loans on grain storage and drying equipment under its authorities intermittently since 1949. CCC stopped making new storage facility loans in 1982 because studies indicated that producers had sufficient on-farm storage for their crops at that time. The Farm Storage Facility Loan program was again implemented by CCC under an interim rule published in the *Federal Register* on May 11, 2000.

Grain storage capacity has increased modestly (2%) since its low in 1997 as a result of expansion in both on- and off-farm facilities. However, these small increases in capacity have not kept pace with expanding production, particularly in the western growing areas. Between 1987 and 1999, U.S. grain and soybean production increased by 20 percent, from 12.8 and 15.4 billion bushels. The largest regional increases were in the western Corn Belt and central plains states where grain and soybean production increased 31% during the period. These regions are also the regions where storage capacity has been especially short following the past three harvests and where rail abandonment has been a significant problem. On-farm grain storage capacity has expanded in the past 2 years substantially more than off-farm capacity, with the largest share of that expansion coming in 1998. [19]

Commodity loan programs, starting in 1933, allowed producers of designated crops to receive loans from the government at a crop-specific loan rate per unit of production by pledging production as loan collateral. A farmer may obtain a loan for all or part of a crop at any time following harvest through the following March or the following May, depending on the crop. For production put under loan and pledged as loan collateral, the farmer receives a per-unit amount equal to that year's loan rate (by county) for the crop. Under the loan program, the producer must keep the crop designated as loan collateral in approved storage to preserve the crop's quality. The producer may repay the loan (plus interest) at any time during the 9 to 10 month loan period. Before marketing loans were introduced, the farmer could satisfy the loan by repaying the loan principal plus accrued interest charges. Alternatively, the farmer could choose to settle the loan at the end of the loan period (loan maturity) by keeping the loan proceeds and forfeiting ownership of the loan collateral to the government. Thus, the program supported prices by removing crops from the marketplace. Marketing loans for wheat were implemented in 1993. Marketing loan provisions allow farmers to repay commodity loans at less than the original loan rate when market prices are lower. Alternatively, farmers may choose to receive benefits through direct loan deficiency payments. [74]

New provisions of the marketing loan program distinguish loan rates for different grades of wheat, which will affect areas that produce lower priced grades of wheat adversely, likely lowering wheat acreage planted.

The current farm marketing loan program ends after 9 months. The now discontinued FOR program provided incentives for farmers to store wheat for longer periods, depending on market prices. The FOR began in 1977 and was terminated in 1996. [57] The elimination of subsidies as incentives for long-term storage has reduced the amount of grain carried over from one crop year to the next. Grain reserve programs provide strong income just for storing grain and not necessarily to maintain the quality of the product, acting in an almost counter-productive manner. [43]

Under the voluntary Conservation Reserve Program, USDA pays farm owners and operators to idle highly erodible and/or environmentally sensitive cropland for 10-15 years. Participants receive annual rental payments during the contract period, and half the cost of establishing grass or trees on enrolled acreage. Begun by the 1985 Food Security Act during a period of excess commodity supplies, low prices, and farm financial stress, the CRP was initially conceived as much for supply control as for environmental improvement. However, beginning with the droughts of the late 1980s, supply control became less important, and CRP implementation increasingly reflected its environmental and natural resource objectives. In April 1996, Clinton signed into law FAIR that continues the CRP through the year 2002. Under the act, USDA can re-enroll existing eligible CRP acres as well as enroll new land, subject to a maximum annual enrollment of 36.4 million acres. Although the elimination of annual acreage reduction programs by the 1996 farm act makes the CRP the principal remaining program that reduces cropland availability, USDA has made it clear that it will operate the CRP not as a supply control program, but to conserve and improve natural resources including wildlife habitat, water quality, and soil. [76] The CRP had been one of USDA's most ambitious program efforts. At the height of the program in 1993-95, some 36.4 million cropland acres had been enrolled in the environmentally oriented land retirement program. Approximately 60% of those acres were located in the Great Plains States, where wheat is the main crop. According to a 1993 survey, nearly 41% of CRP land had been planted to wheat prior to their enrollment. [76]

Rail abandonment during the last 20 years has also increased storage demand. Reductions in the size of the U.S. rail network, primarily from the loss of branch lines that once served rural and agricultural areas, has resulted in many farmers having to rely on trucking, a less cost-effective transportation alternative. Still other farmers are finding that Class I railroads are tending to de-emphasize carload business, preferring shipments of unit-train length or for the short-line feeder railroads to provide the gathering functions. These changes have left farmers in many areas with fewer and less accessible markets and a greater need for on-farm grain storage. [19]

Changes in the rate structure for railroad transportation have resulted in more grain being moved by truck than ten years ago and grain is now less likely to be officially inspected. The rate changes also have made it more likely that wheat used domestically will be stored at the first handler level (country elevator) rather than at terminal elevators. Grain moving to export is received at traditional terminal elevators or new regional high-speed loading facilities, which have the capability to efficiently load 25 to 100 car unit trains.

The impending introduction of genetically engineered wheat varieties and other quality differentiated varieties will require increased reliance on identity preservation systems, and contribute to the need for expanded on-farm storage and handling capacity. [19] Identity preservation involves the isolation and tracking of specific qualities or lots of wheat as they move through the marketing system. Currently, identity preservation's importance is seen in storage of special quality, often value-added, wheat being marketed for specialty use. In such lots not only must the special quality be maintained, but also the lot must be isolated to ensure that other quality wheats do not contaminate it and that it is accessible at the time of sale. Identity preservation's role in the wheat marketing system will only increase in the future as genetically modified wheat, currently under development, enters the general marketplace.

The need for identity preservation poses other unique challenges to the U.S. grain storage system. Commercial grain storage facilities heavily rely upon blending to manage grain quality and insect infestation in their wheat stores. Identity preservation inherently prohibits grain blending as a quality control technique. Identity preserved wheat's need to be isolated and accessible will also remove emphasis from the large, high-capacity storage bins and warehouses that are the basis of contemporary commercial storage and increase reliance upon small bin storage. Identity preservation needs especially increase reliance upon on-farm storage, since that is where the segregation and isolation responsibilities will begin.

Foreign wheat producers have become more competitive. As described above, U.S. wheat exports have declined in recent years as imports have increased at a rapid rate. These changes in international wheat grain trade reflect the increasing production and quality of foreign wheat and a widely held perception of U.S. wheat as low quality and "dirty."

Pest management costs have increased recently as stored grain managers strive to comply with increasingly strict safety regulations. The increased costs may be in the form of more training requirements for pesticide applicators, or new restrictions on the method of application of pesticides. Over time, this may reduce the amount of regulated pesticide used in grain storage, placing more emphasis on best management practices.

Wheat quality standards are rising, which imposes additional pressure on storage managers to maintain wheat quality. In Japan, millers have long requested cleaner U.S. wheat, resulting in the Japanese Food Agency, which controls most imports in Japan has tightened dockage requirements to a 0.3% maximum. [77] The U.S. may need to meet this level to remain competitive as the Japanese say that dockage in Canadian wheat imports averages 0.2%. Taiwan also has voiced concerns about dockage levels in U.S. wheat, and in 1998 instituted a maximum dockage level of 0.5%. [89]

The demand for higher quality wheat is seen spreading to other parts of the world, such as South Africa, where privatization of wheat buying is occurring and customers are expected to become more sophisticated and specific about their grain purchases. The Canadian Wheat Board subsidizes quality maintenance, which export customers say provides cleaner wheat than the U.S. Growth of U.S. wheat exports has been limited in recent years because cleaning facilities are not widely available within the U.S. export distribution system. Canadian dockage is 0.2% to 0.3% and Australian dockage is 0.3% for buyers concerned about cleanliness, with dockage running slightly higher to less sophisticated buyers. [89]

The 2002 Farm Bill included new incentives for hard white winter wheat, which is in greater demand for export. The bill adds $20 million to other government wheat subsidies to build up white wheat production. [80] Some types of oriental noodles require hard white wheat, of which the U.S. produces little. Now, hard white wheat varieties are being developed for U.S. farmers that would be competitive with Australian varieties for this noodle market. Some hard white wheat is currently produced in the Pacific Northwest region for export to Asia. Elsewhere, however, U.S. production of hard white wheat is very limited because previously available varieties produced low yields. Varieties are now being released that have yields comparable to the hard red wheat varieties. It is unlikely that substantial premiums would be offered initially for the white wheat to encourage the growers to switch. High premiums are not likely because there will be some initial expenses as the marketing system adapts to keep the white wheat segregated in the hard red wheat areas. Grain storage and transportation systems will have to handle a second class of wheat in these areas. The white grain will have to be kept separate from other wheat varieties through the entire production chain to the end-user. [383]

As in the current market, insecticides will play a vital role in insect control and quality maintenance in stored wheat under the emerging market conditions. Insecticides will remain particularly vital in regions especially conducive to insect infestation, like the Southeast and the Pacific Northwest. As emphasis within the U.S. grain storage system shifts in response market pressures from centralized commercial storage to small bin and on-farm storage, so too will the need for insecticides. In response to increased volume of small-bin storage and international and domestic demands for high quality wheat, grain protectant use will increase in volume and significance. New closed fumigation systems have potential to supplement the reliance upon grain protectants for small bin quality maintenance. The effective use of these fumigation systems will require much of the nation's small grain storage facilities to be retrofitted with the equipment necessary to fumigate, including bin sealing and installation of fumigant circulating equipment. With much of the nation's storage capacity at or near the end of its serviceable life, installation of such fumigation systems will be restricted to only the newer, sounder storage structures. Older structures and those in ill repair will continue to rely upon grain protectants to secure the quality of grain stored within.

Reldan's Impending Cancellation

Chlorpyrifos-methyl is currently in the midst of a voluntary phase-out schedule that is set to complete on December 31, 2004. The regulatory process that led to its phase-out is rooted in some features of its original registration. Chlorpyrifos-methyl was first registered for use as a stored wheat and small grain insecticide in 1985. The original registration was granted for three formulations, all marketed under the name Reldan. These formulations included a 2% dust, a 3% dust, and an emulsifiable concentrate. These products could be used on small grains including wheat, barley, oats, rice, and sorghum. Food tolerances were established, including meat and milk products. To expedite and simplify the registration of chlorpyrifos-methyl as a grain protectant, much of the toxicity data from chlorpyrifos-ethyl, marketed under many names including Lorsban and Dursban, was "bridged" for use on chlorpyrifos-methyl. This data bridge allowed many of the regulatory decisions supporting the registration of chlorpyrifos-methyl to be based on data for chlorpyrifos-ethyl. Use of the bridge was justified by the chemical similarities between chlorpyrifos-methyl and chlorpyrifos-ethyl.

On August 3, 1996 the Food Quality Protection Act (FQPA) was passed into law. FQPA amended the Federal Food, Drug and Cosmetics Act with the expressed purpose to better protect children and other sensitive subpopulations of Americans from risks associated with pesticide use and exposure. FQPA mandates that pesticide tolerances be recalculated, considering the aggregated risks of exposure through drinking water, food consumption and non-occupational exposure. FQPA also mandates that the risks of active ingredients with common mechanisms of toxicity be considered cumulatively. Aggregate and cumulative risks are then evaluated and managed through the potential addition of a 10x safety factor applied to uncertainty in the supporting data or to mitigate risk to children and other sensitive subpopulations. In implementing the required FQPA tolerance reassessments, the U.S. Environmental Protection Agency (EPA) designated organophosphates, including chlorpyrifos-methyl, as the first major class of chemicals to be reassessed.

Upon conducting the FQPA tolerance reassessment, the data bridge between chlorpyrifos-ethyl and chlorpyrifos-methyl was disallowed, producing several gaps in the chlorpyrifos-methyl toxicity characterization database. Regardless of the data gaps, an initial risk assessment was conducted. It was determined that acute and chronic dietary risks for chlorpyrifos-methyl were below EPA's level of concern. When considering the use pattern of chlorpyrifos-methyl, EPA did not anticipate any residues in drinking water and therefore did not conduct a drinking water assessment. Likewise, because there are no residential uses of chlorpyrifos-methyl a residential risk analysis was not conducted. Based on these findings, the dietary, water, and residential aggregate risks for chlorpyrifos-methyl were below the EPA level of concern and no risk mitigation measures were proscribed. These calculations included the 10x FQPA safety factor.

When conducting occupational exposure assessments, data from the Pesticide Handler Exposure Database were used. Based upon these calculations, risks at or above the level of concern were generated in all but one application scenario (automated liquid admix application). To further analyze the occupational risks of concern, EPA required a full chlorpyrifos-methyl database, which did not exist after the chlorpyrifos-ethyl data bridge was removed.

EPA noted the presence of residues in foods frequently consumed by children, specifically teething biscuits, cookies, and crackers. [54] Among these cited residues of concern the highest single detect measured 0.265 ppm and was observed in teething biscuits. The average residue level among the 25 teething biscuits sampled was 0.0204 ppm. When considered within the context of the established chlorpyrifos-methyl tolerance of 6.0 ppm, the average teething biscuit residue represents residues at 0.34% of tolerance and the maximum detect represents only 4.42% of tolerance. Even after application of a 10x safety factor for children and sensitive subpopulations, the average residue represents 3.4% of the 10x safety factor reduced tolerance and the maximum detect would occupy less than half of the 10x reduced tolerance. Among the other cited cookies and crackers of concern, none had mean residue levels higher than 0.02ppm, 0.33% of the 6.0ppm tolerance, or higher maximum residues than 0.107ppm, 1.8% of tolerance. [55][51][52]

To satisfy the data gaps produced by disallowing the data bridge, the EPA Health Effects Division identified a list of specific data to be supplied by chronic dog, chronic mouse, 2-generation rat reproduction, rat developmental toxicology, and metabolism studies. [18] The list of data gaps and corresponding studies was then expanded in September of 1999 to include, acute oral toxicity rat, acute dermal rabbit, acute inhalation rat, primary ocular irritation rabbit, primary dermal irritation rabbit, dermal sensitization guinea pigs, delayed neurotoxicity hens, acute neurotoxicity rat, subchronic dermal toxicity rat, chronic toxicity dog, prenatal developmental rabbit, 2-generational reproductive rat, developmental neurotoxicity rat, general metabolism rat, aspirated grain fraction field trial, and occupational exposure studies. A data call in (DCI) was issued for studies that could supply the needed data. [18]

After considering the costs associated with satisfying the data call in, estimated at or above $4 million with the developmental neurotoxicity study alone costing approximately $1.5 million, Dow AgroSciences applied for a minor use waiver for the acute, subchronic, and developmental neurotoxicity studies in December 1999. [83] In March of 2000, EPA rejected Dow's request for the neurotoxicology DCI waiver. The reason cited for denial was the presence of chlorpyrifos-methyl residue in Food and Drug Administration Total Diet Study samples. [49]

On August 16, 2000, following the rejection of the neurotoxicology DCI waiver request, Dow AgroSciences entered into negotiations with the EPA regarding a voluntary cancellation agreement for chlorpyrifos-methyl. The negotiations were completed on December 20, 2000 and the agreement was finalized January 30, 2001. Under the voluntary cancellation agreement, the sale of chlorpyrifos-methyl dust formulations would stop on March 30, 2001. Use of chlorpyrifos-methyl dust could continue until December 31, 2001. This early removal of the dust formulation was designed to mitigate the high occupational exposures associated with application of the dust formulation. To allow the grain industry time to transition to new insect management products and techniques, the end sale date for liquid chlorpyrifos-methyl formulation was established on December 31, 2003 with an end use data of December 31, 2004. To allow treated grain to clear the marketing channels, EPA will not revoke tolerances on chlorpyrifos-methyl until 2008.

Beyond the near immediate discontinuation of the chlorpyrifos-methyl dust formulation, risk mitigation measures mandated for the duration of chlorpyrifos-methyl's phase-out include a number of label changes. Among the changes, all registered uses of chlorpyrifos-methyl other than direct application to grain and treatment of empty grain bins were cancelled, application as an empty bin spray must be made from outside the bin while wearing basic personal protective equipment plus an approved respirator, and all direct grain applications must be made by an automated admixture apparatus.

While entering into a voluntary cancellation agreement and adopting prescribed risk mitigations measures reduced the amount of data supplements required by EPA, it did not eliminate all the data gaps. To continue with the phase-out of chlorpyrifos-methyl as negotiated, the registrant still needed to supply studies including acute neurotoxicity in hens and two-generation rat reproduction. [18]

Alternative Combination Products

Three combination products are being developed that could address some of the registration problems of chlorpyrifos-methyl by allowing its use at a reduced rate. Chlorpyrifos-methyl, when used alone, is an effective and inexpensive insect control measure, however, it can be more effectively used in combination with other insecticides. By combining chlorpyrifos-methyl at a reduced rate of 3 ppm, compared to the current rate of 6ppm, with cyfluthrin at 2 ppm, a broad spectrum and cost-effective residual insecticide is created. This product has been developed, under the trade name Storcide, and tolerances for the cyfluthrin component on stored grain were approved in September,

2002. Efficacy data generated by Oklahoma State University demonstrated 100% mortality among both lesser grain borer and rice weevil, two of the most prevalent and damaging stored wheat insects, for up to 48 months after treatment with Storcide. [40] In 2000 and 2001, the South Dakota Department of Agriculture requested Section 18 emergency registrations for Storcide to control infestations of lesser grain borer. The Section 18 was granted in 2001 and feedback from farmers using the product was resoundingly positive. The Idaho Department of Agriculture submitted a Section 18 request for use of Storcide in Idaho, Montana, Oregon and Washington State in July of 2002. The EPA approved that application.

The estimated cost per bushel for Storcide is $0.035. The cost for Storcide is approximately 1.5 times that of chlorpyrifos-methyl. Because it is a liquid applied in the same manner as chlorpyrifos-methyl, no capital expenditures for application equipment or storage facility modification would be required. The chlorpyrifos-methyl in a liquid formulation that is applied through an automated admix to the grain flow or from outside an empty bin to the interior surfaces eliminates the occupational exposure concerns of the EPA that surrounded the dust formulations and empty bin application from the inside. Further reducing occupational exposure concerns and mitigating the already below tolerance food detect of concern for chlorpyrifos-methyl is the reduced rate at which chlorpyrifos-methyl is used in Storcide. Inclusion of chlorpyrifos-methyl at 3ppm, half that of the current, stand-alone labeled rate, automatically halves the chlorpyrifos-methyl residues deposited on grain and exposed to workers.

A similar product combining 3 ppm Chlorpyrifos-methyl with 0.5 ppm Deltamethrin is currently being considered by Gustafson and Bayer. This combination has proven effective against both lesser grain borers and rice weevils. [92] While the prospective registrant of this product is still considering the feasibility of bringing it to market, both Chlorpyrifos-methyl and Deltamethrin have established CODEX MRLs for stored wheat, enabling wheat treated with this combination product to enter the international marketing system. However, before this product becomes a viable alternative for use in U.S. stored wheat, Deltamethrin must be granted food tolerances and a registration for use on stored wheat in the U.S. by the EPA.

A third combination product, with chlorpyrifos-methyl and Spinosad, is also in development. Spinosad is the most promising stored wheat insecticide in the research pipeline. Spinosad recently received an experimental use permit for elevator scale efficacy and residue trials. In laboratory trials conducted at Kansas State University, Spinosad provided total, 100% mortality among populations of lesser grain borer for twelve months at application rates as low as 0.1 ppm. The same study also examined Spinosad's efficacy against red flour beetle. At twelve months of storage, mortality dropped to 50% with treatment at 1ppm and 80% with treatment at 3 ppm. [31] Another study conducted by the same researcher demonstrated efficacy of Spinosad at 1ppm on rice weevils where mortality rates dropped below 83% on hard red wheat after only fourteen days. [31] If combined with chlorpyrifos-methyl for its weevil and flour beetle control, in a similar manner as Storcide, Spinosad/chlorpyrifos-methyl could prove a very effective insecticide.

Requisite for these combination products to be viable stored grain protectants is a continued registration for chlorpyrifos-methyl. Cyfluthrin, Deltamethrin, and Spinosad are particularly effective against the Lesser Grain Borer, an insect with demonstrated resistance to chlorpyrifos-methyl. Conversely, Cyfluthrin, Deltamethrin, and Spinosad are relatively ineffective against weevils, insects against which chlorpyrifos-methyl is particularly effective. Without a continued registration for chlorpyrifos-methyl, even if at a maximum rate half the current, these three promising alternative products would be irrelevant. This would leave a situation in which the most promising new stored grain protectants control only Lesser Grain Borer allowing weevil infestations to continue unchecked.

NCFAP Survey

A survey of growers who store grain on-farm was conducted to determine the significance of chlorpyrifos-methyl in on-farm storage systems and to examine the alternatives that would be used by farms were chlorpyrifos-methyl no longer available. While the survey was distributed nationwide, the Pacific Northwest received special attention during distribution because of their historical reliance on grain protectants.

In February 2002, the National Center for Food and Agricultural Policy (NCFAP) issued a call for feedback regarding the significance of chlorpyrifos-methyl in farm stored wheat. The issued press release included a brief discussion of the regulatory status of chlorpyrifos-methyl. The call for feedback requested that any individual or group interested in the chlorpyrifos-methyl specifically or in stored grain pest management in general contact NCFAP. This request was distributed through regional newspapers, agricultural journals and periodicals, and state and national grain and feed associations via newsletters, web postings, and e-mail digests.

The call for feedback was subsequently augmented by NCFAP through the issuance of a storage pest management survey. The survey was distributed in a number of short, long, and industry specific forms by the National Association of Wheat Growers in conjunction with several state wheat commissions and crop improvement associations. Respondents were asked to comment on the general size and scope of their grain storage, the significance of chlorpyrifos-methyl in their storage operation, the impact any cancellation of chlorpyrifos-methyl may have on their storage operation, and what alternatives, if any, would be employed to compensate for the loss of chlorpyrifos-methyl.

The call for feedback and various surveys have generated approximately 200 responses to date. The storage operations and goals of respondents vary widely, including farmers storing as little as 10,000 bushels of wheat on-farm, commercial storage elevators with many hundreds of thousands of bushels stored, and seed producers concerned with storing wheat specifically for certified seed. Each type of respondent has different concerns regarding chlorpyrifos-methyl's future, but all share common satisfaction with the product.

Most survey respondents reported rarely experiencing economically damaging insect infestation in chlorpyrifos-methyl treated storage, but fear that without the product the incidence of these infestations will increase. Farm storage managers universally expressed concern that a loss of chlorpyrifos-methyl would force them to adopt toxic and volatile phosphine fumigants as their primary means of insect control. Regardless of the size and nature of storage, current level and frequency of infestation, or willingness to adopt phosphine, all respondents project negative economic impacts ranging from loss of a few cents per bushel to "monumental" economic impacts following a phase-out of chlorpyrifos-methyl.

No statistical conclusions can be drawn from the survey, but the responses qualitatively describe the views and needs of on-farm storage managers. All respondents who currently use chlorpyrifos-methyl in their storage described complete efficacy throughout the storage season. None of the respondents noted discounts or penalties having been assessed at time of sale for insect damage in treated wheat. One farmer who stores wheat on-farm in North Dakota noted receiving a $0.02 per bushel premium for chlorpyrifos-methyl treated wheat.

When asked what they will do should chlorpyrifos-methyl no longer be available, farmers responded with a variety of answers, but all expressed consternation and concern. A few farmers stated that they would abandon on-farm wheat storage or wheat production all together. Many responded that they would have to sell their wheat earlier in the storage season before large insect infestations develop, suffering low prices to avoid quality discounts. The rest of respondents, including farmers who grow and store wheat for seed, who are unwilling to sell early for low prices see no other option but to use phosphine fumigants or revert to malathion. Among this group, most recognize malathion's inefficacy, yet they feel that it may provide them at least some minimal protection against insect infestation. Those who plan to use phosphine fumigants are not satisfied with their alternative. All respondents are concerned about the toxicity and dangers associated with phosphine use and recognize that multiple applications may be required to affect insect management.

For seed producers, the prospect of using phosphine is especially problematic. Seed is frequently stored in small marketable bags or in bins as small as 50 bushels. The use of phosphine fumigants to control insects in these storage vessels would require them to be wrapped in plastic and fumigated individually. Such scenarios involve large amounts of labor and maximize possible exposure to toxic fumigants. Regardless of the strategies farm-storage managers will use to compensate for chlorpyrifos-methyl's loss, they all concede that their ability to maintain wheat quality and retain already slim profit margins will be compromised.

Impact

The completion of the chlorpyrifos-methyl phase-out will leave U.S. grain storage, and especially wheat farmers who store on-farm, in a precarious position. With the elimination of the only currently available effective grain protectant, storage managers are left with few truly feasible options.

The potential impact of chlorpyrifos-methyl cancellation to on- and off-farm wheat storage is based on USDA wheat production data and chlorpyrifos-methyl sales and use data supplied by Gustafson. In 2000, U.S. wheat growers produced approximately 2.3 billion bushels of wheat of all classes. With an average market value of about $2.65/bu, this production was valued at $6.1 billion. [20]

Approximately 67,700 lbs. of chlorpyrifos-methyl were applied to stored wheat in 2001. According to USDA NASS, 18,900 lbs. are applied to wheat held in commercial storage, leaving 48,800 lbs. that is assumed used in on-farm storage. [72] When used at the labeled rate of 0.00036 lb/bushel, on-farm chlorpyrifos-methyl usage accounts for approximately 130 million bushels treated. This is approximately 16% of all wheat stored on-farm and has a value of $345 million. Off-farm use is estimated at approximately 53 million bushels treated, with a total value of $139 million.

The cost of treating the 183 million bushels of wheat is estimated at $0.02/bu or $3.66 million total. Without chlorpyrifos-methyl, it is assumed that all previously treated wheat will become infested and be assessed discounts averaging $0.10/bu. The potential loss for the 183 million bushels currently being treated with chlorpyrifos-methyl is $18.3 million dollars. The net loss, when the savings for not applying Reldan are included, is $14.64 million dollars. This aggregate loss represents $0.08 per bushel loss suffered on each currently treated bushel. Table 17 shows estimated losses broken down by on- and off-farm use.

This estimate is made upon the assumption that all wheat currently being treated is either not discounted at the time of sale or receives a lower discount than would be expected if not treated with chlorpyrifos-methyl.

The estimated losses represent a maximum loss to stored insect pest damage in stored wheat due to the loss of chlorpyrifos-methyl as an option for grain protection, under current market conditions. Managers would be expected to attempt to limit these losses by increasing expenditures on storage insect pest management. Multiple fumigation applications in current on farm storage to maintain quality at a level equivalent with foreign producers and raising commercial standards will certainly elevate that cost of insect control without increasing wheat value.

Losses may become greater as reliance on on-farm storage increases, identity preservation becomes more significant, transportation costs increase, and grain standards are tightened. The compounded economic impacts of the damage due to the loss of grain protectants, an increased reliance upon multiple on-farm fumigations, and an increased need for on-farm and small bin storage drive the cost of stored wheat quality maintenance higher with uncertain potential for increased revenue through value-added specialty

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wheat.

The statements of farmers augment the quantitative analysis of lost revenues. Grain protectants are an integral part of U.S. stored wheat quality maintenance, especially in areas where on-farm storage is prevalent, where pest pressure is high or where facilities or environmental conditions are not amenable to aeration or fumigation. Farmers have made it clear that they are unwilling and unable to store wheat without the assistance of grain protectants, and chlorpyrifos-methyl is their last available and effective grain protectant for wheat.

To ensure the sustained stability and success of the U.S. wheat storage and marketing system, the needs of on farm and small bin storage must be met. The continued availability of safe and cost-effective stored grain insecticides is primary among these needs, requiring regulatory action to provide for the extended use of current insecticides and expedited registration of new products. A minor-use waiver for acute, subchronic, and developmental neurotoxicity studies must be granted for chlorpyrifos-methyl for use at 3 ppm, half the current rate. Use at this rate will mitigate any dietary concerns generated by anomalous food detects of chlorpyrifos-methyl while providing for the development and use of highly effective combination insect control products. Unfortunately, this transition to lower rates and greater efficacy cannot be made immediately. CODEX MRLs or equivalent interim measures must be established for all components of combination products for use in stored wheat. Until these MRLs are set, any combination product treated wheat is limited exclusively to domestic marketing. To maintain U.S. presence and competitiveness in international wheat trade, use of chlorpyrifos-methyl at 6 ppm must be continued until the CODEX MRLs for combination product components are available. Additionally, to provide growers with the greatest number of insect control options and to promote positive resistance management, Spinosad and Deltamethrin must be granted U.S. registration for use on stored wheat. With these regulatory actions:

- granting of a chlorpyrifos-methyl acute, subchronic, and developmental neurotoxicity minor use waiver at 3 ppm

- continuation of chlorpyrifos-methyl use at 6ppm until MRLs for combination product components are established,
- establishment of international MRLs for Cyfluthrin and Spinosad for use on stored wheat and,
- domestic registration of Spinosad and Deltamethrin for use on stored wheat,

U.S. wheat storage managers, especially those on farm or using small bins, will have the most cost-effective, safest, and varied insect control options possible.

In recognition of the constraints placed upon crop protection companies by the small market and specialized use patterns of stored grain protectants, it is difficult for companies to develop and market new grain storage insecticides at costs practical for use by on-farm storage managers. With this understanding and the above-prescribed regulatory actions, the U.S. grain storage and marketing system is provided with the greatest opportunity to maintain its prominent and competitive place in international markets.

Table 1. U.S. Wheat Production 2001 by State

State	Area Planted *1,000 Acres*	Yield *Bushels/Acre*	Total Value *1,000.0*
AL	170	48.0	7,896.0
AZ	94	91.6	31,795.0
AR	1100	52.0	118,534.0
CA	615	76.1	112,544.0
CO	2397	33.8	190,054.0
DE	60	61.0	8,519.0
FL	10	41.0	830.0
GA	300	53.0	21,730.0
ID	1280	71.0	279,144.0
IL	750	61.0	107,604.0
IN	400	66.0	60,192.0
IA	25	54.0	2,430.0
KS	9800	40.0	902,000.0
KY	550	66.0	60,588.0
LA	175	50.0	22,000.0
MD	190	63.0	27,011.0
MI	570	64.0	87,808.0
MN	1867	43.0	238,798.0
MS	250	52.0	28,665.0
MO	900	54.0	100,548.0
MT	5360	22.9	316,746.0
NE	1750	37.0	165,760.0
NV	15.0	90.0	844.0
NJ	31.0	45.0	2,795.0
NM	500.0	34.0	21,216.0
NY	125.0	53.0	15,582.0
NC	680.0	39.0	46,742.0
ND	9,450.0	32.2	831,420.0
OH	950.0	67.0	150,750.0
OK	5,600.0	33.0	341,880.0
OR	930.0	38.0	133,050.0
PA	170.0	52.0	22,048.0
SC	220.0	43.0	20,769.0
SD	3,025.0	37.6	219,949.0
TN	500.0	54.0	45,900.0
TX	5,600.0	34.0	310,080.0
UT	160.0	42.8	19,426.0
VA	200.0	60.0	23,460.0
WA	2,490.0	55.7	442,680.0

WV	12.0	58.0	1,137.0
WI	178.0	64.1	24,628.0
WY	168.0	24.2	8,263.0
TOTAL	59,617.0	51.4	5,573,815.0

Source: [87]

Table 2. Common and Scientific Names of Wheat-Infesting Insects

Common Name	Scientific Name
Sawtoothed grain beetle	*Oryzaephilus surinamensis*
Red flour beetle	*Tribolium castaneum*
Confused flour beetle	*Tribolium confusum*
Rice weevil	*Sitophilus oryzae*
Lesser grain borer	*Rhyzopertha dominica*
Rusty grain beetle	*Cryptolestes ferrugineus*
Flat grain beetle	*Cryptolestes pusillus*
Angoumois grain moth	*Sitotroga cerealella*
Indian meal moth	*Plodia interpunctella*

Table 3. Insect Infestation in Farm-Stored Wheat 1980

State	No. of samples	% infested	Avg. insect density/1000 g
North Dakota	1455	24.8	90
Minnesota	616	42.9	103
South Dakota	542	32.5	117
Nebraska	244	18	30
Montana	777	11.6	81
Kansas	232	20.3	15
Colorado	159	25.2	135
Illinois	1	100	109
Michigan	2	50	10
Oregon	42	28.6	14
Washington	27	3.7	1
Oklahoma	23	34.8	13
Idaho	19	10.5	264
Wyoming	17	5.9	17
Utah	9	0	
Texas	3	33.3	2
New Mexico	3	0	
All states	4171	25.1	105

Source: [13]

Table 4. Elevator manager ranking of insect problems encountered 1992

State	RGB	GW	IMM	LGB	RFB	RW	Other
Colorado 2.00 1.7 2.75 2.29 2.67 4.67 Idaho	3.11	2.00	4.00	2.18	1.61	5.20	2.00
Indiana **3.11 1.51** 2.30 3.39 2.87 4.43 Kansas	**3.45**	**1.92**	**2.82**	**2.57**	**3.07**	**4.96**	**3.00**
Montana 3.11 1.72 3.72 2.37 2.08 5.63 Nebraska 3.00 2.00 2.75 2.25 3.50 6.00 N. Dakota	2.79	1.74	2.93	3.18	2.59	5.90	1.33
Nevada	3.19	1.83	2.60	3.20	2.90	5.20	1.75
Oklahoma	3.38	1.81	3.02	2.56	3.71	4.19	3.78
S. Dakota	3.29	1.58	2.79	3.51	2.94	5.01	1.33
Texas	2.65	1.68	3.00	2.39	3.48	4.15	2.67
Wyoming 1.00 2.00 1.00 Nationwid e	3.14	1.77	2.84	2.77	2.95	4.92	2.28

Note: 1=most important, 5=least important
RGB: Flat and rusty grain beetles
GW: Granary weevil
IMM: Indian meal-moth
LGB: Lesser grain borer
RFB: Red and confused flour beetles
RW: Rice weevil
Source: [28]

Table 5. Percentage of bins where insects were detected in commercial and on-farm storage in Oklahoma (1985-1988)

Insect	% Infested			
	1985-86	*1986-87*	*1987-88*	*1988-89*
Rice/granary weevils	0	0	11	13
Indian meal moth	43	18	4	77
Tribolium spp.	23	56	21	68
Lesser grain borer	23	49	62	48
Cryptolestes spp.	36	66	32	77
Long horned flour beetle	0	0	4	0
Sawtoothed grain beetle	15	25	21	5
Hairy fungus beetle	0	0	0	41
Foreign grain beetle	0	0	0	27
Black fungus beetle	0	0	0	5
Corticaria spp.	0	0	0	41
Cynaeus spp.	0	0	0	9

Source: [2]

Table 6. Grades and Grade Requirements for all classes of wheat, except Mixed wheat

Grade	Minimum limits of	Maximum limits of			
	Test weight per bushel	Damaged kernels	Wheat of other classes[2]		

Hard Red Spring Wheat or White Club wheat (pounds) All other classes and subclasses (pounds) Heat damaged kernels (percent) Total (percent) Foreign material (percent) Shrunken and broken kernels (percent) Defects[1] (percent) Contrasting classes (percent) Total[3] (percent) U.S. No. 1 58.0 60.0 0.2 2.0 0.4 3.0 3.0 1.0 3.0 U.S. No. 2 57.0 58.0 0.2 4.0 0.7 5.0 5.0 2.0 5.0 U.S. No. 3 55.0 56.0 0.5 7.0 1.3 8.0 8.0 3.0 10.0 U.S. No. 4 53.0 54.0 1.0 10.0 3.0 12.0 12.0 10.0 10.0 U.S. No. 5 50.0 51.0 3.0 15.0 5.0 20.0 20.0 10.0 10.0 U.S. Sample grade

U.S. Sample grade is wheat that:

a. Does not meet the requirements for the grades U.S. Nos. 1, 2, 3, 4, or 5; or
b. Contains 32 or more insect-damaged kernels per 100 grams of wheat; or
c. Contains 4 or more stones or any number of stones which have an aggregate weight in excess of 0.1% of the sample weight, 1 or more pieces of glass, 3 or more crotalaria seeds (*Crotalaria* spp.), 2 or more castor beans (*Ricinus communis* L.), 4 or more particles of an unknown foreign substance(s) or a commonly recognized harmful or toxic substance(s), 2 or more rodent pellets, bird droppings, or equivalent quantity of other animal filth per 1000 g of wheat[4]; or
d. Has a musty, sour, or commercially objectionable foreign odor (except smut or garlic odor); or
e. Is heating or of distinctly low quality.

1 Includes damaged kernels (Total), foreign material, shrunken and broken kernels.
2 Unclassed wheat of any grade may contain not more than 10.0 percent of wheat of other classes.
3 Includes contrasting classes.
4 Contains 5 or more in any combination of animal filth, castor beans, crotalaria seeds, glass, stones, unknown foreign substance.

Source: [39]

Table 7. Special Grades and Special Grade Requirements

Special Grade	Definition
Infested	Representative sample contains two or more live weevils, or one live weevil and one or more other live insects injurious to stored grain, or two or more live insects injurious to stored grain OR the lot as a whole when two or more live weevils, or one live weevil and one or more other live insects injurious to stored grain, or two or more other live insect injurious to stored grain are found in, on , or about the lot
Ergoty	Contains more than 0.05% of ergot
Garlicky	Contains in a 1000 gram portion more than two green garlic bulblets or an equivalent quantity of dry or partly dry bulblets
Light smutty	Has an unmistakable odor of smut, or which contains, in a 250 g portion, smut balls, portions of smut balls, or spores of smut in excess of a quantity equal to 5 smut balls, but not in excess of a quantity equal to 30 smut balls of average size
Smutty	Contains, in a 250 g portion, smut balls, portions of smut balls, or spores of smut in excess of a quantity equal to 30 smut balls of average size
Treated	Wheat that has been scoured, limed, washed, sulfured, or treated in such a manner that the true quality is not reflected by either the numerical grades or the U.S. Sample grade designation alone

Source: [39]

Table 8. Summary of Survey Results on Wheat Discounts

Source	Year of Survey	Geographic Area	Description	Number of Observations	Proportion Receiving Discounts	Discount ($/bushel)
Barak et al. 1981 [48] $0.07[b]	1980	Minnesota	Live insects [a]	46	16.6%	
Reed, et al. 1989 [11]	1986-87	Kansas	Live insects	465		$0.02-$0.041
damage[c] Denicksson, et al. 1989 [50] $0.18	1988	South Dakota	Insect	624		
Kenkel, et al. [28]	1992	U.S.	Insect infestation	1020	30.0	$0.081
Reed, et al. 1993 [24] $0.132/$0.044[h]	1991	Kansas	Live insects and insect damage			

a Includes samples with 5 or more live insects per 1 kg sample.
b Average discount reported by elevator managers, not based on actual discounts given.
c Average Bushels Docked and Percent of Producers Surveyed Receiving Dockage on Stored Grain Due to Insect, Insect Damage and Mold Damage
d Average 1984-87.
e Sum of discounts for fumigation charges, odors or insect damage, and musty or mold damaged grain.
f Number of farmers surveyed/Number of elevator managers surveyed
g As reported, one in five of the 56.4% of respondents who received discounts said the discount was due either to live insects or insect damage
h Average discount as reported by farmers/Average discount as reported by elevator managers

Table 9. Summary of Aggregate Wheat and Combined Grain Loss Estimates

Source	Year of Estimate	Geographic Area	Description	Percentage Loss	Value Loss	Basis of estimate
Pimental [61]	Not given	U.S.	Postharvest losses	9%	Not given	1965 USDA ARS report
Harein [17]	1990	15 states/U.S.a million[a]	Losses to Insects and Mold in Corn and Wheat	Not given	$239 million/$356	Survey of Extension Entomologists
Cuperus, et al. [26]	Not given	Oklahoma	Losses to insects and mold in stored grain	Not given	$50 million	Not given
USDA ARS [58]	Average[b] 1951-1960 3%	U.S.	Losses caused by insects		Not given	Not given
KSU [59]	Not given	U.S.	Losses to insects in stored corn and wheat	5-10%	$1 to $3 billion	Citing industry analysts estimate
Cuperus, et al. [60]	Not given	U.S.	Damage caused by insect, molds, heat and sprouting		$1 billion	Not given
University of Georgia [23] costs[c]	1993	Georgia	Total stored grain product control	Not given	$3.6 million	Assuming 60% of production is treated with insecticide at $0.05/bushel and 50% is subject to other insect management practices at $0.05/bushel
South Dakota Department of Agriculture [29]	Average 1995-99	South Dakota	Lower quality due to lesser grain borer	Not given	$10.9 million	Assuming 33% of production receives $0.29/bushel discount

a Loss estimates from 15 states reporting extrapolated to national level.

b Does not include cost of insect control or secondary costs due to damage or contamination of insects
c Includes corn, wheat, oats, sorghum and rye.

Table 10. USDA NASS Postharvest Wheat Pesticide Use Data 2000

	Diatomaceous Earth	Malathion	Chlorpyrifos-methyl	Methyl Bromide	Aluminum Phosphide

% Treated Total Applied (1000 Lbs) % Treated Total Applied (1000 Lbs) % Treated Total Applied (1000 Lbs) % Treated Total Applied (1000 Lbs) % Treated Total Applied (1000 Lbs) Surveyed States 0.37% 114.2 1.05% 14.9 2.09% 18.9 0.35% 19.0 18.43% 115.4 CO 3.28% 7.3 15.05% 1.9 ID 2.39% 7.8 4.96% 1.0 7.63% 0.5 KS 1.30% 0.9 0.30% 0.2 0.97% 6.0 33.48% 16.5 MN 0.40% 0.4 MO 0.73% 0.4 1.28% 0.4 25.77% 8.6 MT 0.34% 2.7 0.12% 0.1 1.12% 0.3 3.01% 1.1 NE ~ 4.42% 5.0 23.16% 7.1 ND 0.13% 0.2 1.37% 1.1 0.98% 0.7 OH 0.8% 7.9 1.01% 0.4 10.48% 1.9 OK 0.59% 5.3 48.65% 24.3 OR 4.29% 2.4 SD 0.94% 0.2 4.88% 1.1 TX .05% 1.5 0.14 <0.05 43.96% 40.4 WA 6.27% 12.3 5.84% 9.1 Source: [49]

Table 11. 1994 Oregon Commercially Stored Wheat Grain Protectant Use

	Willamette Valley	Columbia Basin (Dryland)	Columbia Basin (Irrigated)	Central Oregon	Treasure Valley
Chlorpyrifos -methyl	90%	90%	100%	90%	60%
Malathion	3%	3%			

Source: [46]

Table 12. Elevator Managers Reporting Use of Particular Insecticides in Hard Red Wheat Storage

	Malathion		Chlorpyrifos-methyl		D.E.	
	Concrete	Steel	Concrete	Steel	Concrete	Steel
	% Use	% Use	% Use	% Use	% Use	% Use
	% Control	**% Control**	**% Control**	**% Control**	**% Control**	**% Control**
CO	**11.76**	**25.00**	**5.88**	**14.29**	**0.00**	**4.76**
90.00 **68.75** **52.50** 60.00 ID	35.00	24.24	45.00	45.45	0.00	0.00
55.00 55.00 100.00 81.13 IN	**29.54**	**34.15**	**7.14**	**6.90**	0.00	0.00
76.00 85.71 92.50 92.50 **KS**	22.29	25.79	21.94	21.27	1.95	2.56
80.14 **78.56** 92.86 **85.43** 85.00 MT	**38.89**	**44.40**	**47.60**	50.00	**5.88**	**6.25**
40.00 73.00 89.00 81.57 ND	31.91	34.78	**49.06**	58.70	2.33	**3.33**

68.13 75.40 79.93 84.74 100.00 NE	**22.50**	**36.05**	3.75	9.50	0.00	0.76
84.17 **80.80** **85.88** **OK**	16.67	24.10	5.13	8.04	1.29	0.00
82.50 80.60 **90.00** 83.33 SD	25.71	31.82	35.29	36.36	0.00	6.33
77.00 79.38 87.50 84.19 100.00 TX	**18.0**	**21.21**	**6.52**	9.09	2.17	**10.91**

85.60 79.71 96.50 88.50 86.67 W

Y 66.67 0.00 **0.00** 65.00 **AVG.**	23.44	29.61	19.00	23.24	1.33	3.56
	77.41	78.83	88.11	84.22	85.00	90.00

Source: [28]

Table 13. Tennessee Elevators Reporting Use of Various Insecticides

	Malathion	Chlorpyrifos-Methyl	D.E.	Actellic	Phosphine	Methyl Bromide

Empty Bin Residual Spray 72% 14% 3%

0% N/A N/A **Grain Protectant** **38% 19% 0% 0% N/A** N/A **Top-Dress** **37% 15% 0% 15%** N/A N/A **Fumigation**	N/A	N/A	N/A	N/A	29%	7%

Source: [30]

Table 14. Alabama Farmers Reporting Insecticide Use in 2001

	% Adoption	% Of Adaptors Using Malathion
Empty Bin Residual Spray	77%	53%
Grain Protectant	50%	60%
Top-Dress	31%	75%

Source: [22]

Table 15. 1987 Oklahoma Stored Wheat Management Practices On and Off Farm [2]

		Adoption	Malathion	Chlorpyrifos -Methyl	Methoxyc hlor	Other
Residual Bin spray	% On Farm	85%	77%	8%	5%	4%
	% Off Farm	**88%**	**87%**	3%	5%	13%
Grain Protectant % On Farm 62% **69% 10%** **% Off** Farm 35% 63% 17% **Top Dress** % On Farm 42% % Off Farm 35% Phosphine Methyl bromide Chloropicrin 80/20* Other Fumigation	% On Farm	**48%**	0%	**2%**	**3%**	**47%****
	% Off Farm	94%	2%	**1%**	**0%**	**3%**

*Use still reported even though 80/20 fumigants were banned in 1985.
**Number may result from misunderstanding of what fumigants are. Several producers listed malathion, chlorpyrifos-methyl, and methoxychlor as fumigants used.

Table 16. Gustafson Sales Data by Region

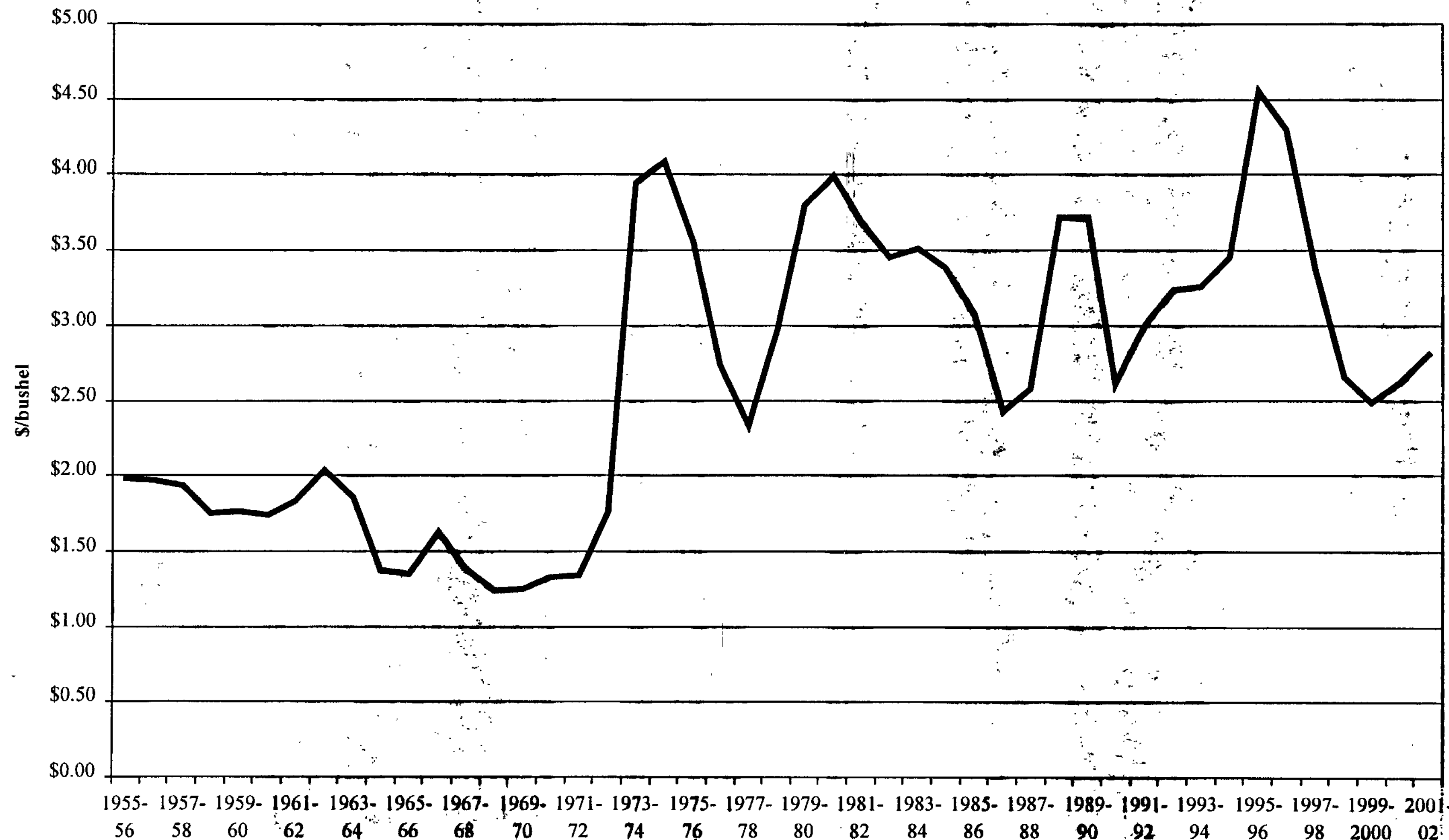
	Sales	80% of Sales	Bushels Treated	State Production (1000 Bu)	% of Prod. Trtd
East	3,124	2,499	6,929,600	74,297	9%
Midwest	10,652	8,522	23,628,073	533,960	4%
Northern Tier	16,188	12,950	35,906,818	1,615,176	2%
Plains	12,507	10,005	27,741,691	1,719,720	2%
PNW	16,433	13,146	36,450,339	854,874	4%
South	10,729	8,583	23,798,873	397,114	6%
West	15,020	12,016	33,317,091	241,275	14%
Total	84,652	67,721	187,772,485	10,631,557	2%

Source: [84]

Table 17. Estimated Losses Due to Cancellation of Chlorpyrifos-methyl in Stored Wheat

	On-farm	Off-farm	Total
Chlorpyrifos-methyl use (lbs.)	48,800	18,900	67,700
Wheat treated (bushels)	130 million	53 million	183 million
Revenue loss	**$13 million**	**$5.3 million**	**$18.3 million**
Cost savings	**$2.6 million**	**$1.1 million**	**$3.66 million**
Net loss	$10.4 million	$4.3 million	$14.64 million

Figure 1. Wheat Prices Received by Farmers 1955-56 to 2001-02



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EMBED Excel.Chart.8 \s

Figure 3. US Wheat Production by Class 2001

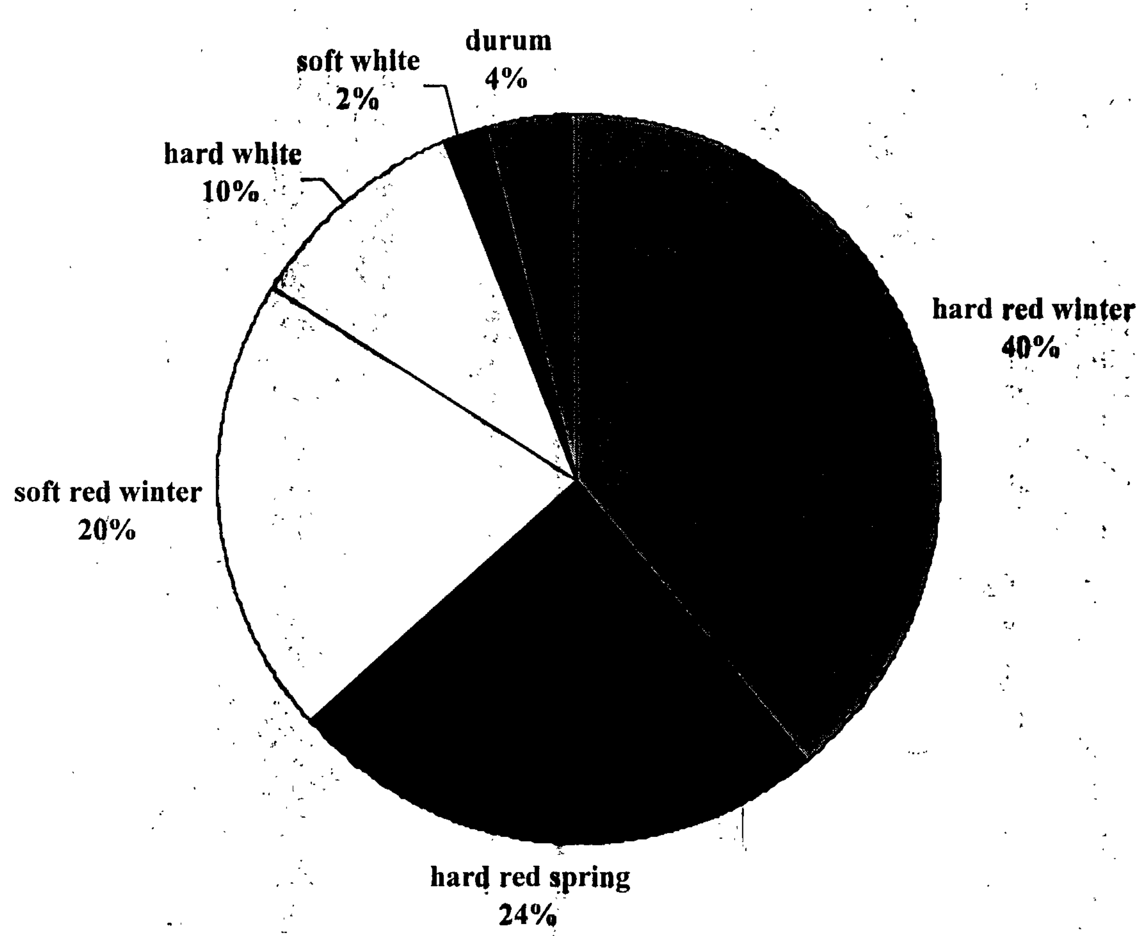
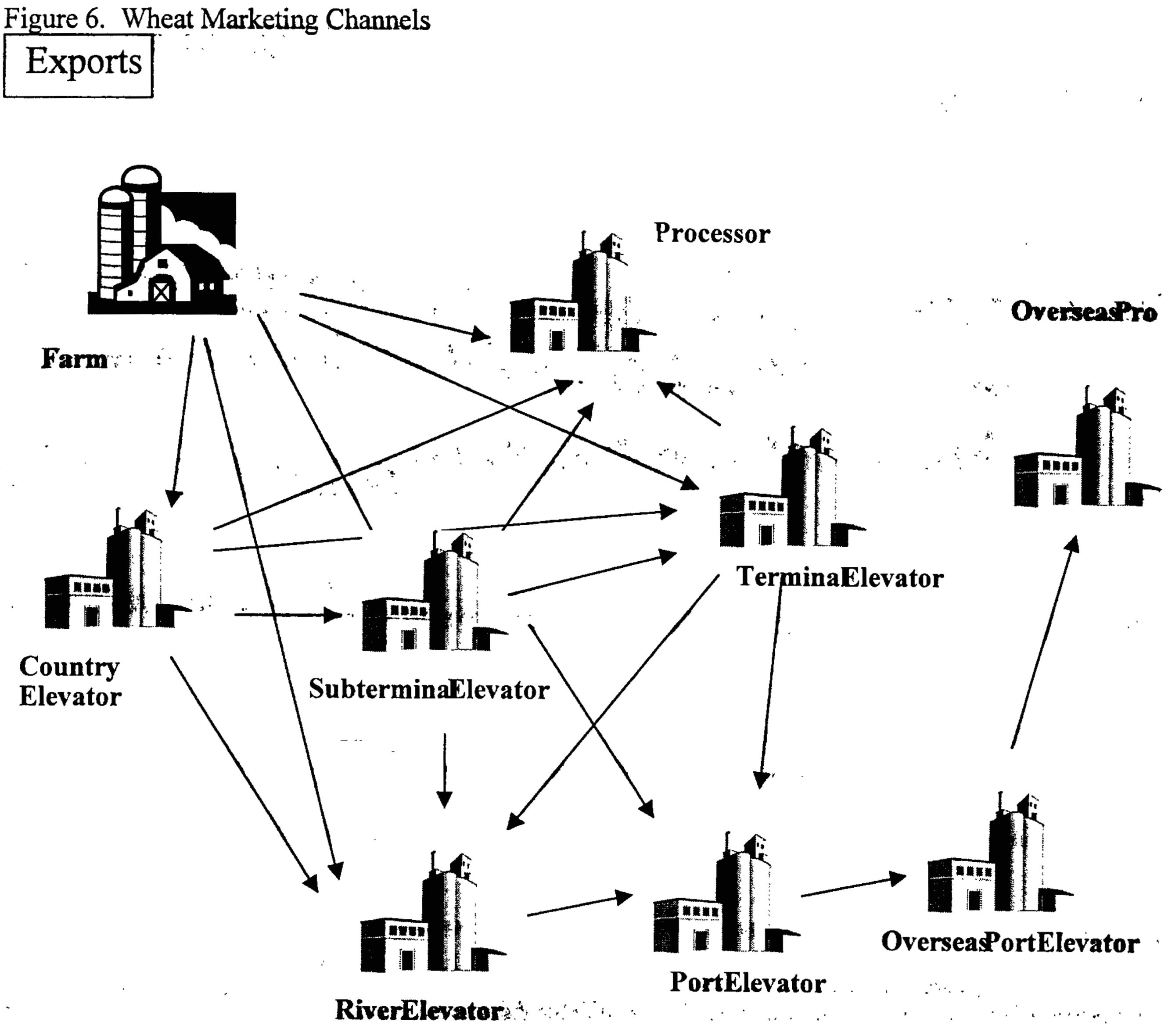


Figure 4: U.S. Wheat Acres Planted 2001

EMBED Excel.Chart.8 \s

Figure 6. Wheat Marketing Channels



Source: [27]

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Source: [87]

Figure 7. Maximum Storage

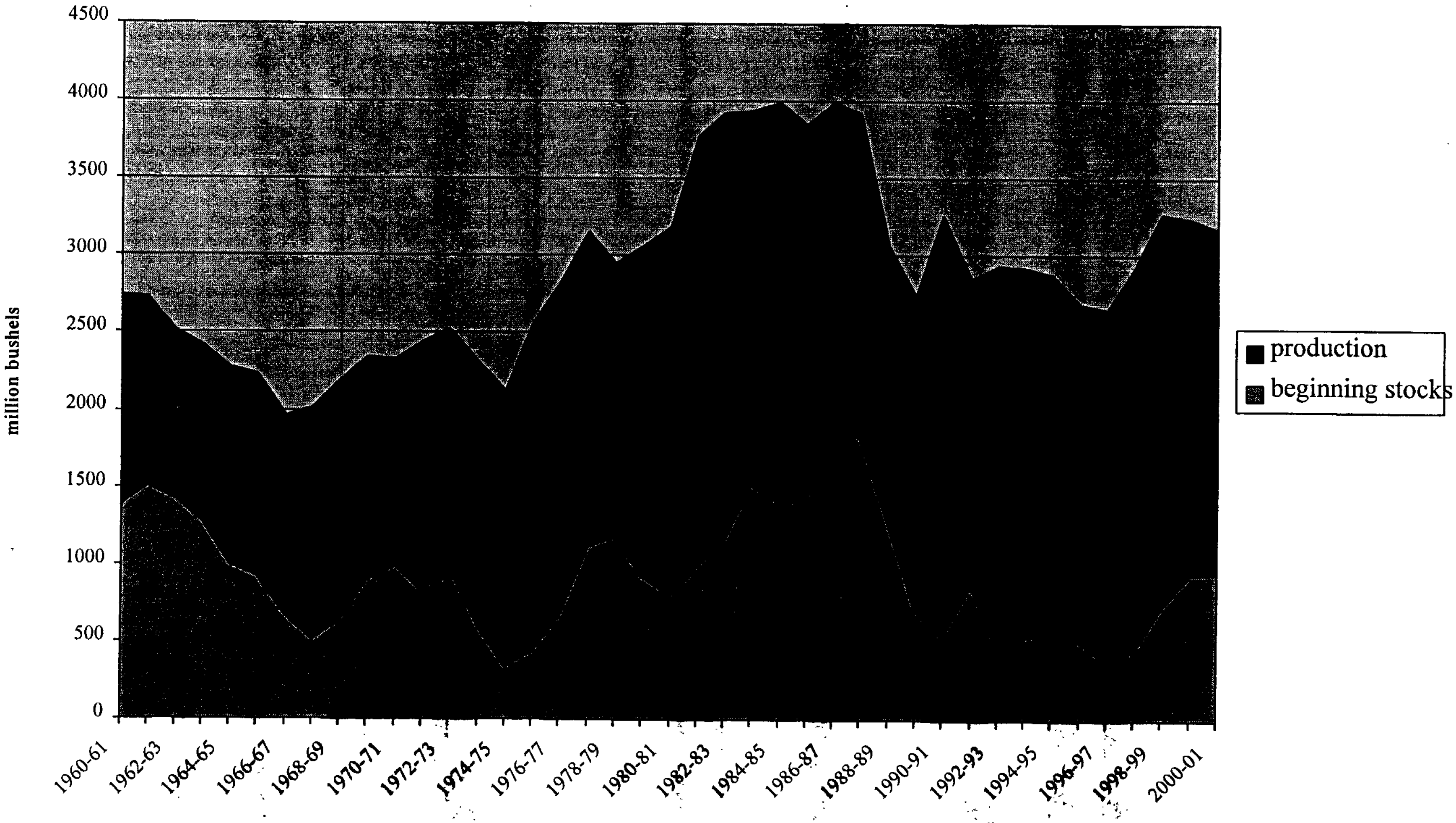

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Figure 8. On-farm and Off-farm Storage

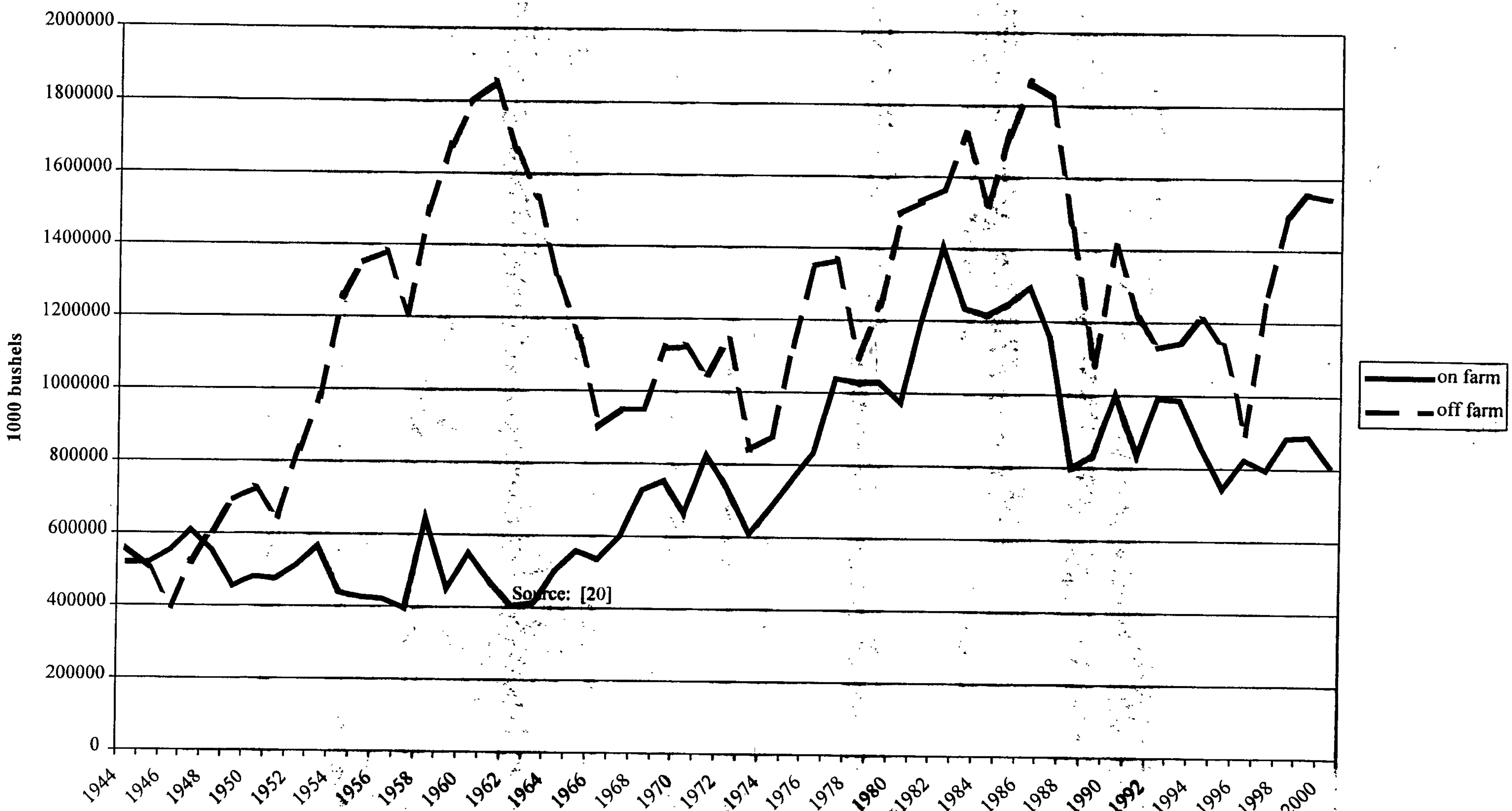

Figure 9: Chlorpyrifos-methyl Wholesales by Geographic Region

Appendix

The immediate concern regarding the stability of the U.S. wheat storage and marketing systems is the current lack of safe, effective, and inexpensive chemical insect control options, especially for farmers storing their harvest on-farm. While this concern must be promptly and directly addressed, its remedy will not ensure a stable and competitive future for U.S. wheat. No single improvement in pest management considered and implemented in isolation can accomplish this. To ensure a stable and competitive future for U.S. wheat a host of pest management tools must be developed to ensure that U.S. wheat remains internationally competitive.

The efforts to provide storage managers with the most effective set of pest management tools possible include the provision of information, not just the development of new insecticidal products. Among the most promising and important information sources that must be provided to storage managers are expert systems for the prediction and control of insect infestations, crop profiles, and Pest Management Strategic Plans for various grain storage regions. Expert systems for pest management are computer programs that allow storage managers to input data reflecting the current characteristics of their storage bins. These data include exterior and interior environmental, insect sampling, and storage facility data. After data input, the system gives a recommendation regarding appropriate pest control options. This system is heavily reliant upon two types of data, insect population models and insect damage economic thresholds, which are currently being developed. Insect population models take the data provided regarding the current insect infestation levels and extrapolate how the population will grow based upon provided and projected environmental data. These population models are then applied to the economic damage thresholds, levels of insect infestation needed to create damage within the storage mass that would result in discounts at the time of sale. By combining these data, the expert system can advise storage managers when treatment for infestation is warranted. These systems reduce the cost of insect control by advising against unnecessary treatments, saving managers treatment costs and time, while simultaneously reducing pesticide use.

Pest Management Strategic Plans address pest problems and pest control options for specific crops from a regional perspective, providing a comprehensive overview of the pest challenges.

The document is directed toward EPA, USDA, universities, and pest management stakeholders as a source of information regarding the status of regulations, research, and education regarding pests and pest management in specific crops. The information for Pest Management Strategic Plans are assembled from state and regional crop profiles, researchers, producers, and pest management professionals. The value of this document is as a one-stop, easily accessible resource for regulators and stakeholders. The development of a Strategic Pest Management Plan for wheat in the southern and northern plains and the Pacific Northwest would vastly improve the body of descriptive information specifically directed at individuals without agricultural experience who make decisions that directly impact wheat production and pest management. The current absence of this information contributes to a sub optimal environment in which pest management is often regulated without full understanding of the crop/pest system by all parties involved.

Similar to Pest Management Strategic Plans, crop profiles are general overview documents designed to inform both a technical and popular audience about the entire system of a specific crop's production and marketing. Crop profiles already exist for wheat production in many states, however, these profiles do not address the specific concerns of wheat storage. A stored wheat profile has been developed as a prototype in Kansas, however it is not currently available through the Office of Pest Management Policy. The further development and dissemination of crop profiles for stored wheat would not only provide the regulatory community with a comprehensive description of storage management practices and pesticide use, but also provide a definitive guide of accepted best management practices for storage managers. With the current lack of these profiles, there is not reliable and comprehensive source of pesticide use data for wheat storage. Without reliable and comprehensive pesticide use data and an accurate depiction of industry practices, regulation of stored grain pesticides can only be conducted though assumption and analysis of old, incomplete, and inaccurate data.

While improvements in the aggregation and presentation of information regarding pest management in stored wheat will certainly advance both regulatory and pest control effectiveness, improvements in pest management technology are equally important. Beyond new or continued pesticide registrations, the largest advances in stored wheat pest management technology are taking place with the storage facilities themselves. Three interconnected technologies are greatly improving storage managers' ability to employ true IPM techniques: internal electronic monitoring systems, automated aeration systems, and closed system fumigation. Many new storage facilities are designed to employ these technologies and some older facilities are being retrofitted to accommodate them. Internal electronic monitoring systems are comprised of a series of wires that run throughout the grain mass, measuring temperature and moisture at several locations. These measurements can be used by storage managers to monitor the conditions within the grain mass, recognize infestations, and make pest management decisions. Internal electronic monitoring systems can be particularly effective when paired with an automated aeration system. These systems compare information gathered by the monitoring system with external environmental conditions. When significant and appropriate differences exist between the external and internal temperature and moisture, the aeration system is automatically turned on and off to maximize its cooling effect and energy efficiency.

Advances are also being made in fumigation technology. The most promising and practical of them is closed system fumigation. Closed system fumigation can use the same fumigants currently employed for insect infestation crisis control more effectively that traditional fumigation practices. Closed system fumigation uses aeration fans configured with special ducts to re-circulate fumigants through the grain mass. This type of fumigation requires completely closed and sealed grain bins to be effective. If this closure is achieved, the re-circulation ensures that the fumigant is evenly distributed throughout the mass, eliminating safe havens in which insects could survive within the mass. To take best advantage of closed system fumigation, new cylinderized fumigants are being developed. These cylinderized fumigants, including phosphine gas and carbon dioxide, are introduced into the grain mass directly in a gaseous state, rather than the traditional solid or liquid states, further improving fumigant distribution within the grain mass. The cylinderized carbon dioxide fumigants being developed have the added advantage of being less toxic to workers than phosphine fumigants.

References

1. NGFA, "Wheat; What it is, How it's marketed, and How it's used," http://www.ngfa.org/wheat.htm.

2. Cuperus, Gerrit, et al, 1990, "Management Practices in a High-Risk Stored-Wheat System in Oklahoma," American Entomologist, Summer 1990, pp. 129-134.

3. Hagstrum, David, Carl Reed, and Phil Kenkel, 1999, "Management of Stored Wheat Insect Pests in the USA," IPM Reviews, 4, pp. 127-142.

4. Zettler, Larry, and Frank Arthur, 1997, "Dose-Response Test on Red Flour Beetle and Confused Flour Beetle (Coleoptera: Tenebrionodae) Collected from Flour Mills in the United States," Econ Entomol, 90:5, pp. 1157-1162.

5. Arthur, Frank, 1999, "Survival of Red Flour Beetles (Coleoptera: Tenebrionidae) on Concrete Partially Treated with Cyfluthrin," Econ Entomol, 92:4, pp. 981-987.

6. Arthur, Frank, 1994, "Cyfluthrin Applied with and without Piperonyl Butoxide and Piperonyl Butoxide Plus Chlorpyrifos-methyl for Protection of Stored Wheat," Econ Entomol, 87:6, pp. 1707-1713.

7. Arthur, Frank, Jim Throne, Richard Simonaitis, 1992, "Degredation and Biological Efficacy of Chlorpyrifos-methyl on Wheat Stored at Five Temperatures and Three Moisture Contents," Econ Entomol, 85:5, pp. 1994-2000.

8. Arthur, Frank, Jim Throne, and Richard Simonaitis, 1991, "Chlorpyrifos-methyl Degredation and Biological Efficacy Towards Maixe Weevils (Coleoptera: Curculionidae) on Corn Stored at Four Temperatures and Three Moisture Contents," Econ Entomol, 84:6, pp. 1926-1932.

9. Reed, Carl, et al, 1991, "Pitfall Traps and Grain Samples as Indicators of Insects in Farm-Stored Wheat," Econ Entomol, 84:4, pp. 1381-1387.

10. Zettler, Larry, Gerrit Cuperus, 1990, "Pesticide Resistance in Tribolium castaneum (Coleoptera: Tenebrionidae) and Rhyzopertha dominica (Coleoptera: Bostrichidae) in Wheat," Econ. Entomol, 83:5, pp. 1677-1681.

11. Reed, Carl, et al, 1989, "Effects of Insect Infestation of Farm-Stored Wheat on Its Sale Price at Country and Terminal Elevators," Econ Entomol, 82:4, pp. 1254-1261.

12. Subi, Phil Harein, Cutkomp, 1989, "Organophosphate Resistance in Adult Red Flour Beetle (Coleoptera: Tenebrionidae) and Sawtoothed Grain Beetle (Coleoptera: Cucujidae) Infesting Barley Stored on Farms in Minnesota," Econ. Entomol, 82:4, pp. 989-995.

13. Storey, C. L., D. B. Sauer, and D. Walker, 1983, "Insect Populations in Wheat, Corn, and Oates Stored on the Farm," Econ Entomol, 76:6, pp. 1323-1330.

14. McGaughey, William H., Edwin Dicke, and John Schesser, 1978, "Indian Meal Moth Infestation of Farm-Stored Wheat in Kansas," Econ Entomol, 71:3, pp. 503-506.

15. LaHue, Delmon, 1977, "Chlorpyrifos-methyl: Doses that Protect Hard Winter Wheat Against Attack by Stored-Grain Insects," Econ Entomol, 70:6, pp. 734-736.

16. Arthur, Frank 1995, "Aeration Alone Versus Chlorpyrifos-methyl Treatment Followed by Aeration for Wheat Stored in Georgia: Simulated Field Tests," Econ Entomol, 88:6, pp. 1764-1770.

17. Harein, Phil 1990, "Insects: Species and Losses," Proceedings of the 3rd National Stored Grain Pest Management Training Conference, pp. 79-84.

18. OPP, EPA, 2001, "Report on FQPA Tolerance Reassessment Progress and Risk Management Decision for Chlorpyrifos-methyl."

19. Norton, Jerry, FSA, USDA, 2000, "Cost-Benefit Assessment: Farm Storage Facility Loan Program,"

20. ERS, USDA, 2001, "Wheat Situation and Outlook Yearbook, WHS-2001."

21. NASS, USDA, 2001, "Grain Stocks."

22. Flanders, Kathy, 2001, "Assessment of IPM Tactics for Ion-Farm Stored Grain in Alabama."

23. Douce, G. K., and R. M. McPherson, 1995, "Summary of Losses from Insect Damage and Costs of Control in Georgia: 1993," Georgia Agricultural Experiment Station Special Publication 87.

24. Reed, Carl, and Fred Worman, 1993, "Quality Maintenance and Marketing of Wheat Stored on Farms and in Elevators in Kansas: Description, Techniques, and Innovations," Kansas State University Agricultural Experiment Station Bulletin 660.

25. Shen, Sue-Chi, 2002, Letter to Richard P. Dumas, OPP, EPA, July 27, 2000.

26. Cuperus, Gerrit, et al, "Stored Grain management in Oklahoma," Oklahoma Extension Publication F-7180.

27. OK Coop Extension, 1995, "Stored Product Management," Oklahoma Extension Publication E-912.

28. Kenkel, Phil et al, 1992, "Current Management Practices and Impact of Pesticide Loss in the Hard Red Wheat Post-Harvest System," Oklahoma Extension Publication E-930.

29. Berven, Brad 2001, "Storcide Section 18 Application, South Dakota Department of Agriculture."

30. Hensley, Darrell, 1995, "A Survey of Pesticide Use in Stored Grain Facilities During 1994 in Tennessee," Tennessee Department of Agriculture.

31. Fang, Liang, Bh. Subramanyam, Frank Arthur, 2002, "Effectiveness of Spinosad on Four Classes of Wheat Against Five Stored-Product Insects," Econ Entomol, 95:3, pp.640-650.

32. Gustafson LLC, "Reldan 4E Insecticide," http:/www.gustafson.com/labels/Reldan4E.pdf.

33. ERS, USDA, 2001, "U.S. Wheat Areas of Planting," http://www.ers.usda.gov/briefing/wheat/maps%20gallery.htm.

34. Washington State Extension, 2001, Informal Survey of Grain Elevators.

35. Desmarchelier, Bengston, 1979, "The Resicual Behavior of Chemicals of Stored Grain," Proceedings of the 2nd International Working Conference on Stored-Product Entomology, pp. 138-151.

36. Arthur, Frank, 1994, "Residual Efficacy of Cyfluthrin Applied Aline or in Combination with Piperonyl Butoxide or Piperonyl Butoxide+Chlorpyrifos-methyl as Protectants of Stored Corn," J. Entomol. Sci., 29:2, pp. 276-287.

37. Department of Entomology, University of Nebraska, Lincoln, "Lecture 15: Pyrethroid Insecticides," http://entomology.unl.edu/toxicology/pyrethroids.htm.

38. Speirs, Redlinger, Boles, 1967, "Malathion Resistance in the Red Flour Beetle," Econ Entomol, 60:5, pp. 1373-1374.

39. FGIS, USDA, 2001, "Official United States Standards for Grain."

40. Phillips, Tom and Edmond Bonjour, 2002, Stored Grain Insecticide Efficacy Data, Oklahoma State University.

41. Thomas, K. P., 1990, "The Effects of Low-Volume Aeration on the Residues and Biological Effectiveness of Chlorpyrifos-methyl Applied to Wheat," Pesticide Science, 29, pp. 135-142.

42. Matin, Marshall, et al., 1997, "Stored Wheat IPM Practices and Pesticide Use in Key Regions of the United States and Canada: 1996," Purdue Extension Publication B-752.

43. Harein, Phillip K., 1990, "Insects: Species and Losses," Proceedings of the 3rd National Stored Grain Pest Management Training Conference, Minnesota.

44. Subramanyam, Bh., L. K. Cutkomp, B. Kouable, 1987, "Effects of Short Term Feeding by Adults of Prostephanus Truncatus (Horn) (Coleoptera: Bostrichidae) on Shelled Maize," J. Stored Prod. Res., 23:3, pp. 251-255.

45. Kenkel, Phil, et al., 1999, "Assessing Pesticide Uses and IPM Practices in Wheat Storages in the Southern Plains," Southern Region Pesticide Assessment Program.

46. Rinehold, Jenkins, 1995, "Oregon Pesticide Use Estimates for Small Grains, Forage, and Livestock 1994," Oregon Extension Publicantion EMXXX.

47. Storey, C. L., et al., 1982, "Insect Infestation in Wheat and Corn Exported from the United States," Econ Entomol, 75:5, pp. 827-832.

48. Barak, Alan V., and Phil Harien, 1981, "Losses Associated with Insect Infestation of Farm Stored Shelled Corn and Wheat in Minnesota," Minnesota Agricultural Experiment Station Misc. Pub. 12.

49. NASS, USDA, 2002, "Agriculture Chemical Usage Postharvest Applications - Wheat March, 2002,"

50. Derickson, Julson, 1989, "1988 Stored Grain Management Practices In South Dakota," American Society of Agricultural Engineers and Canadian Society of Agricultural Engineers Meeting Presentation.

51. Gustafson LLC., "Reldan Market Basket Detect"

52. OPP, EPA, 2002, "Chlorpyrifos-methyl Tolerances," 40 CFR Chapter I Part 180 Number 419.

53. USDA, 1980, "Insects and Fungi in Wheat Corn and Oats Stored on the Farm," Table 13.

54. OPP, EPA, 2000, "Denial of Chlorpyrifos-methyl Minor Use DNT Waiver."

55. FDA, 2000, "Total Diet Study."

56. Arthur, Frank, 1998, "Residual Toxicity of Cyfluthrin Wettable Powder Against Tribolium confusum (Coleoptera: Tenebrionidae) Exposed for Short Time Intervals on Concrete," J. Stored Products Research, 34:1, pp. 19-25.

57. Hart, Chad and Bruce Babcock, 2000, Time for a New Farmer-Owned Reserve?, The Center for Agricultural and Rural Development, Briefing Paper 00-BP 31.

58. ARS, USDA, 1965, Losses in Agriculture, Ag. Handbook No. 291.

59. AES&CES, KSU, 2001, "Impacts," Fall 2001.

60. Cuperus, Gerrit and Vera Krischik, 1995, "Why Stored Product Integrated Pest management is Needed," In Stored Product Management, Oklahoma Cooperative Extension Service, Circular Number E-912, p.199.

61. Pimentel, David, 1991, "World Resources and Food Losses to Pests," in Ecology and management of food-industry pests.

62. Beeman, Richard W. and Valerie F. Wright, 1990, "Monitoring for Resistance to Chlorpyrifos-methyl, Pirimphos-Methyl and Malathion in Kansas Populations of Stored-Product Insects," J Kansas Entomological Society, 63:3, pp. 385-392.

63. Vincent, L. E. and D. L. Lindgren, 1967, "Susceptibility of Laboratory and Field-Collected Cultures of Confused Flour Beetle and Red Flour Beetle to Malathion and Pyrethrins," J Econ Entomol, 60:6, Pp. 1763-1764.

64. Personal communications with Greg Lowry, 2002, Association of Official Seed Certifying Agencies.

65. Personal communications with Daryl Strouts, 2002, Kansas Crop Improvement Association.

66. Personal communications with Vernon Schaffer, 2002, Kansas State University.

67. Cuperus, Gerrit, et al, 1986, "Insect Populations in Aerated and Unaerated Stored Wheat in Oklahoma," J Kansas Entomological Society, 63:4, Pp.620-627.

68. Horton, Paul M., 1982, "Stored Product Insects Collected From On-Farm Storage in South Carolina," J. Georgia Entomol. Soc., 17:4, Pp. 485-491.

69. FGIS, USDA, 2002, HYPERLINK "http://www.usda.gov/gipsa/programsfgis/services.htm" http://www.usda.gov/gipsa/programsfgis/services.htm .

70. March 2002, Federal Register, March 7, 2002, 67:5, Pp. 10355.

71. Beeman, Richard W. and Valerie F. Wright, 1990, "Monitoring for Resistance to Chlorpyrifos-Methyl, Pirimiphos-Methyl and Malathion in Kansas Populations of Stored-Product Insects," J Kansas Entomological Society, 63:3, Pp.385-392.

72. Pitts, J. Terry, Gustafson LLC, 2000, Letter to Richard P. Dumas, OPP, EPA, August 25,

2000.

73. Horton, Paul M., 1982, "Stored Product Insects Collected from On-farm Storage in South Carolina," J Georgia Entomological Society, 17:4, pp. 485-491.

74. ERS, USDA, "Commodity Loan Programs – Price Supports and Marketing Loans," AER-801.

75. Ryan, Mary E. and William H. Meyers, 1981, "The Farmer-Owned Grain Reserve Program: A Survey of Farmers' Response and Options," Dept. of Agricultural and Applied Economics, University of Minnesota, Economic Report 81-6.

76. Osborn, C. Tim, 1997, "Wheat and the Conservation Reserve Program: Past, Present, and Future," Wheat Yearbook and Situation Outlook, ERS, USDA, WHS-1997.

77. Souza, Christine, 2002, "Dockage is in USDA's Vision for Upgraded Wheat Standard," Ag Alert, June 19, 2002, p.7.

78. Federal Register 3-7-02.

79. McAvoy, Susan, USDA, "Glickman Promotes Cleaner Wheat Exports," October 18, 2000, News Release No. 0368.00.

80. Hegeman, Roxana, 2002, "White Wheat Grows in Demand," Associated Press, June 7.

81. Vocke, Gary, 1998, "Noodle End-Use Characteristics for Wheat in East and Southeast Asia," Wheat Yearbook, WHS-1998, USDA ERS.

82. Reed, Carl and J. Harner III, 1998, "Thermostatically Controlled Aeration for Insect Control in Stored Hard Red Winter Wheat," Applied Engineering in Agriculture, 14:5, Pp. 501-505.

83. OPMP, USDA, 2001, "The Reldan Transition Meeting," Kansas City, MO, March 29, 2001.

84. Shen, Sue-Chi, Gustafson LLC., personal communication.

85. Guedes, Dover, et al, 1996, "Resistance to Chlorpyrifos-Methy, Pirimiphos-Methyl, and Malathion in Brazilian and U.S. Populations of Rhysopertha dominica (coleoptera: Bostrichidae)," Econ. Entomol, 89:1, pp. 27-32.

86. USDA, NASS, 2002, Wheat Acreage, http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bba/acrg2001.pdf.

87. USDA, NASS, 2002, Ag Stats 2002.

88. USDA, ERS, 2002, Wheat Situation and Outlook Yearbook.

89. Jager, Lisa and Tracy Sayler, 2000, Will USDA Get Into the Grain Cleaning Business?, available at HYPERLINK "http://www.smallgrains.org" www.smallgrains.org .

90. "Methoprene," EXTOXNET, HYPERLINK "http://ace.orst.edu/cgi-bin/mfs/01/pips/methoprene.htm" http://ace.orst.edu/cgi-bin/mfs/01/pips/methoprene.htm .

91. "Delatmethrin," EXTOXNET, HYPERLINK "http://ace.orst.edu/cgi-bin/mfs/01/pips/deltamet.htm" http://ace.orst.edu/cgi-bin/mfs/01/pips/deltamet.htm .

92. Arthur, Frank, 1994, "Efficacy of Unsynergised Deltamethrin and Deltamethrin + Chlorpyrifos-methyl Combinations as Protectants of Stored Wheat and Stored Corn (Maize)," J. Stored Prod. Res., 30:1, pp.87-94.

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