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FUMIGATION DECISION-MAKING PROCESSES: ECONOMIC LOSSES VS. RISKS

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ABSTRACT

Management of the stored wheat system needs to include the producer, local elevator, terminal elevator, and processor. The system in the Southern United States is a fumigant intensive system with increased fumigant use at each level in the system. The decision to fumigate and the factors that intimate fumigation vary at each of these levels. Decisions at each point are based on a combination of known insect infestations, potential economic losses, market risks, enterprise risks, and the unknown. One of the primary reasons for fumigation at the farm and local elevator level is the relative abundance of insects. Timing of fumigation is surprisingly close to the population dynamics of this system. At the local level, subterminal, terminal, and processor, the increasing role of enterprise, market, and economic risk increase the frequency and utilization of fumigants. Some of these are not based on biological occurrence, but on risk reduction philosophies.

We examined this system and implemented a research-based pesticide education program examining the biology and sociology of this system. Managers at all levels monitored their system extensively checking grain moisture, insect and temperature levels more frequently than we often recommend. Factors that can improve management include: monitoring and management of insect migration in and around facilities; improved utilization of temperature to manage molds and insects; and improved use of fumigants.

INTRODUCTION

The United States (U.S.) annually produces and stores nearly 27 million tonnes of hard red winter wheat, *Triticum aestivum*. Stored grain insect infestations and mold densities are determined primarily by storage time, management practices, grain temperature and moisture. These conditions have been shown to differ dramatically across the U.S. hard red winter and spring wheat system. The risk varies significantly across the U.S. with average moisture contents (m.c.) at harvest ranging from a low of nearly

8% to an average of nearly 15%. Additionally, the temperature at harvest time varies from nearly 20°C to 35°C (Hagstrum and Heid, 1988; Storey *et al.*, 1979). Most survey work on grain storage, producer, and elevator operator management and pesticide practices in the north central U.S., indicate very low usage of grain protectants, fumigations, aëration to cool grain, and other integrated pest management (IPM) practices (Storey *et al.*, 1984; Harein *et al.*, 1985). Studies in the southern plains indicate much higher usage of on-farm and elevator IPM practices (Cuperus *et al.*, 1990; Reed *et al.*, 1988).

Effective management decisions require a knowledge of the wheat storage and marketing system. On-farm, commercial storage, processing, and distribution segments of the wheat storage system need to be considered in designing a management program (Hagstrum and Heid, 1988; Gardener *et al.*, 1988). Insect, mold, and heating damages occur in all segments of this system, and this is a pesticide and IPM intense system (Cuperus *et al.*, 1990; Hagstrum and Heid, 1988). The management practices used by each segment and their interaction are not well understood but are crucial to managing the grain storage system.

The differences in types of storage structure are important because the different storage structures require significantly different management strategies. For example, grain in round steel bins is difficult or impossible to turn. Likewise fumigation application is significantly different between concrete, round steel, and flat storage structures. In concrete facilities most managers fumigate wheat during turning, with a near perfect distribution of phosphine pellets and very low worker exposure. Fumigation of round steel bins requires significant worker time and exposure for probing-in the pellets/tablets, and then covering the surface to minimize gas loss. Flat structures are the most difficult and time-consuming to fumigate and have the greatest chance for failure due to the large surface to volume ratios and the inability to adequately seal the structures. The reasons behind the differences in the structures are linked to the period when the structures were built and to the amount of on-farm vs. commercial storage.

It is not uncommon throughout the U.S. to encounter stored wheat in poor condition. For numerous reasons it is critical that this situation change. Also, in the southern portion of the U.S. it is not uncommon to see excessive usage of fumigants. The combination of these two factors gave rise to the topic of this paper.

The following subjects are covered in this paper:

To implement any Integrated Pest Management (IPM) program we need to understand the ecology of the system and understand the flow at various steps along the way.

An overview of our experiences with the decision-making process regarding fumigation: an examination of the factors that trigger these treatments.

An overview of the consequences of these actions -- what happens either way at each step of the marketing system.

The future of fumigation and decision making within our stored product system.

THE GRAIN BULK ECOSYSTEM AND IPM

Uncertainty about making decisions is multifaceted and goes back to a lack of understanding of the grain system as a living and breathing system. Let us take a look at the way many Cooperative Extension Service (CES) programs operate and perhaps some Agricultural Research Service (ARS) attitudes. The CES knows the composition of the pest situation in storage, what control measures are effective and when they work, what the economic consequences are, and what different components are being utilized.

Interestingly, educational materials and programs may not adequately integrate what is available. For example, in the high plains area (Table 1) literature emphasized granary weevils (*Sitophilus granarius*) and rice weevils (*Sitophilus oryzae*). Our growers and elevator operators state that these are their biggest problems yet we have only once found the granary weevil, and the rice weevil is found in only 5% of all facilities. The rice weevil is related to moisture problems but these are not common in this area.

The relationship between producers, elevator operators, and processors, in this system is often cited as uncoordinated or even antagonistic (Barak and Harein, 1981). Price discounts are often cited as a major inducement for producers and elevator operators to adopt IPM practices, or as a penalty for those who don't adopt practices (Harein *et al.,* 1985; Gardner *et al.,* 1988). Dockage discounts can cost from 1-2 cents up to 10-20 cents per bushel. Little is known about the discount policies of elevator managers in the southern high plains, but the discount policy does not appear to be as strong (Cuperus *et al.* 1990; Reed *et al.*, 1988;1989).

Many processors are beginning to state "a no malathion requirement" meaning that grain has no malathion residue or that the grain has not be treated with malathion. One of the paradigms we work with is that the market penalty is so large that the grain must be protected; however, this simply is not the case.

The market does drive this system. Discounts, ability to sell, future sales, "Insect Damaged Kernels" (IDK), premiums, location where the product is being sold, etc., do determine the market price of grain in the U.S. However, it seems that in Kansas and Oklahoma, market forces for elevator operators are not the driving forces because discounts are low and not invoked (Table 2).

However, a scrutiny of flour mills and the milling industry shows that discounts are involved and are a market force (Table 3).

As one goes down along the grain pipeline (Table 4), the risk is increased - dollar wise, and also regarding marketability and future sales.

In contrast to the northern areas, situations often arise in the southern or central regions where the grain can be completely decimated (due to IDK issues, grain loss, marketability, etc.). This is a major concern to the people who store grain and grain products in our region. Let us examine this situation more closely. This deals with our paradigms of what we knew and what the elevator operators knew.

Table 1: Greatest insect problems as related by grain producers (on-farm) and elevator operators in Oklahoma, USA* (expressed in percentage).

On-farm

Year	1986	1991
Granary weevil	85	43
Rice weevil	1	7

In elevators.

Year	1986	1991
Granary weevil	68	67
Lesser grain borer	39	51
Rice weevil	13	13

*Responses from 89 farmers and 112 elevator operators in 1986, and 141 farmers and 152 elevator operators in 1991.

The question arises as to the concerns of farmers and why they are treating their grain. Interestingly, most of our producers do not know what insects are involved and why they are treating (Table 1). We examined insect recoveries at on-farm and commercial elevators and these did not correspond to what farm producers or elevator operators thought they had (Table 5).

Producers may worry, but the risk of tremendous loss from insects is limited. However, elevators which deliver to flour mills run a much greater risk due to flour mill quality standards.

We have always believed that elevator operators are better managers and know their "stuff". However, the elevator situation is not much better than that of the producers.

Elevator managers believe that the granary weevil is their major insect problem. Why do weevils appear in their rankings when they are not an actual problem? The term "weevily grain" has been used for decades in the Great Plains area of the U.S. Also, CES literature is filled with the term "weevily grain". The insect populations involved may be composed of several species. Also, weevils are menacing in that they appear to be destructive and have the reputation of being destructive to grain (Table 1).

Table 2: A survey of 1020 commercial elevator managers reflecting their response at reception of infested hard red wheat, and the cost of treatment [1].

State	Percent Response[2]				
	Refuse Grain	Charge for Fumigation	Discount	No Discount	Charge $US/tonne
Colorado	28.6	42.8	21.4	7.1	2.31
Idaho	24.2	63.6	18.1	3.0	4.32
Indiana	26.8	23.1	42.7	2.4	2.82
Kansas	27.6	46.1	24.4	3.6	2.89
Montana	47.2	47.2	18.2	2.1	3.63
N. Dakota	24.8	41.1	33.3	3.3	3.59
Nebraska	24.5	42.2	31.9	4.8	2.31
Oklahoma	21.4	40.2	33.0	8.9	2.49
S. Dakota	27.2	46.6	45.4	6.8	3.11
Texas	28.0	26.5	14.4	3.0	3.19
National average	38.5	26.8	30.0	4.7	2.97

[1] From surveys of 1020 commercial elevator managers.
[2] Numbers may be greater than 100% due to multiple answers.

Table 3: US Federal Grain Inspection Service (F.G.I.S.) standards for No. 1 hard red winter wheat versus millers' contract specifications.

Quality Factor	F.G.I.S.	Millers
Insect Damaged Kernels (IDK) per 100 g	32	7.2
Foreign Material (FM)	1.0	1.5
Percent live insects (1000 g sample)*	2.0	0.2
Pesticide residues (ppm)	8.0	0.0

*The presence of 2 or more live insects injurious to stored grain or 1 live weevil will cause the wheat to be graded "infested". The numerical grade is not affected.

Table 4: Average storage capacity of grain facilities in Oklahoma, U.S.A.

Site	Tonnes
Farm	710
Elevator	26,480
Terminal	409,500

This situation seems to indicate that the system is disorganized. To a degree it is, but looking deeper it appears that the mechanism regulating the system is economic risk. Elevator managers treat their grain when they have insects, but treatments are not based on the ecology of the system, nor the biology of the insect. The treatment and the biology just happen to coincide. This is a simple concept we have tied into educational programs throughout the U.S. As biologists, we stress biological risk. Elevator managers do not understand the simple thing we take for granted, such as effects of temperature on insects, and their rate of development.

In our system, risk seems to dominate decisions. Can managers afford the real losses? Losses probably drive decisions across the U.S. Some risk factors driving the system are as follows:

- Probably a significant risk that affects sales both between the growers, local market, and the local market terminal or export, is the risk of a bad reputation arising from presence of dockage or refusal.
- For a manager who is risking $5 million of stored grain, an extra $5,000 for fumigants, or $10,000 for extra turning, looks a cheap price to pay.
- A hired manager will not get dismissed for too many inputs in the form of conservation measures, but if he loses $100,000 due to insect/mold damage and an unmarketable product, his position will be forfeited.

One must understand the economics, and pest population dynamics in order to manage molds, insects, and the engineering components. When we started looking at this system, we were not really sure what we were looking at. Fig. 1 shows insect infestation and temperature levels in storage facilities in Oklahoma with a comparison of the population dynamics in aerated and unaerated facilities.

Fig. 2 from Hagstrum and Flinn 1991, shows population dynamics in storage structures. This is exactly what we saw before we knew what was occurring. However, this and other research may often be done while CES and the industry may simply be unaware of it. Clearly, temperature management in wheat is critical for the Great Plains area of the U.S. and aeration seems critical in order to accomplish effective storage.

FUMIGATION

The question arises as to how managers are making fumigation decisions and how these decisions should be made. An examination of the frequency at which elevator managers fumigate and the amount of fumigants used indicates that there is some improvement (Table 6). In Oklahoma fumigation frequency decreased from 2.6 times to 1.9 times per year between 1986 and 1992.

Table 5: Comparison of commercial operators and producer rankings of pest problems in Oklahoma[1].

	Ranking of commercial manager[2]					Producer response[2]	Insect recoveries[3]	
Insect Pest	1	2	3	4	Total		87-88	88-89
Flat/rusty grain beetle	16	7	14	20	57	0	32	77
Sitophilus granarius	58	18	10	6	92	76	0	0
Plodia interpunctella	14	17	27	15	73	19	4	77
Rhyzopertha dominica	11	33	18	15	77	1	62	48
Tribolium spp.	5	8	15	9	37	4	21	68
Sitophilus oryzae	3	12	8	3	26	76	11	13
Long horned flour beetle	0	0	0	0	0	0	4	0
Sawtoothed grain beetle	0	0	0	0	0	0	21	5
Hairy fungus beetle	0	0	0	0	0	0	0	41
Foreign grain beetle	0	0	0	0	0	0	0	27
Corticaria spp. (Lathridiidae)	0	0	0	0	0	0	0	41
Cynaeus spp. (flour beetle)	0	0	0	0	0	0	0	9

[1]From surveys of 89 producers and 11 commercial managers.
[2]Producers were asked to identify number 1 insect problem. Commercial managers were asked to rank problems. Producers did not distinguish between rice and granary weevils.
[3]Taken from 28 bins for both 1987-88, and 1988-89 storage years. Numbers indicate percent of bins in which insects were detected.

However there remain some areas of concern. Some (35%) producers and elevator managers did not know what a fumigant was. Nor was it clear why many operators fumigate in July and August. This does not make sense since the grain is received into the bins from the fields at high temperatures (>35°C) and uninfested since this temperature is in the upper threshold limits for significant development of most storage insects. One wonders why commercial elevators are fumigating so many times. It would appear that 26% of the producers and 25% of the elevator managers are fumigating at the incorrect time. In the U.S., phosphine is the major fumigant used on stored grain, with over 92% of those fumigating reporting that they use phosphine.

Cuperus (1990) showed that there is a relationship between population dynamics in grain bins and the times fumigations were carried out (Fig. 3). Historically, one gets the impression that the criteria upon which elevator managers been timing their treatments are: experience (success of previous treatments), wisdom, and "witchcraft".

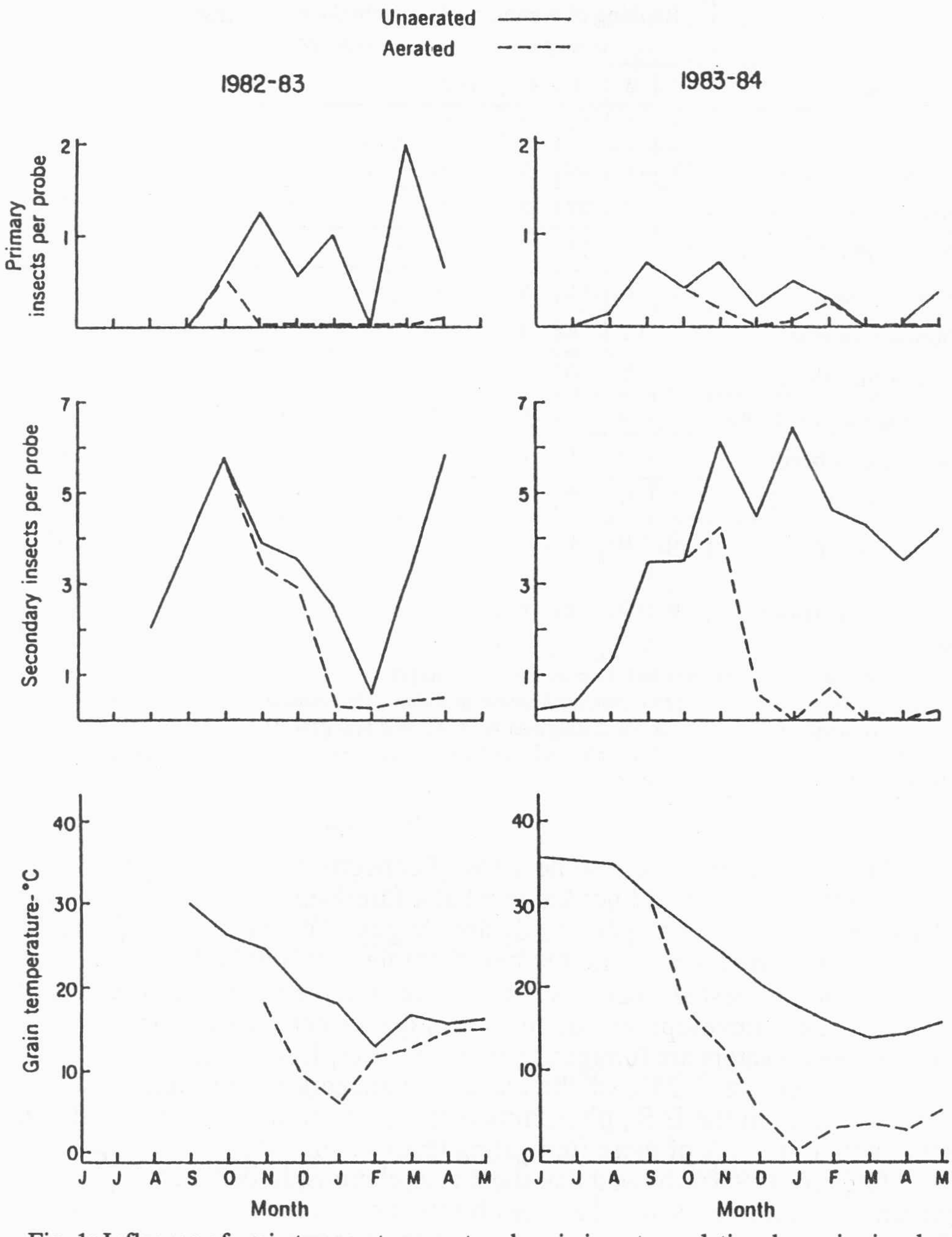

Fig. 1: Influence of grain temperature on stored-grain insect population dynamics in wheat storage in Oklahoma.

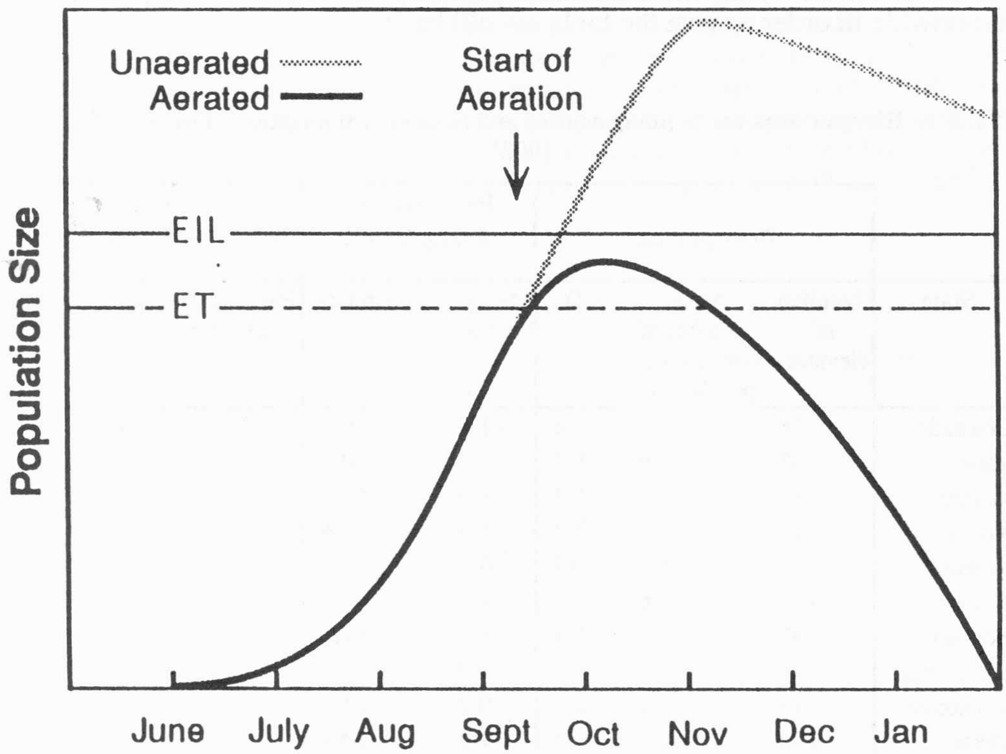

Fig. 2: Population dynamics of stored-grain insects over time (Hagstrum and Flinn, 1991).

Insect resistance to phosphine

Insect resistance is beginning to cause serious concern and influence business decisions. Fumigant usage is still very high. As stated, in 1986, Oklahoma commercial elevators averaged almost three fumigations per year, and yet, interestingly they are now averaging less than 1.5 fumigations per year. In the early 1980's, Oklahoma elevator operators used chemicals extensively, yet suffered severe losses due to insects. They did not use existing aeration equipment during that time. This may be related to the fact that fumigants have been historically looked on as "the magic bullet" to solve all problems, and the product of choice when an insect problem arose.

When we look at fumigant usage in Oklahoma, historically it has been very high when compared with many areas of the U.S. both at on-farm storage and elevators (Table 7). Zettler and Cuperus, (1990) identified phosphine resistance in Oklahoma. We believe the resistance results from the high usage of phosphine and ineffective application practices. Consequently we have started tying the resistance problem into educational programs nationwide in order to save the tools we still have.

Table 6: Elevator response to fumigant used and number of fumigations during the fall of 1992[1].

State	Fumigations			Percentage of fumigant use		Percentage of fumigations carried out by	
	Number of elevators	Mean number of fumigations per elevator	S.D.	Methyl bromide	Phosphine	Pest control operator	Elevator personnel
Colorado	28	2.2	1.6	21.4	78.4	30.0	70.0
Idaho	33	1.9	1.2	0.0	100.0	9.0	91.0
Indiana	82	1.9	1.3	3.7	52.4	4.6	95.4
Kansas	221	3.1	7.3	5.4	79.6	14.4	85.6
Montana	36	4.7	4.7	0.0	77.8	0.0	100.0
N. Dakota	138	3.6	5.6	4.3	61.6	13.3	86.7
Nebraska	147	2.6	1.8	25.9	59.9	8.1	91.9
Oklahoma	112	1.9	1.7	5.4	82.1	22.4	77.6
S. Dakota	88	3.6	4.7	10.2	72.7	5.4	94.6
Texas	132	2.3	1.1	9.8	84.8	13.3	86.7
Wyoming	3	1.0	-	-	33.3	0.0	100.0
National	1020	2.7	4.49	9.1	72.2	11.7	88.3

[1] From surveys of 1020 commercial elevator operators.

We have seen a tremendous change in the way elevator managers manage their facilities. They have become "biologically intense" in their sampling practices. They are using insect traps, thermocouples and good scientific principles. We have succeeded in transferring the importance of obtaining biological information to the elevator managers and they are understanding the role of pest management.

Elevator managers and producers have come a long way since the early 1980's and are now meeting us half way. We also have a better understanding of the storage system and program delivery.

IMPORTANCE OF AERATION IN IPM

In southern climates, elevator managers understand the importance of aeration . They are also relating to insect populations present at various times of the year and now understand the role of insect migration and sanitation in good management practice. The cyclic migration of stored-grain insects into bins is directly related to ambient weather conditions. Interestingly, the highest insect capture is in the eaves of storage structures. This is understandable considering that these areas are designed to allow air to move during aeration. When 13,000-tonne capacity bins are aerated in summer, the sides of the bins will swarm with insects because the air moving through the tops of the bins draws-in insects from the surroundings. Migration studies indicate the importance of understanding the biological as well as marketing aspects of grain storage.

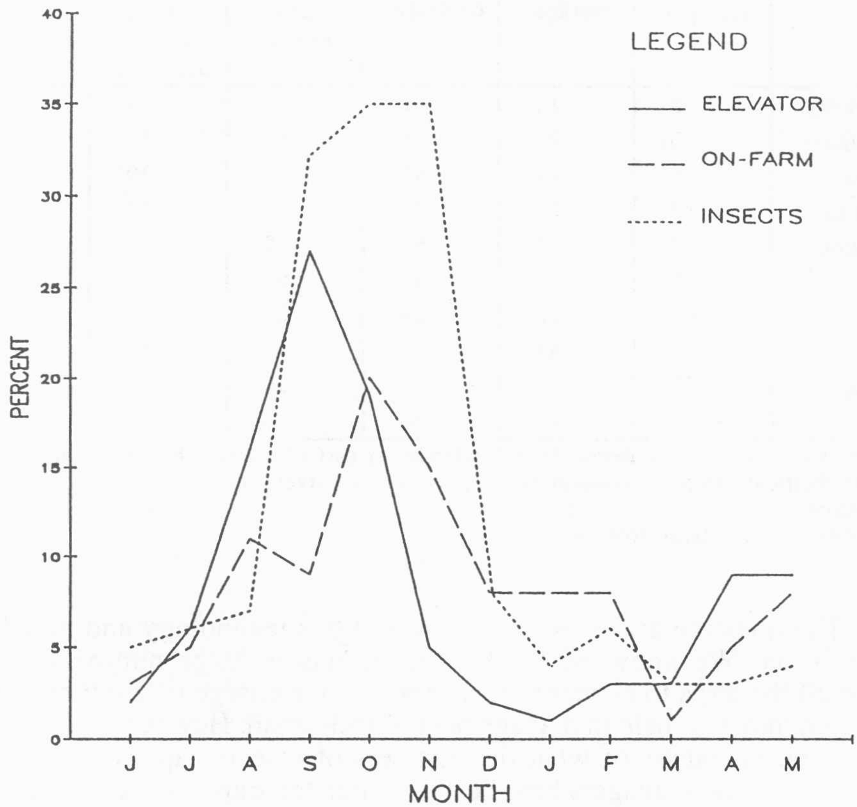

Fig. 3: Frequency of fumigation (%) by commercial managers and producers, and relative insect abundance (%). Insect abundance is for aerated grain bins, 1982-1985. Fumigation surveys conducted in 1987 included 89 producers and 112 commercial managers (Cuperus *et al.*, 1986).

INSECT TRAPS

It was mentioned previously that managers are using unbaited drop traps. The relationship between flight traps and drop traps was shown to be significantly positive and most importantly was a great educational tool (Vela-Coiffier, 1993).

Table 7: Fumigation practices and residual insecticide use at commercial elevators in selected states of the U.S.A. during the fall of 1992[1].

State	Percent fumigated upon receipt[2]	Percent fumigated during storage	Percent using empty bin treatment	Percent applying protectant during binning	Percent using post-binning surface treatment	Percent of empty bins fumigated
N. Dakota	8	14	78	78	38	22
Montana	10	23	66	58	36	31
Indiana	16	19	91	42	29	30
Nebraska	17	22	80	42	34	27
S. Dakota	19	26	67	52	32	28
Idaho	36	30	88	61	18	29
Colorado	43	28	64	29	36	18
Kansas	60	44	80	41	39	32
Oklahoma	73	76	87	30	42	34
Texas	68	65	86	34	53	35

[1]Survey conducted by Oklahoma State University as part of a research project funded by the USDA-Pesticide Impact Assessment Projects. From surveys of 1020 commercial elevator operators.
[2]Indicates receiving farm-stored wheat.

The question arises as to how we use this technology and new found information. We knew we could trap insects in large numbers and we delivered the traps to elevator managers with the charge to use them, telling them that they will help in management of their grain. However, we could not inform the managers of what the numbers of insects captured meant, nor could we tell the managers how best to utilize the traps. A trap capture may consist of 200 insects of miscellaneous species and one lesser grain borer. What did this mean? The work may involve more than standard sampling and yet standard sampling is easier for them to comprehend. Traps may make more sense in a processing system than in bulk grain storage.

We make it seem like "magic" to the growers; however, it simply is not that complicated.

CONSTRAINTS IN IMPLEMENTING IPM SYSTEMS

We must realize if we continue to try to force numerous management practices upon producers or managers they will prioritize and emphasize risk periods. For example, we can provide a $2,000 aeration controller with excellent technology which requires programming. Yet one can make an aeration controller for $150 that will do the same job. We often tend to oversell technology and overlook the simple things that will achieve the same result.

One of our objectives was to get an understanding of the decision making process. We all need to understand that there is a tremendous drain on time resources of producers and elevator managers. The most critical management time is when the producers are planting, working cattle, or harvesting wheat or other crops. Consequently the elevator managers are selling fertilizer, appeasing the board of directors, buying and selling grain, seed or feed. The decisions are made by people with limited time and so they require integrated management information. The decisions sometimes are made with limited biological information, but often are sound financial decisions. We deduce that the reasons for providing an understanding of these systems includes the human aspect of the matter related to work coordination with producer associations, elevator associations, and different disciplines (e.g. research and extension people, entomologists, plant pathologist, economists, marketing specialist and pesticide information specialist). We firmly believe this coordinated and interactive approach has and will provide the answers to many applied problems.

If we do not integrate realistic risk components, i.e. actual loss, potential loss, with other factors, educational message is often difficult to deliver. At present, the system forgives poor management; the grain is blended, the local elevator does not penalize poor producers or managers, and does not give rewards to good managers. We often say that there is a lack of research, yet the research results are there for dramatically improving management. Most of the research in the U.S. lies with ARS, and research agencies and industry must work closely with ARS.

CONCLUSION

In conclusion, our objective should be to adopt known technologies for the improvement of IPM systems. Future research and extension postharvest IPM systems look a promising basis for grain preservation both within the U.S. and world-wide.

ACKNOWLEDGMENT

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