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TRAPPING AND SAMPLING STORED-PRODUCT INSECTS BEFORE AND AFTER COMMERCIAL FUMIGATION TREATMENTS

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ABSTRACT

Fumigation treatments of food processing structures or bulk grain storage facilities are costly and dangerous undertakings. We conducted studies in a flour mill and in bulk grain storage structures to determine relative insect numbers before and after commercial fumigation procedures. Pheromone traps helped describe spatial distribution of insects at different locations in the mill and on successive dates before and after mill-wide fumigations. Red flour beetle, *Tribolium castaneum*, numbers in traps were reduced in some cases, but not eliminated, following methyl bromide fumigation. Pheromone traps for Indian meal moth, *Plodia interpunctella*, caught high numbers of moths in warehouse and shipping areas both before and immediately after fumigation. Further trapping studies inside and outside the mill building showed that relatively large moth populations existed outdoors and that the mill was subject to re-infestation through opened loading doors after fumigation. Grain probe traps were deployed in the top of a concrete silo and in a large flat storage filled with wheat. Large numbers of grain beetles were trapped soon after poor-quality treatment of the grain with aluminum phosphide pellets. Direct grain samples were taken from eleven other bulk storage structures of wheat that were fumigated with better quality methods using aluminum phosphide tablets and showed that insects were suppressed in most cases. Although insecticide resistance may account for some survival of insects after fumigation, we suspect that ineffective application of fumigant leaves many survivors.

INTRODUCTION

Fumigant insecticides are the best tools for quickly reducing insect pest infestations in food processing structures and bulk grain storages, but their continued effective use in the grain and food industries may be limited. Methyl bromide (MB) is the fumigant of choice in most flour mills and other food processing facilities in North America, but its production and use in the United States are being phased out by 2005 under provisions of the U.S. Clean Air Act and the Montreal Protocol (Anon.

1998). Thus more effective use of less MB is needed during the phase-out period and alternative treatments will be needed following the ban. Phosphine gas (PH_3) is widely used for treatment of bulk durable commodities such as grain, but its use is being restricted under new regulations in the U.S. and potential for PH_3 resistance in pest populations in very high. Very little quantitative data are available on the effectiveness of fumigation for suppressing pest populations in either processing or bulk storage facilities. The objective of the research reported here was to document relative levels of insect pest populations before and after routine application of fumigants in commercial settings.

MATERIALS AND METHODS

Insect trapping and sampling studies were conducted in a commercial flour mill and in several stored grain facilities over a two-year period. In nearly all cases we trapped or sampled over a several week period that include times before and after fumigation treatments. Information on methods of fumigant application and other pest management practices were noted when possible.

In the flour mill sticky traps were used for the Indian meal moth, *Plodia interpunctella*, that were baited with the synthetic female pheromone and thus attracted male moths. In year 1 we deployed traps for *P. interpunctella* throughout the mill according to the methods of Doud and Phillips (2000). In year 2, traps for *P. interpunctella* were deployed at locations on the ground floor only, which included the finished product warehouses and associated corridors, outside the mill building near the truck and rail-loading areas, and in the enclosed gallery rooms above the raw grain storage silos. During the same two years we deployed pitfall traps for the red flour beetle, *Tribolium castaneum*, that were baited with synthetic aggregation pheromone to capture both males and females (Mullen 1992). We acquired additional information about red flour beetle numbers from data collected by mill sanitarians on insects sifted out of flour in a pneumatic conveyance systems that carried flour from bulk storage to the packaging area (see Doud 1999 for details). For each fumigation the milling floors and warehouse areas were treated with MB while the bulk-stored flour bins were treated with PH_3using magnesium phosphide sachets. Operations at the mill were stopped for 2-3 days in each case to allow for structural sealing, treatment and aeration before resumption of production activities. We were not informed of dosages or gas concentrations applied during the flour mill fumigations, which were conducted by an outside contractor.

Insects in bulk grain treated with PH_3 fumigation were studied with traps and by direct sampling of grain in different storage structures. We used WB-II probe traps (Burkholder 1988) to capture beetles moving through wheat in a tall cylindrical concrete silo that was approximately 4 x 30 m with 600 tonnes of grain, and in a rectangular horizontal floor storage, referred to here as a flat storage, that contained nearly 2,000 tonnes of wheat. The concrete silo and the flat storage were treated with poor application methods in which pellets of aluminum phosphide were applied to the top layer of the grain and little or no gas retention methods were used. Grain samples were taken with a motorized vacuum probe sampler (Gates 1995) from four large flat storages and seven large round steel bins, each of which contained 2,000-10,000 tonnes of wheat. Vacuum probe samples of approximately 3 kg (equivalent to 1 gallon volume) were taken at eight consecutive 1.5 m depths at five to ten locations in each of these large storages. These eleven larger structures were all treated with good application methods of PH_3 in which aluminum phosphide tablets (five times larger than pellets) were probed deep into the grain masses and gas retention methods were used.

RESULTS AND DISCUSSION

The Indian meal moths were trapped in the flour mill after both fumigations in year 1; the majority of these moths were trapped on the ground floor of the mill (Fig. 1). Adult moths were trapped on the ground floor immediately after the fumigation treatment in year 2 (Fig 2). Trapping results from both years suggest either that Indian meal moths were not completely controlled by the fumigations or that there was a rapid re-invasion of the facility by moths from another location after each treatment. We observed that large outside doors to the warehouse areas on the ground floor were frequently left open for long periods during loading of finished products into trucks and rail cars. In year 2 we trapped many more moths just outside the flour mill and in the gallery area above the grain silo compared to those trapped indoors (Fig. 3). The moths trapped outside may have originated from grain and flour spilled on the ground or from the bulk-stored grain in the concrete silos. Moths could easily enter and leave the silo area because windows and doors to the gallery rooms above the silos were frequently opened. It seems very likely that moths trapped inside the mill on the ground floor may have immigrated from outdoors through the opened warehouse doors. Such immigration would explain the capture of moths in traps immediately following fumigation. Also, immigrating moths could easily start new infestations in the mill and thus negate the effectiveness of the MB fumigation.

Red flour beetles were trapped following fumigation treatments at the flour mill in both years, although there was a significant decrease in capture after the first treatment in year 1 (Fig. 4, top) and also after the one treatment in year 2 (Fig. 5, top). Beetle captures were generally low in year 1, but increased in year 2 due presumably to in improvement in trap design (Doud 1999). Phosphine fumigation of the bulk flour bins had little impact on beetles recovered from the pneumatic load-out system after the first treatment in year 1, but beetle numbers dropped significantly after the second treatment that year (Fig. 4, bottom). Sanitation staff at the mill were aware of a red flour beetle infestation inside transition pipes between a specific flour bin and the pneumatic system, and they applied a targeted dose of MB to that region of the system during the second fumigation treatment in year 1. The targeted treatment of the pneumatic system probably caused the precipitous drop in beetles recovered from the system following treatment (Fig. 4, bottom). The numbers of beetles trapped on the floors did not significantly correlate with numbers

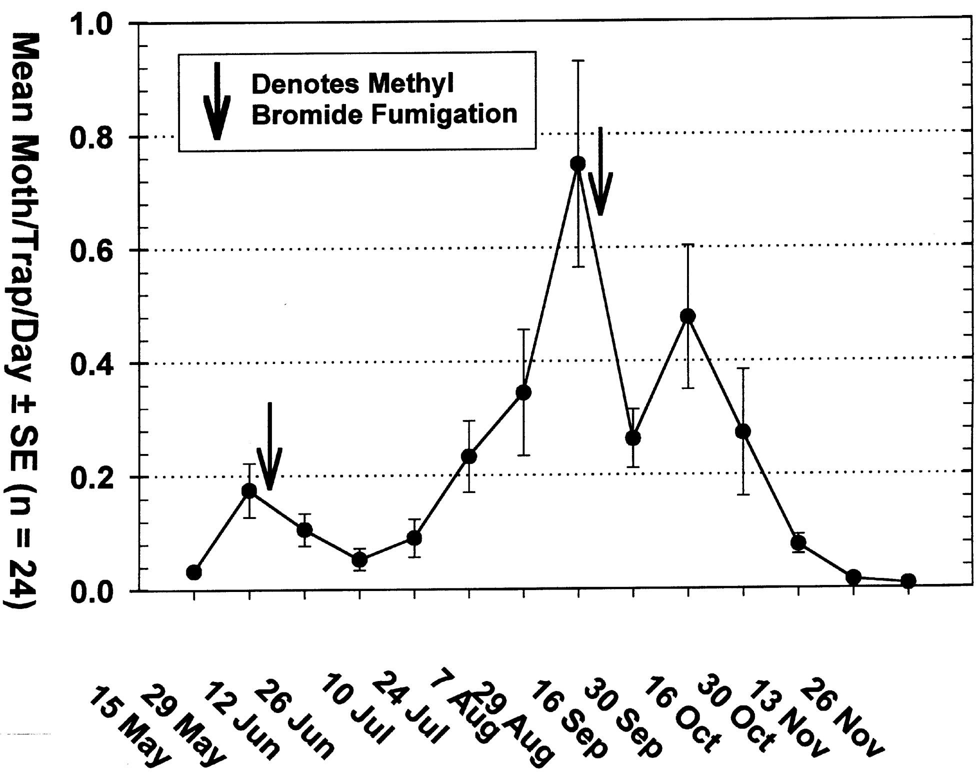

Fig. 1. Mean number of *P. interpunctella* males caught per trap per day during year 1 of a study at a flour mill. Arrows denote times when the mill was fumigated with methyl bromide. Traps were deployed on all floors of the mill and were removed just before fumigation and replaced just after fumigation.

recovered from the pneumatic conveying system in year 1 (Doud 1999), which suggests either that the two groups of beetles experienced different population dynamics or that the two sampling methods estimate beetle populations differently. In year 2 the red flour beetle traps were placed only near areas where the pneumatic system was sampled and the two sets of data were significantly, but very weakly, correlated (Doud 1999). These results suggest that trapping data may be useful for estimating population levels of red flour beetles existing throughout the mill, including the product conveyance system. Alternatively, our trapping and sampling data point to the possibility that sub-populations of red flour beetles may exist in different habitats within a flour mill, each experiencing different population dynamics.

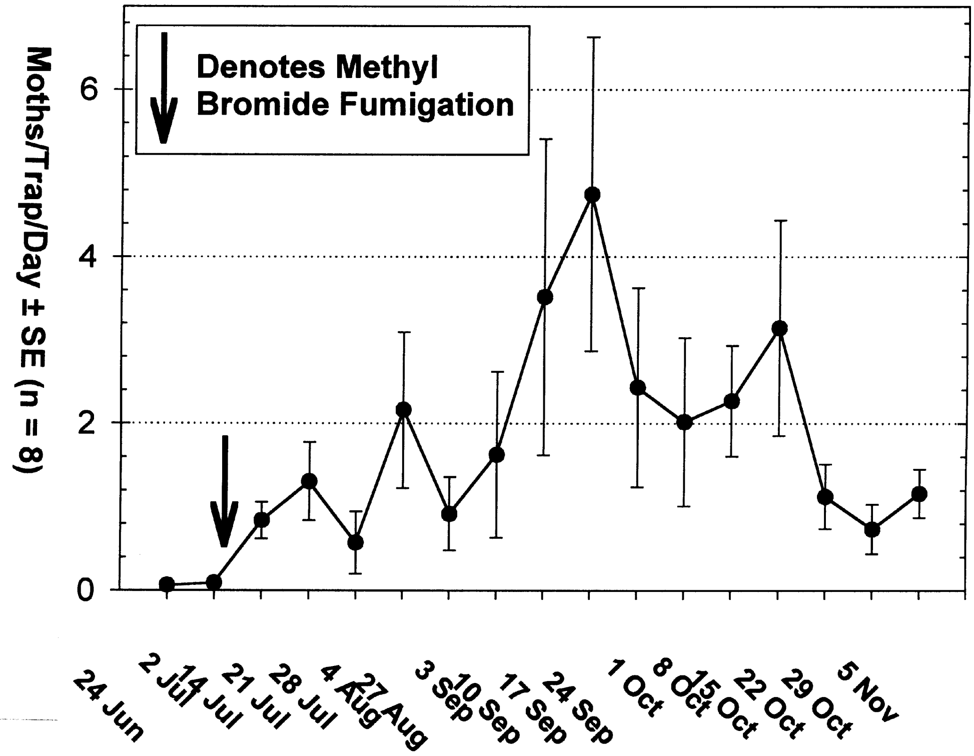

Fig. 2. Mean number of *P. interpunctella* males caught per trap per day during year 2 of a study at a flour mill. Arrows denote times when the mill was fumigated with methyl bromide. Traps were deployed on the ground floor of the mill and were removed just before fumigation and replaced just after fumigation.

Decrements in red flour beetles trapped on the floors during the weeks immediately following MB treatment, and then subsequent increments in beetles trapped in later weeks, is consistent with a scenario of population suppression followed by resurgence. Presumably, the majority of adult beetles and other life stages were killed by the fumigation, but surviving immature beetles contributed to an increased adult population approximately 4-6 weeks after the treatment. This scenario is suggested by data from the one treatment in year 2 (Fig. 5), and the first treatment of year 1 (Fig. 4), but not by data from the second treatment in year 1. Trapping data can be useful in assessing the effectiveness of a fumigation treatment on red flour beetles. Both trapping and sampling data collected at the flour mill we studied demonstrate that red flour beetles can persist in measurable numbers following treatment, and raise serious economic questions about cost-effectiveness of mill-wide fumigation treatment.

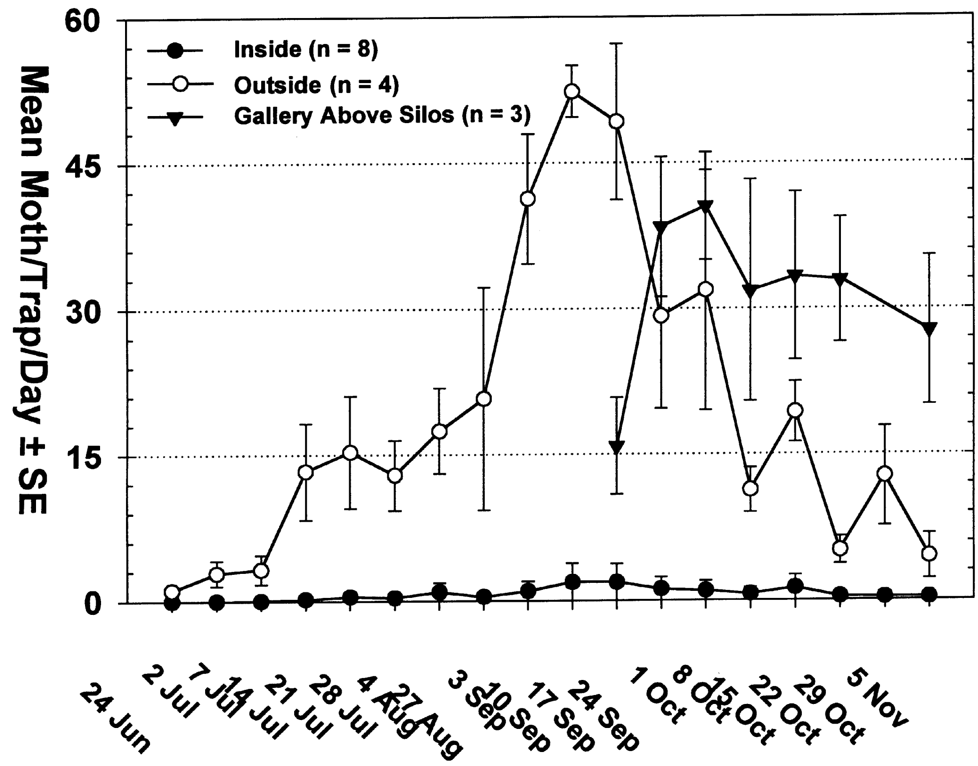

Fig. 3. Mean number of *P. interpunctella* males caught per trap per day during year 2 of a study at a flour mill. Traps were deployed inside the mill on the ground floor (same data as Fig. 2), outside the mill near loading areas, and in the enclosed rooms (the gallery) above the concrete silos where bulk wheat was stored.

Beetle populations persisted and eventually increased after PH_3 treatments in bulk grain structures that were treated with relatively poor application methods (Figs. 6-8). The WB II probe trap in a vertical concrete silo caught no beetles one week after aluminum phosphide pellets were distributed on the top of the grain, but approximately 5,000 rusty grain beetles (*Cryptolestes ferrugineus*) were trapped 3 weeks after treatment (Fig. 6). Four probe traps placed in a flat storage caught rusty grain beetles, lesser grain borers (*Rhyzopertha dominica*) and rice weevils (*Sitophilus oryzae*) throughout the season despite four separate treatments with aluminum phosphide in which pellets were distributed in the top 50 cm of grain (Figs. 7 and 8). Numbers of the three beetle species dropped to zero following the fourth treatment, in which a polyethylene sheet was used to cover the grain and retain gas. However, large numbers of beetles were trapped 5 weeks after this last treatment (Figs. 7 and 8). Although some beetles trapped after fumigation of bulk grain in these two structures may have been new immigrants to the facilities, we

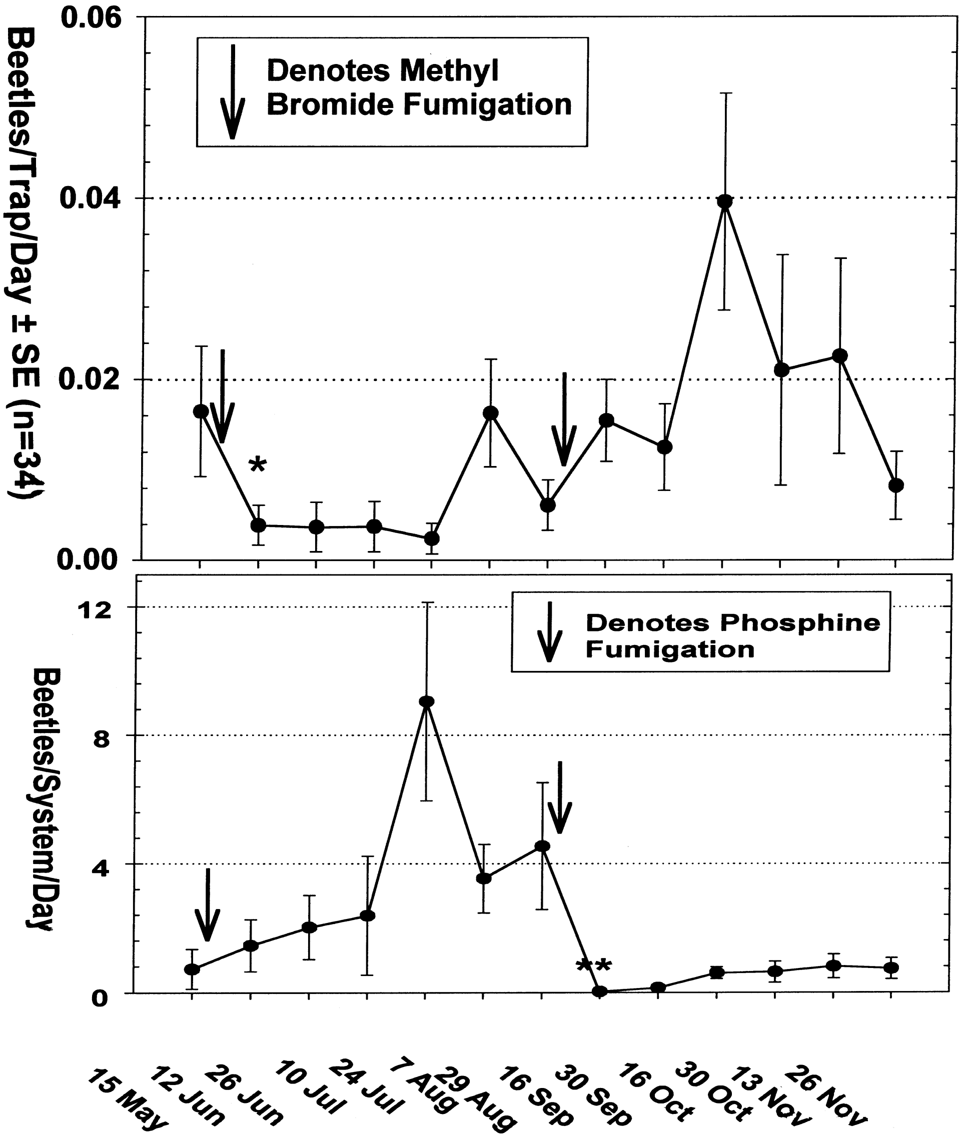

Fig. 4. Capture of *T. castaneum* in traps distributed throughout a flour mill (top) and recovery of *T. castaneum* sifted from bulk-stored flour passing through pneumatic conveyance systems (bottom) of the mill in year 1. Arrows denote times when the mill building was fumigated with methyl bromide and the bulk-stored flour was fumigated with phosphine. Stars indicate significant differences in beetle numbers before and after fumigation.

believe that the majority of beetles trapped were already present, or represent progeny of those present, in the grain at the time of treatment. Phosphine gas was probably delivered only to the top portions of the grain masses in these two cases because aluminum phosphide pellets were applied just to these areas of the grain. Application rates of pellets were clearly well below those recommended for the sizes of the given masses of grain. Therefore many parts of the two grain masses probably received no PH_3 gas and insects in these areas probably were not killed.

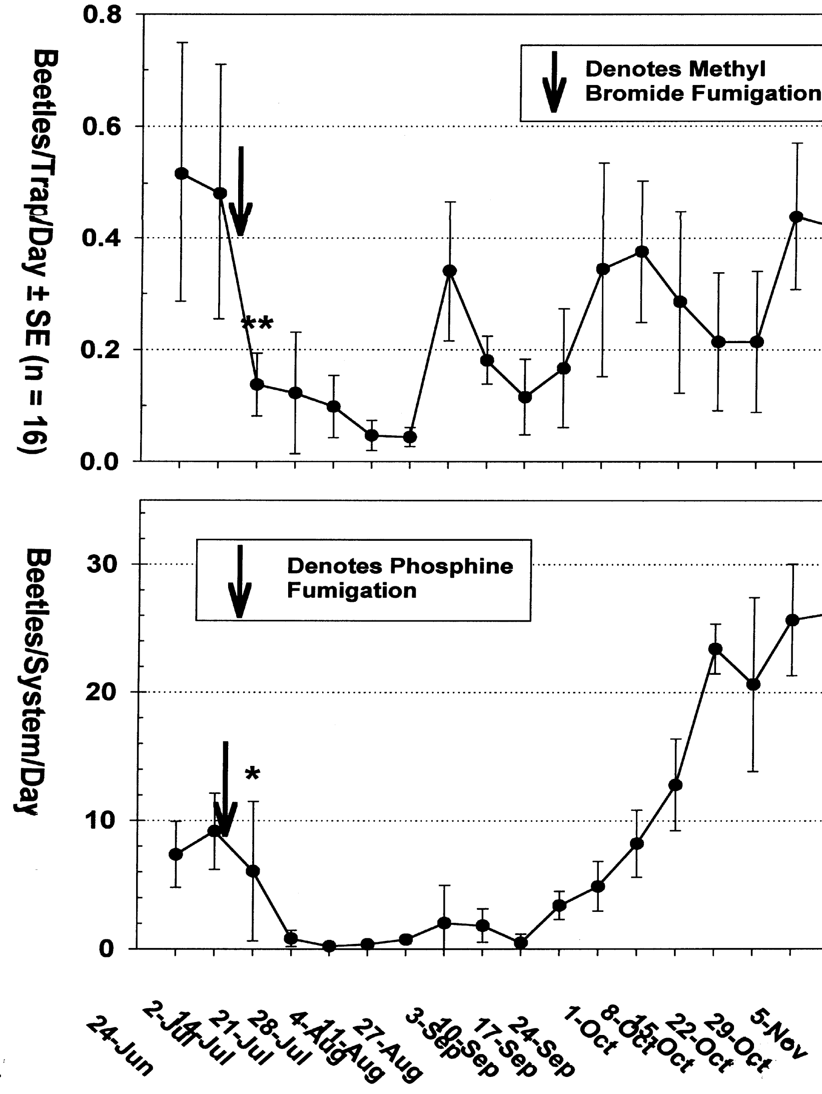

Fig. 5. Capture of *T. castaneum* in traps distributed throughout a flour mill (top) and recovery of *T. castaneum* sifted from bulk-stored flour passing through pneumatic conveyance systems (bottom) of the mill in year 2. Arrows denote times when the mill building was fumigated with methyl bromide and the bulk-stored flour was fumigated with phosphine. Stars indicate significant differences in beetle numbers before and after fumigation, (* P<0.05, **P<0.01).

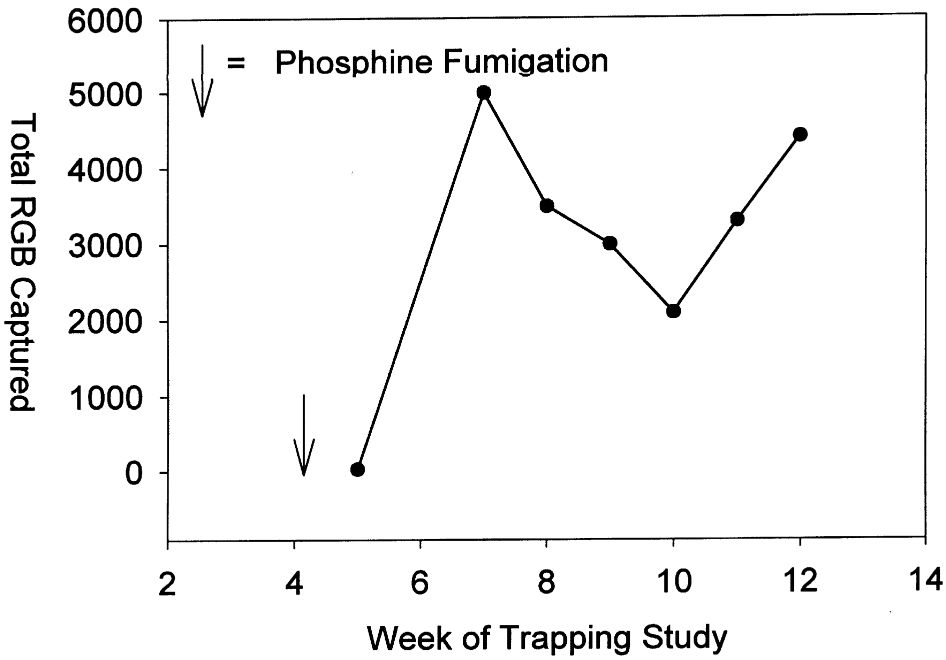

Fig. 6. Total numbers of rusty grain beetles (RGB), *C. ferrugineus*, captured in a WB-II probe trap placed 30 cm below the grain surface in concrete silo filled with wheat. The silo was treated by distributing pellets of aluminum phosphide on the top surface of the grain four weeks (see arrow) after the silo was filled with wheat.

The eleven grain storage structures that were treated with good PH_3 application methods had relatively low insect populations both before and after treatment Fig. 9). Insects were not detected in grain samples following fumigation in eight out of the eleven bins. Insect numbers were relatively low prior to fumigation in most cases. The action threshold we recommend for grain pest management is one live insect per kg of grain (Phillips *et al.*, 1999). Each one-gallon grain sample taken in these 11 bins was equivalent to about 3 kg of wheat, thus density of insects per kg can be estimated from the data in Fig. 9 by dividing each mean value by 3. Bins 2, 10 and 11 were therefore the only structures in which one or more live insects per kg were detected and the other bins would not have met the criteria for treatment if a strict action threshold were applied. Despite the relative need for fumigation among these eleven bins, these structures had a history of good grain management and fumigation practices. All of the structures were equipped with aeration systems for cooling grain to reduce increase in pest populations. Managers at these facilities practiced good sanitation and maintenance of the bins between storage cycles. Commercial fumigators and grain managers made efforts to seal gas leaks in all the structures prior to treatment with PH_3. Most of the eleven structures were treated

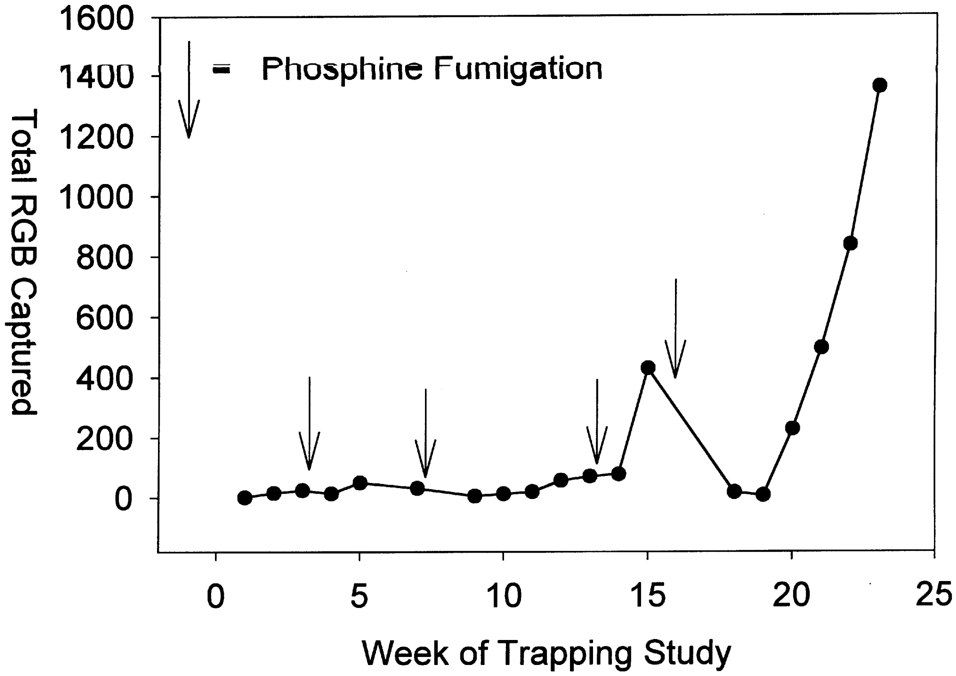

Fig. 7. Total number of rusty grain beetles (RGB), *C. ferrugineus*, in four WB-II probe traps placed 30 cm below the surface of the grain, in a flat storage of wheat. Traps were no less than 5 m apart nor less than 5 m from the side-walls of the storage. The grain mass was treated by distributing pellets of aluminum phosphide 30-60 cm below the top surface of the grain at four different times (arrows). No gas retention was utilized for the first three treatments, but for the fourth treatment (week 16) the top of the grain mass was covered with a polyethylene sheet, 6 mil thickness.

with the maximum allowable levels of aluminum phosphide tablets for the total amount of grain stored, so that the ultimate gas concentrations and exposure times were maximized for improved insect control. Three of the eleven structures were equipped with gas re-circulation systems that helped ensure $PH_3$was distributed evenly throughout the grain masses

The case studies presented here demonstrate that broad variation exists in the effectiveness of commercial fumigation treatments applied to structures for control of stored-product insects. Fumigation treatment of flour mills can be very expensive, both from the cost of the treatment and from revenue lost while mill production is halted, so ineffective treatment or poor management that allows for rapid pest re-invasion following treatment are undesirable. The regulatory loss of MB by the year 2005 will force mill managers to adopt effective alternatives to mill-wide fumigation, such as pest sampling with traps and targeted applications of

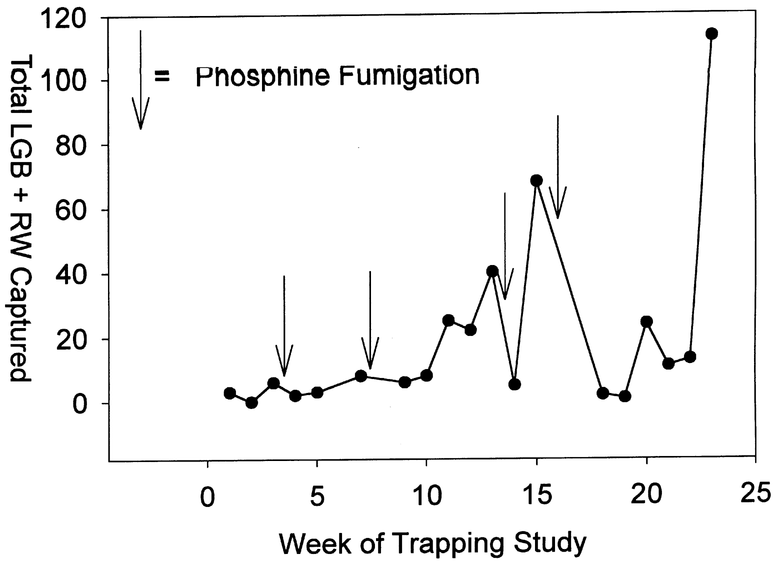

Fig. 8. Total number of lesser grain borers (LGB), *R. dominica*, and rice weevils (RW), *S. oryzae*, captured in four probe traps placed in a flat storage of wheat. All conditions and treatments are the same as in Fig. 7.

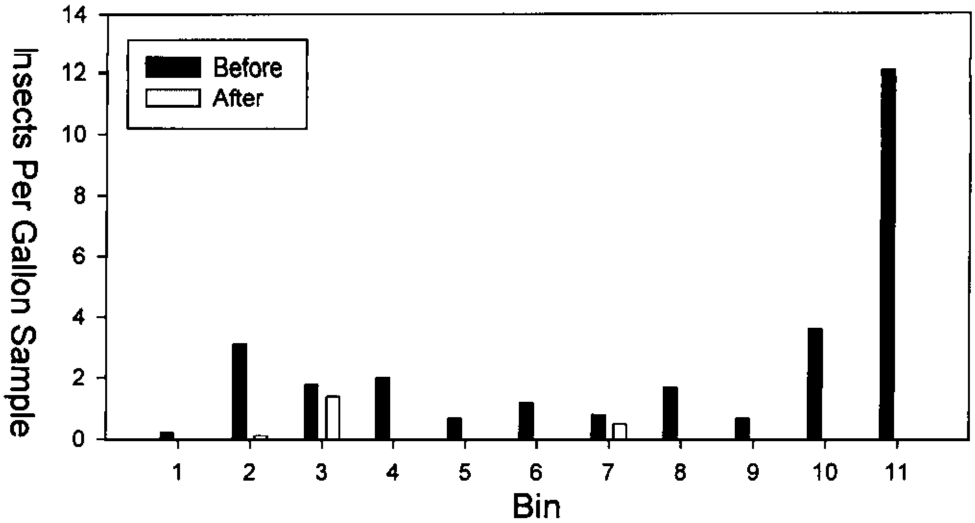

Fig. 9. Mean number of all beetle pests recovered from 3 kg samples (1 gallon) collected with a vacuum probe sampler in 11 different grain storage bins (37-68 samples per mean). Dark bars are those insects recovered 1-14 days prior to treatment with phosphine and light bars are the largest number of insects recovered at a given sampling time up to 9 months after treatment.

insecticides when action thresholds are met. We suspect that ineffective application of PH_3 fumigants to bulk grain, such as we observed in some cases here (e.g., Figs. 6-8), is widespread in the United States. Misuse and over-use of PH_3 fumigants in leaky structures is expensive, unsafe for workers in grain facilities, and probably contributes to evolution of PH_3 resistance in pest populations due to proliferation of survivors that receive sub-lethal doses. Our results also show that grain fumigation may not always be needed if pest populations are below critical levels. Trapping and grain sampling to estimate pest populations can be important tools for grain pest management.

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