FUMIGATION TRIALS WITH FARM-STORED GRAIN

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ABSTRACT

Fumigation of grain stored in bolted-iron farm silos was investigated in trials at Temora, Condobolin and Tamworth, 1976-82. Fumigant leakage from unsealed bins reduced the effectiveness of carbon disulphide, applied at dosages that were effective for 24 h fumigation in bins enveloped in plastic sheeting. Fumigation with 2, 6 or 12 g phosphine per tonne, applied as tablets containing aluminium phosphide probed into the grain, was effective both in unsealed bins and in bins enveloped in plastic sheeting for 7 to 10 days. Another tablet formulation containing aluminium phosphide, urea and ammonium bicarbonate, tested in conjunction with the aluminium phosphide, ammonium carbamate formulation used previously in these trials, gave comparable results at 6 g phosphine per tonne after 7 - 8 days in unsealed bins.

INTRODUCTION

The large quantity of grain stored on farms in eastern Australia (Lipton, 1980) includes grain for animal feeding that may be kept for long periods, depending on the availablity of natural fodder. It is usually held in iron silos of 25-80 t capacity, and is a potential source of insects (Greening, 1969, 1973) which may spread to harvesting equipment and contaminate newly harvested grain (Sinclair *et al.*, 1980).

Many farmers rely on periodic fumigation of the grain to prevent its destruction by insects. Carbon disulphide is commonly used in New South Wales. It is easily applied by pouring the liquid fumigant onto the surface of the grain in a bin. The need to confine the fumigant vapour in the bin (Hinds, 1924) is often overlooked. This prompted an investigation of the effectiveness of carbon disulphide fumigation in silos constructed from bolted iron sheets. The importance of distributing the fumigant as a spray over the grain surface (Walkden *et al.*, 1951) was also tested in these trials.

They were followed by trials of phosphine fumigation of grain stored under similar conditions. Phosphine became a popular fumigant for use on farms after the Grain Elevators Board of N.S.W. adopted it in 1955. For farm-stored grain, particularly in bulk sheds, phosphine was recommended for many years at dosages up to 10 g phosphine/t and the 1978 trial was

conducted with that in mind. In later trials the choice of dosages was influenced by a review of grain fumigants used on farms (Williams *et al.*, 1980) in which 6 g phosphine/t was the maximum dosage recommended.

MATERIALS AND METHODS

Trial sites and formulations

Fumigation trials with carbon disulphide were conducted at Temora Agricultural Research Station (southern N.S.W.) in March, 1976 and April, 1977 and at Condobolin Agricultural Research Station (central N.S.W.) in May, 1977. Carbon disulphide manufactured by Stauffer Chemicals Ltd., Tomago, N.S.W. (1.2 kg carbon disulphide per litre) was used.

Phosphine fumigation trials were conducted at Condobolin Agricultural Research Station in April, 1978 and March, 1980 using Phostoxin (R) fumigation tablets (active ingredients, aluminium phosphide 56%, remainder inert ingredients including ammonium carbamate) manufactured by Degesch GMBH, Frankfurt/Main, FGR.

In May, 1982 at F. Klepzig & Sons' farm at Nemingha northern N.S.W. a trial was conducted to compare the efficacy of Phostoxin with that of a new material – Gastion (R) tablets (active ingredient, aluminium phosphide 57%, remainder inert ingredients including urea and ammonium bicarbonate), manufactured by Casa Bernardo Ltda, Santos, S.P. Brazil.

Silos

Grain was fumigated in silos made of curved steel sheets (galvanised iron) bolted together without sealant, a type of bin commonly used on Australian farms. They had flat concrete floors, except at Tamworth where both silos had conical concrete bases. The silos used at Temora in April, 1976 ranged in size from 37 to 113 m^3. In later trials at Temora and Condobolin, silos of total volume 83 m^3 each were used. Their nominal capacity was 50 t (73 m^3) and they held aproximately 40 t grain. At Tamworth silos of 50 t capacity holding approximately 45 t grain were used.

Fumigation sheets and exposure periods

In each trial, except in 1982, fumigation of silos completely covered with nylon-reinforced polyvinyl chloride sheeting was compared with fumigation of unsealed silos. After the first trial, when separate plastic sheets covering roof and wall were joined around two silos, a silo cover, tailor-made from the same type of plastic sheeting was used. The covering was removed 24 h after dosing in trials with carbon disulphide. In the trials with phosphine the covering was removed after 10 days in 1978, 7 days in 1980.

Insects

Steel cages, containing wheat infested with rice weevil, *Sitophilus oryzae* (L.), were inserted into the grain in the fumigated silos and in an adjacent unfumigated control silo for each trial, except in 1982. Each cage contained approximately 60 g wheat in which there were approximately 600 adult *S. oryzae* in 1976, 1977 and 1978 and approximately 200 adults in 1980. The latter was a composite equal parts of cultures aged 9, 12, 16, 26, 28 33 and 36 days incubated at 25°C, 70% r.h. Stainless steel wires attached to the cages enabled them to be retrieved for examination after fumigation. The contents were sieved immediately to determine the adult mortality, then the wheat was incubated at 27°C, 55% r.h. for 8 weeks before it was examined again to determine if there had been any survival of immature insects.

Sampling

Grain samples from the surface and outlets of each silo were taken before and after fumigation and examined for insects. In 1982, results were based on more extensive grain sampling: surface samples from 5 points, sub-surface samples, obtained with a Corcoran spear probe, from 0.75, 1.5, 2.0, 3.0 and 4.0 m deep, and samples from the grain outlet of each silo. Sub-surface samples were taken from a control bin also. Each sample was approximately 500 g.

Dosing

Carbon disulphide was hand-pumped from a bucket at ground level to the top hatch where, in the first trial, it flowed onto sacks hanging from the hatch rim inside the silo. In later trials carbon disulphide was sprayed over the grain surface. A stirrup pump fitted with petrol-resistant hose was used. A shallow layer of water, covering the carbon disulphide in the bucket, reduced evaporation during pumping. Carbon disulphide is highly flammable. Precautions necessary against accidental ignition of carbon disulphide liquid or vapour include earthing the fumigant container and spray nozzle against static electricity (Cotton, 1963).

Tablets containing aluminium phosphide, each generating 1 g phosphine on exposure to moisture, were probed into the grain, using a tubular steel probe designed for that purpose. At 14 positions on the grain surface (approximately 1.2 m apart) tablets were placed at 6 levels vertically (approximately 0.6 m apart) using 85, 252 and 480 tablets to achieve fumigant dosages of 2, 6, and 12 g phosphine/t respectively. In 1982, approximately 300 tablets were used in each silo (a dosage equivalent to 6 g phosphine per tonne capacity of the bin) including 10 tablets probed into grain in the conical base of the bin through the auger chute.

Temperature and moisture

Grain temperature was measured before fumigation with a thermistor probe, moisture content was determined with a "Motomco" meter.

RESULTS AND DISCUSSION

The effectiveness of carbon disulphide or phosphine for grain fumigation was measured in 5 trials by the mortality produced in *S. oryzae* cultures exposed in cages in the grain (Table 1). S. oryzae was chosen as the test insect because the occurrence of its immature stages inside the grain kernels provides a measure of the penetration of fumigant gas. It is recognised that immature stages of *Sitophilus spp.* are most difficult to control by fumigation with phosphine (Reynolds et al., 1967). These results were supplemented by observation of the effect of fumigation on naturally occurring insect infestation of the grain.

In the trials with carbon disulphide, fumigation was effective only in covered silos and when the fumigant was distributed over the grain surface by spraying. In 1977, adult insects were controlled in 24 h fumigations with applied dosages of 0.06 L m^{-3} at Temora and 0.12 L m^{-3} at Condobolin. Few progeny developed from the caged wheat fumigated at Temora and none from that fumigated at Condobolin. The dosage was altered to suit prevailing atmospheric temperature (16-40°C at Temora, 5-33°C at Condobolin), although the mid-bulk grain temperature did not differ correspondingly. Because of insect infestation, grain in the covered silo at Condobolin (33°C) was warmer than grain in the covered silo at Temora (29°C). The natural infestation at Condobolin, mainly lesser grain borer, *Rhyzopertha dominica* F., and rust-red flour beetle, *Tribolium castaneum* Herbst, was controlled by carbon disulphide fumigation.

In trials with phosphine, fumigation was effective in both sealed and unsealed silos. This was indicated by the mortality of adult *S. oryzae* caged in the grain (Table 1) and by the incubation of the cage contents, which showed that immature stages of *S. oryzae* did not survive fumigation. Control mortality of *S. oryzae* caged in an unfumigated silo, 0.1, 1.5 and 3.0 m deep in grain, was 5% or more in 1978 but < 1% in 1980. Supplementary results obtained from grain samples (Table 2) indicated effectiveness of fumigation against *R. dominica*, *T. castaneum*, long-headed flour beetle, *Latheticus oryzae* Waterhouse and flat grain beetle, *Cryptolestes sp.* in 1978 and against *T. castaneum* after fumigation, in grain samples from bins that were not covered for fumigation was probably due to re-invasion of those bins from infested grain in adjacent silos. *T. castaneum* is noted for its mobility at atmospheric temperature > 25°C which prevailed then. Mean sub-surface grain temperature

in the 1978 trial was 41°C in the covered silo (barley, 11.0-12.9% moisture) and 32°C in the silo fumigated without covering (wheat, 9.4-9.7% moisture). In the 1980 trial it was approximately 30°C in all silos (wheat, 10-12% moisture).

In the phosphine fumigation trial at Tamworth the results achieved by the 2 fumigant formulations were similar. *T. castaneum*, occuring throughout both silos, was a convenient indicator. Very few insects of other species occurred alive in the grain. Complete mortality of insects on the grain surface and in the centre of the grain bulk was found in both silos 7-8 days after fumigation (Table 3). Some insects were found alive then in samples from the grain outlets of both silos. They were *T. castaneum* and *S. oryzae* that may have invaded the bins recently, as supposed for similar occurrences at Condobolin. Additional samples from the grain surface of each silo, taken close to the silo wall at the 4 compass points, contained no living insects after fumigation. Corresponding samples taken before fumigation from Silo 1 contained numerous *T. castaneum* alive. Similar samples were unobtainable then from Silo 2 because it was full. Wheat removed later to make headroom for probing was held in a transportable bin as a control. *T. castaneum* remained alive in the control bin during the trial. Grain temperature 0.75-5.0 m sub-serface was 27-31°C in Silo 1 (wheat, 11.4-12.2% moisture), 26-36°C in silo 2 (wheat, 10.3-12.3% moisture).

Probing the tablets into grain was a convenient method of obtaining accurate placement of fumigant in these trials. In practice, the working headspace might not be available, and it could be necessary to add the tablets to grain as it is turned from one bin to another. An effort to distribute the fumigant formulation evenly amongst the grain may be necessary to achieve the same results as were obtained in these trials. Their is a possibility that some insects may survive fumigation in the grain because of lack of penetration of phosphine at low doses (Lindgren *et al.*, 1958).

CONCLUSION

The trials with carbon disulphide, at dosages commonly recommended for farm-stored grain, demonstrated that fumigation in unsealed bins is unreliable, and that distribution of the fumigant over the grain surface in sealable bins is desirable. The danger of using this highly flammable fumigant is minimised when fumigating grain in isolated farm silos.

Trials with phosphine demonstrated that this fumigant can be used effectively in farm silos without sealing. Even distribution of the fumigant formulation in the grain is considered necessary in this instance. The dosage used in the initial phosphine fumigation trial was slightly greater than the

Table 1. Mortality (%) of caged *Sitophilus oryzae* in fumigation of grain in farm silos at Temora and Condobolin

Trial	Depth in grain (m)	Carbon disulphide 0.06 L m^{-3} for 24 hours		Carbon disulphide 0.12 L m^{-3} for 24 hours		Phosphine 12 g t^{-1} for 10 days		Phosphine 6 g t^{-1} for 7 days	Phosphine 2 g t^{-1} for 7 days	
		Silo covered	Silo not covered	Silo covered	Silo not covered	Silo covered	Silo not covered	Silo not covered	Silo covered	Silo not covered
Temora March 1976	0.1	87	0	100	0					
	2.0			100,88	0					
	3.0	<5	100		100					
	4.5	100,100	100	100	100					
Temora April 1977	0.2	100,100	65,100,100							
	3.0	100,100	78							
	4.5	100,100								
Condobolin May 1977	0.1			100,100	100,100					
	2.0			100,100	100,100					
	4.0			100,100	100,97					
Condobolin April 1978	0.1					100,100,100	100,100,100			
	1.5					100,100,100	100,100,100			
	3.0					100	100			
Condobolin March 1980	0.1							100,100	100,100	100,100
	1.5							100,100	100,100	100,100
	3.0							100	100	100

Table 2. Adult insects alive in grain samples from farm silos, before and after phosphine fumigation at Condobolin

Sampling site	Insects	1978 trial 12 g phosphine/t SILO COVERED before	after	SILO NOT COVERED before	after	6 g phosphine/t SILO NOT COVERED before	after	1980 trial 2 g phosphine/t SILO COVERED before	after	SILO NOT COVERED before	after
Surface	*R. dominica*	140		315		1					
	T. castaneum	50		13		2	1	2			
	L. oryzae	850									
	Cryptolestes sp.	12						5			
Grain outlet A	*R. dominica*	640		132							
	T. castaneum	832		86	3	70	1	74		1	
	L. oryzae	1080									
	Cryptolestes sp.	38									
Grain outlet B	*R. dominica*	540		4							
	T. castaneum	640		7		30		18		1	
	L. oryzae	16									
	Cryptolestes sp.							8			

Table 3. Number of adult *Tribolium castaneum* alive in grain samples from farm silos fumigated with phosphine 6 g t^{-1} at Tamworth, 1982 (without covering)

Sampling depth (m)	Silo 1 Dosed 4th May with "Gastion(R) fumigation tablets"		Silo 2 Dosed 5th May with "Phostoxin(R) DEGESCH fumigation tablets"	
	Pre-fumigation (28th April)	Post-fumigation (12th May)	Pre-fumigation (28th April)	Post-fumigation (12th May)
0	39		45	
0.75	23		6	
1.5	17		6	
2.0	15		6	
3.0	39		6	
4.0	17		7	
grain outlet	15	6	169	+
auger chute	*	8	*	21

* not sampled pre-fumigation

+ 3 *S. oryzae*

maximum then recommended because it seemed appropriate to use the whole contents of a tin of 480 tablets (phostoxin), once it was opened, for each silo. Now that the maximum dose recommended is 6 g phosphine/t, a pack of 300 tablets (Gastion) is an appropriate size for fumigating a 50 t silo. Results obtained with 2 g phosphine/ t indicated that there is considerable margin of efficacy when this fumigant is used at dosages currently recommended for farm-stored grain.

These fumigants play a major role in the control of grain insects on farms. With the very large number of old silos and grain sheds in use, it is impractical to restrict their use to storages that are ideal for fumigation.

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