Fumigation of grain in farmer-level mud stores and metal grain tanks using phosphine

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Abstract

The Natural Resources Institute, funded by the UK's Department for International Development, established two sets of trials to examine the suitability of metal grain tanks and mud stores currently used by African farmers for fumigation purposes

The first trial illustrated the extremely high levels of gas tightness capable of being achieved in one tonne metal grain tanks. Gas concentrations in excess of 150 ppm were maintained for over 27 days-well beyond the 5 to 7 day minimum exposure period required However, such results were only achieved by sealing inlets and outlets-leakage dramatically reduced the effectiveness of the fumigation

The gas-tightness of traditional mud silos was examined in the second of the two trials. Despite the stores being in good condition, gas loss was so rapid that fumigations failed after less than 24 hours exposure Rendering of the walls with either cement or a bitumen/soil mixture improved gas tightness only slightly. Covering with a gas-tight sheet further reduced gas loss, although fumigations still failed due to gas loss into the ground. Only by painting the walls with a oil-based paint could *some* of the stores be fumigated successfully.

The effectiveness of phosphine for on-farm fumigations depends on the type and condition of structure available. Difficulties in constructing gas-tight stores with natural materials, and the health and safety risks associated with the improper use of phosphine, lead the authors to conclude that fumigation is an unsuitable pest control method for traditional storage systems.

Introduction

In many countries, phosphine generating compounds are only available to trained fumigators, and not to the general public because of the inherent dangers associated with their use. However, in some countries in sub-Saharan Africa, these compounds can be obtained without restriction from retail outlets Farmers and consumers are therefore able to purchase tablets for use in the home or store.

Over the next 10 years, the use of methyl bromide will become severely restricted and so phosphine will be the only common fumigant available for commodity disinfestation. Incorrect usage of phosphine has been shown to permit insects to develop resistance to this chemical (Taylor, 1989) and it is essential that the rate of increase of resistance is minimised. This may not be achieved in those countries with no restrictions on the sale of aluminium phosphide formulations and where the use of the gas will remain widespread, often by people with no training.

It may be impractical, however, to expect farmers to relinquish the use of phosphine generating tablets if they are readily available and are a cheap method of grain protection. This project was designed to explore the opportunity for safe and effective fumigation of on-farm storage structures.

A review of available literature indicates that few investigations into the fumigability of farmer-level grain storage structures had been performed. Wohlgemuth and Harnisch (1986) claimed to have successfully fumigated mud silos, but examination of their results indicated that the gas concentrations achieved do not meet current recommendations for phosphine fumigations (150 ppm for five days). Even when application rates were doubled, fumigations were still deemed to have failed. Qasim Chaudhry and Anwar (1988) found that phosphine could not be retained for more than 24 hours in a variety of mud-built structures (plastered and unplastered, made from either mud or from mud blocks with cement mortar) of 0.43 to 4.05 m^3 capacity. Only when the mud silo was lined with plastic sheeting could a successful fumigation be achieved Webley and Harris (1979) fumigated square mud-built grain stores or granaries using phosphine tablets. Although they managed to maintain sufficient gas concentrations for four days, the rate of gas loss was demonstrated to be extremely high despite wall thickness' of 650 mm and cement floors.

Metal storage bins are used in Swaziland (Boxall et al., 1997), Guatemala (Breth, 1976), Korea (Tyler, 1978) and India (Baksi and Bhatnagar, 1971) for on-farm storage Qasim Chaudhry and Anwar (1988) found that metal bins and plastic drums were extremely effective for fumigation purposes. Harris (1970) found that mud or dung mixtures were not suitable for sealing large holes, but may be suitable

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for the small gaps around tank inlets and outlets Qasim Chaudhry and Anwar successfully used mud plaster to seal possible sites of gas leakage However, as metal tanks age so the joints between the metal sheets will widen, reducing their gas tightness and the efficacy of fumigations.

Case Study on Phosphine Use on Small Farms

A survey was conducted to determine the degree of small-scale phosphine usage, and the methods employed, in the three northern regions of Ghana. Small-scale, in this sense, refers to practices employed by individual farmers or families to protect food stored for seed or home consumption, either in rural or in urban areas. Four traders selling chemicals and 14 farmers in nine villages were interviewed in Tamale and Damongo districts. Other groups of farmers were interviewed briefly in villages in Saboba district, along the border with Togo.

Phosphine has been available for many years. One farmer admitted using tablets for 12 years and another for six years. Main suppliers in the north obtain their stocks from a market in Kumasi where there are several traders selling chemical products including phosphine preparations-these traders belong to a chemical association which obtain supplies directly from importers. Tablets, which release 1g phosphine (sufficient to treat 300 kg of grain), are the only formulations commonly available in Ghana.

Tablets are packed by the manufacturers into tubes of 10 (enough to treat 30 sacks) or into flasks of 30 or 300-even the smallest packs contain far too many tablets for the average farmer. The retailer often sells individual tablets, usually in unsealed polythene bags (150 – 300 gauge). Under ambient conditions in northern Ghana, these tablets will begin to release gas about 30 minutes after exposure to air-long before the farmer has reached the homestead. It is quite likely that, by using this method of packaging, tablets have caused phosphine poisoning without the patient realising the cause of the symptoms-this problem is likely to increase in the future as the sale of tablets increases. No pellets are available in Ghana-given that they are equivalent to ⅕ of a tablet, pellets would be more suited to the small quantities of grain fumigated by farmers.

Farmers obtained information regarding the use of tablets from both chemical retailers and the local MOFA officials Previously, staff of the Plant Protection and Regulatory Department (PPRD) within the MoFA sold polythene sack liners to be used with the tablets and they conducted a series of one-day training courses (6) in different districts to explain the method of use. There is not, however, sufficient extension effort to deter people from using incorrect fumigation techniques, the subject is rather neglected, with too much emphasis being placed on selling tablets to provide income.

However, none of the farmers interviewed used sack liners Farmers simply placed one tablet in each bag-a dosage rate far in excess of that recommended. (To prevent the residue of the tablet contaminating the grain after the gas has been liberated, each tablet is wrapped in a small piece of cotton cloth before being placed into the grain) Despite the high application rates, fumigations are unlikely to produce any more than a cosmetic effect as the gas will diffuse out through the walls of the sack too quickly for all of the insects to be killed Only one farmer had attempted to address this situation-after placing the tablets in individual sacks he then covered the entire stack with a plastic sheet. Although the enclosure was not particularly gas-tight, it was likely to be effective because of the high application rate

Whilst most farmers interviewed followed or exceeded recommended dosage rates, a few farmers under-dosed in an attempt to reduce costs – for example, a farmer in Damongo used only five tablets to treat 70 sacks of maize. However, this was not a common occurrence.

Tablets are commonly used in all types of on-farm store. Even though some of these stores may be plastered with cow dung and mud, they would not be sufficiently gas-tight to prevent the rapid diffusion of phosphine through the walls.

Retailers and wholesalers verbally instruct purchasers on the methods to employ when using tablets However, the suppliers themselves are not sufficiently conversant with the properties of the gas to enable them to provide correct and adequate information. Two retailers stated that one tablet is used for grain in a woven polypropylene sack but two tablets are introduced if the grain is in a jute sack Both believed, incorrectly, that the polypropylene sack would retain gas more effectively. One retailer, who stocks both tablets and sachets of powdered aluminium phosphide, believed the formulations functioned in different ways, he was unaware that both produced phosphine gas. This lack of knowledge was exemplified by several farmers who stated they put tablets in sacks but that after a few days when a grey powder remained (after decomposition to aluminium hydroxide), they mixed the powder with the grain and hoped to provide protection for several months. These farmers, as well as some retailers, were unaware that the active component was a gas.

It was quite common to hear reports of people suffering from headaches and feeling nauseous when they handled tablets. Whole villages were reluctant to use phosphine because of the 'bad scent'. Many of the interviewees said they vacated rooms where the tablets had been used but several felt that it was not a problem if they came in contact with the odour. Due to concerns over theft, some farmers placed the fumigating bags in their own bedrooms! There are no hospital records confirming phosphine poisoning within the region. However, it is very unlikely that medical practitioners would be capable of recognising the symptoms. One large farmer, who is also a retailer in Damongo, said there were on average two suicides every year due to phosphine intoxication. His wife also became affected when she unknowingly entered a room in which grain had just been dosed with tablets. She became nauseous and vomited; she fully recovered after a night in hospital.

Storage Structures in Northern Ghana

The type of structure used by a farmer is largely dependent on the ethnic group. Stores broadly fall into two types – those constructed from woven plant materials, and those constructed from mud.

Woven plant materials

The *Kunchun* is a large basket, more or less spherical in shape, of typically 1.5 to 2.5 metres in diameter, and is formed from either woven split sorghum stalks or, sometimes, from grass. It may or may not be plastered with cow dung and soil, and the entire structure is placed under a conical thatched roof; frequently the roof is so large that the *Kunchun* basket is not visible. The structure is located outside the house, raised at least a metre above the ground on a wooden platform.

The *Kambong* is a cylindrical shaped store, typically 3 to 4 metres in diameter, with walls up to 2.5 metres high. It is constructed from a wooden framework, with the floor and walls consisting of matting made from woven sorghum stalks. The floor is usually raised by 0.5 metres above the ground, although the 'improved' design, as extended by MoFA, is raised by at least 1 metre

These stores, even if covered with a mud and/or dung plaster, are clearly unsuitable for fumigation purposes. The degree of sealing would be expected to be extremely poor, and so there would be no hope of retaining sufficient phosphine over the desired exposure period.

Mud silos

A variety of designs of mud silo can be found in northern Ghana. A typical design, as extended by MoFA, is roughly spherical in shape, ranges in diameter from 1 to 3 metres, and is supported on three mud legs. They are constructed from a mixture of mud and grass, the mud being soil extracted from termite mounds (the termite soil producing a stronger, longer lasting structure than conventional soil). The stores are often divided internally into three compartments enabling different commodities to be stored separately Properly maintained, these stores are reported to last up to 20 years.

The mud silo (with walls between 100 mm and 200 mm thick), at least has the potential to be sufficiently gas-tight for fumigation purposes.

Other structures

Jute sacks are in common use especially among large-scale farmers and those who double as traders. Fired clay water pots, of up to 1 metre in diameter, are often used to store small quantities of grain

Storage Structures in Swaziland

Many traditional storage structures, not unlike the *Kunchun* and *Kambong* found in Ghana, can be found in Swaziland. These are equally unsuitable for fumigation purposes. However, in the 1930s and 40s, a few farmers started to use locally produced metal grain tanks constructed from corrugated steel sheets (Walker, 1976). Their popularity dramatically increased from the mid 1950s. The design is similar to the conventional water tank from which it may have originally been developed. These stores hold far greater possibilities with regard to their suitability for fumigating with phosphine.

Capacities of typical grain tanks range from 0.8 to 1 tonne, although tanks capable of holding 9 to 10 tonnes can be found. The sides of the tanks are constructed from 24 gauge (0.56 mm) galvanised corrugated sheets (thinner roofing sheets are available on the market but these do not bend evenly and are not strong enough to support the grain). Sheets are curved using a special set of corrugated rolls in the workshop. Tanks are either two, three, four or five sheets high. Flat galvanised steel sheets are used for the top, bottom and ancillary components (rims, lids, outlet tubes etc).

All joints are secured using steel rivets; one at each high and low point in the corrugations. Rivets are staggered to improve strength; the rivets in the hollows are approximately 25 mm behind those on the ridges. The edges of the sheets are cleaned using soldering spirits and then covered with solder to ensure a gas tight seal. Vertical joints are staggered to maximise tank strength. Joints between the top and sides, and bottom and sides are formed by folding the top or bottom over the edges of the sides and soldering in place.

An opening is provided in the top for filling and an outlet tube is inserted into the bottom of the wall on the opposite side of the tank to the inlet. Both can be secured with metal covers, and padlocked if necessary.

Experimental Investigetions

No matter how well the fumigators are trained, if the structure cannot be sealed then the fumigation will fail. Traditionally designed structures, in which plant materials such as poles, woven sorghum stalks and grass are used, are obviously totally unsuitable for fumigating with phosphine gas. Examination of metal grain tanks indicated that the structure offered an extremely high *potential* level of gas tightness. The solid construction of the walls of mud silos also suggested that these *may* be sufficiently gas-tight.

Two separate series of experiments were conducted to assess the fumigability of mud silos and metal grain tanks. The criteria for a successful fumigation varied slightly between the trials. In Ghana, where ambient temperatures were in the order of 30℃, a minimum exposure period of 5 days was required. In Swaziland however, where ambient temperatures fell as low as 15℃, the exposure period was extended to 7 days. Irrespective of the exposure period, the minimum gas concentration required at the end of the exposure period was 150 ppm.

Fumigation of mud-built silos in Ghana

Twelve mud silos were constructed at the Savannah Agricultural Research Institute (SARI), Nyankpala near Tamale in the northern Region of Ghana. The silos were constructed from a mud/grass mixture, with volumes of 0.4 to 0.5 m^3. Thick rendering (150 mm thick) was applied to the inner and outer surfaces of eight of these silos (Table 1).

Table 1. Details of the 12 silos built at SARI.

Treatment No.	Surface Treatment (inside and outside)	No. of silos
1	None	4
2	Bitumen/soil rendering	4
3	Cement rendering	4

The fumigation trials were performed between October and December, 1995. Since rapid gas loss was expected, the silos were fumigated using rates of 8 to 12g/m^3, far in excess of the 3 to 4g/m^3 normally recommended (it was planned that these rates would be reduced once a successful design had been identified.) Two nylon gas sampling lines were placed in each silo, passing out of the opening at the top. The top of the silo was sealed using a sheet of thick polythene (50μm), the edges of which were sealed to the outside of the silo using floor-tile adhesive (preliminary trials indicated that this was an extremely effective means of sealing the top of the silo). Phosphine gas concentrations within each silo were recorded daily using an Electro-chemical phosphine meter (Bedfont EC80 phosphine meter).

Initial fumigation trials and the effects of increased thickness of rendering

Despite extremely high application rates, gas concentrations had fallen below 150 ppm within two days of application (Table 2) – all fumigations were deemed to have failed.

Table 2. Gas concentrations during the initial silo fumigation.

Silo No.	Phosphine gas concentration (PPM) after 23 hours	46 hours
Treatment 1 No rendering		
14	372	3
21	325	3
23	298	3
35	387	5
Treatment 2 Bitumen/soil rendering		
15	1533	65
22	902	22
24	1434	51
32	1034	36
Treatment 3 Cement rendering		
12	1422	72
25	1603	127
31	1319	85
33	973	40

Effects of painting the surfaces of the silos

To improve gas-tightness, the inner and outer surfaces of the rendered silos were painted with two coats of an oil-based, gloss paint (having previously repaired any cracks that may have appeared) The unrendered silos were not refumigated Gas concentrations are listed in Table 3.

Table 3. Gas concentrations during the fumigation of the eight painted silos.

Silo No.	Phosphine gas concentration (PPM) after 117 hours	163 hours
Treatment 2 Bitumen/soil rendering		
15	1351	225
22	143	86
24	114	57
32	39	24
Treatment 3 Cement rendering		
12	520	544
25	1193	572
31	1276	513
33	1625	719

Although three of the fumigations still failed (in that their concentrations had fallen below 150 ppm by the 5th day), painting the walls of the silos was shown to produce a significant improvement in the gas tightness of the silos.

To reduce the variability between silos, it was decided to allow time for the rendering to cure fully and therefore reduce the degree of cracking before re-fumigating the silos. The plastic covers were removed from the eight silos, all cracks were repaired with filler and then the repaired areas were repainted. The silos were left for four weeks at which stage all new cracks were also repaired and repainted. The silos were then refumigated as before. The results are listed in Table 4.

Table 4. Gas concentrations at the end of the second fumigation of the eight painted silos

Silo No.	Phosphine gas concentration (PPM) after 117 hours
Treatment 2 Bitumen/soil rendering	
15	1954
22	739
24	590
32	774
Treatment 3 Cement rendering	
12	906
25	1479
31	1126
33	1552

Having allowed sufficient time for the degree of cracking to reduce, all eight of the silos were successfully fumigated over a five-day period. The cement rendered silos still appeared to be better than those with soil/bitumen rendering, although the difference was less significant by the fifth day.

Covering of the silos with gas-proof sheeting

As an alternative to painting the rendered silos, four of the unrendered silos were covered in a gas-proof sheet. The lower edges of the sheet were buried in a shallow trench dug around the outside of the silo in question. Dosage rates were increased to match the total volume enclosed under the sheet. The four unrendered silos were fumigated at the same time, acting as a control Gas concentrations were recorded as before (Table 5)

Despite high gas concentrations being recorded after one day, rapid gas loss occurred in three of the four covered silos by the second day, with the fourth failing soon afterwards. Given the high quality of the sheets used to cover the silos, the only explanation for this loss is absorption of the gas by the ground on which the silos were built. Examination of the soil indicated that its structure was extremely loose and so gas loss in this manner was not surprising. However, the extent of this gas loss was surprising, especially given the extremely high application rate.

Table 5. Gas concentrations during the fumigation of the eight silos in which four were totally enclosed in plastic sheeting.

Silo No.	Phosphine gas concentration (PPM) after		
	21 hours	45 hours	69 hours
Treatment 1 Silos sealed as before			
11	365	0	0
13	575	0	0
21	415	0	0
23	825	6	0
Treatment 2 Silos totally enclosed with plastic sheeting			
14	1550	70	2
26	>2000	115	20
34	>2000	230	55
35	>2000	145	25

Fumigation of metal grain tanks in Swaziland

Nine new grain tanks, each approximately 1.25 m high and 1.15 m diameter, were purchased and installed under a shelter (to prevent excessive temperatures being developed within the tanks) at the Government silos at Matsapha. To produce a level surface and to raise the tanks off the ground, they were positioned on a number of concrete blocks. A short access pipe was installed in each of their top surfaces to facilitate the introduction of gas sample lines. The tanks were filled with approximately 0.9 tonnes of maize to within 25m of the top of the tank. The tanks were fumigated following locally recommended dosage rates, namely, 3 grams per tonne of grain, the tablets being placed on a sheet of paper on the top surface of the grain. The tank, along with the tablets and method of sealing is illustrated in Figure 1.

Fumigation using currently recommended and improved sealing techniques

Ministry recommendations state that the inlets and outlets to the tanks should be sealed with plastic sheeting, typically old fertiliser bags. Three tablets were placed on the top surface of the grain and the silos sealed in the recommended manner. Gas concentrations were recorded over the following five days (Table 6). The tanks were then aerated and then resealed using plastic tape to seal the edges of the polythene sheeting placed over the inlets and outlets (Figure 1). Gas concentrations were recorded (Table 7).

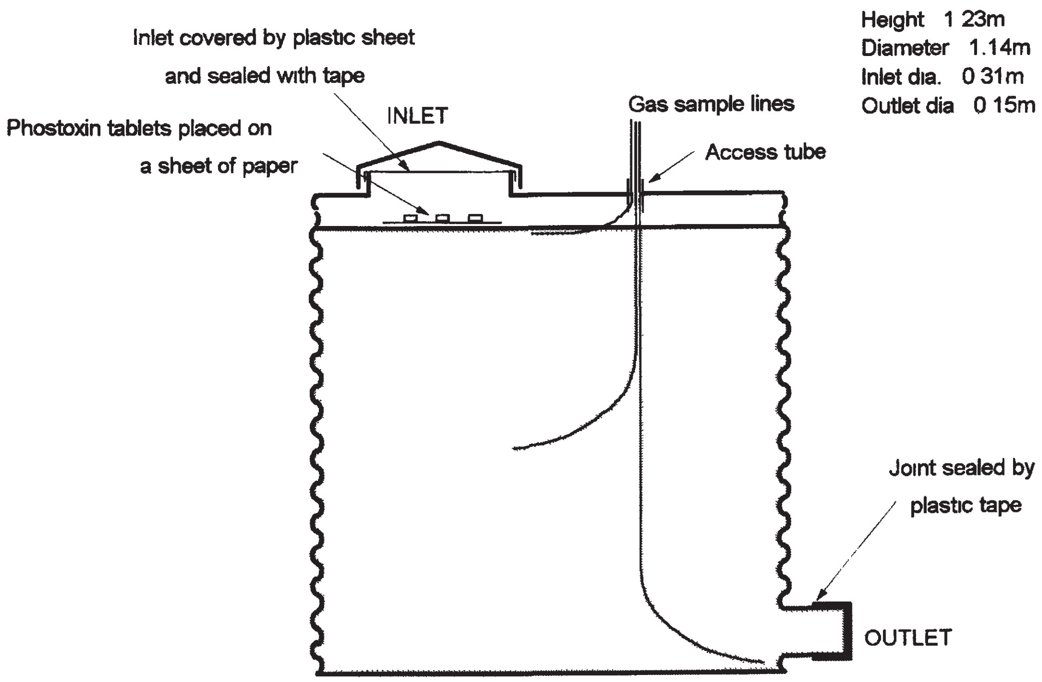

Fig. 1 Tank with tablets, gas sample lines and inlet/outlet sealing.

During the trial, when the high degree of gas tightness achievable by proper sealing became apparent, it was decided to leave three of the tanks sealed for as long as possible Table 8.

Table 6. Gas concentrations recorded in the metal grain tanks using recommended methods of sealing.

Tank No.	Phosphine gas concentration (PPM) after		
	19 hours	118 hours	166 hours
1	917	1664	901
2	707	455	107
3	717	805	253
4	896	829	281
5	498	252	33
6	728	622	153
7	480	411	112
8	790	941	430
9	1031	1382	761

The rate of deterioration in phosphine gas concentrations, when sealed following recommended procedures, varied considerably between tanks (Table 6). The fumigations in four of the tanks fell below 150 ppm before the completion of the seven day exposure period and so were deemed to have failed. Since no obvious faults in the construction of the tanks were apparent, the failure of some of the tanks was assumed to be due to the method of inlet/outlet sealing.

Sealing of the tanks using plastic tape and polythene sheeting significantly improved their gas tightness (Table 7). Whilst all nine tanks were successfully fumigated, the gas concentrations in tanks 7 and 8 were found to fall more rapidly. Examination of the sealing at the end of the trial indicated that, although the metal inlet covers had been carefully closed after sealing, the plastic had been damaged slightly due to the rough edges of the cover.

Table 7. Gas concentrations recorded in the metal grain tanks using Improved methods of sealing.

Tank No.	Phosphine gas concentration (PPM) after		
	26 hours	121 hours	168 hours
1	1987	>2000	1879
2	1994	>2000	1902
3	1996	1925	1527
4	1964	1805	1464
5	>2000	>2000	1868
6	>2000	1876	1505
7	1956	1462	1129
8	>2000	1248	853
9	>2000	1892	1401

Table 8. Gas concentrations recorded in three metal grain tanks using improved methods of sealing, over an extended exposure period

Tank No	Phosphine gas concentration (PPM) after		
	8 days	16 days	27 days
1	1557	769	253
2	1550	864	335
5	1581	734	208

The extremely high gas concentrations maintained in tanks 1, 2 and 5 for over 28 days clearly indicated the high levels of gas tightness capable of being achieved with this type of structure. Rates of fall in gas concentration equated to approximately 50 to 60 ppm per day by the end of the trial.

Discussions

The extremely poor gas tightness of the mud silos in northern Ghana, even when the silos are apparently in good condition and well sealed (far in excess of that likely to be found in the field), is a very worrying finding. The fact that many farmers are actively using phosphine in such structures, and that these fumigations will not be successful, raises very real concerns over the development of insect resistance to phosphine. Concerns over the safety of the farmer and those in the vicinity are also of great importance. Whilst the dangers of carrying individual un-sealed tablets from the supplier to the farmstead, along with the lack of knowledge as to how phosphine works (i e. that it is the gas and not the powder that has the insecticidal properties) have already been expressed, the rapid gas loss from the structure during the fumigation process poses serious health risks

Whilst the metal grain tanks as used in Swaziland were expected to retain the gas very effectively, the *degree* of gas tightness possible was not expected. Given that the tanks were new and better sealed than normally achieved in the field, the degree of gas tightness achievable by the farmer is likely to be considerably less. However, the fact that they are much more suited for on-farm fumigations was clearly demonstrated.

If fumigations are to be advocated as a suitable means of pest control in farm stores (which, given the dangers associated with such a system, is very questionable), then one possibility would be the introduction of metal grain tanks However, there would be at least two concerns. Firstly, and most importantly, would be the cost of such a structure. Whilst farmers in Swaziland may not be termed wealthy, they are, generally, able to afford the relatively high cost of such structures It is extremely unlikely however, that many of the farmers in northern Ghana would be able to afford such stores (Although no data is available on this, this would seem to be the case from personal observations whilst working with the farmers.) Secondly, because of the high degree of sealing possible with the metal grain tank, it is essential that the grain is dried sufficiently before being placed in such structures Severe moulding of the grain will occur if this is not achieved.

An important consideration when improving the efficiency of fumigations is the safety issue during the aeration of the tank at the end of the fumigation. Since little gas loss occurs during the fumigation, there will be extremely high levels of phosphine remaining in the tank and therefore large quantities of gas will be released during aeration.

Conclusions

Traditional, and modified traditional, grain stores are unsuitable for fumigation. Although the presence of cement rendering, both on the inside and outside of the walls, improved gas retention, it was only when the walls were painted with an oil-based paint that successful fumigations were achieved.

Metal grain tanks provide high levels of gas tightness, provided sufficient care is taken in sealing the grain inlets and outlets. Users need to be aware of the criteria for the construction and use of a suitable tank.

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