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THE DEVELOPMENT OF SIROFLO® IN AUSTRALIA

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ABSTRACT

SIROFLO®, a CSIRO proprietary technique, for which patents are pending in many countries, was first introduced on a commercial scale into the Australian grain handling system in 1989. Currently, it is being used extensively in New South Wales and in South Australia and to a lesser extent in the other Australian States. SIROFLO® has provided a means whereby a "nil tolerance" for insects can be met at a time when many markets are also demanding low or nil grain protectant residues.

SIROFLO® has been shown to be particularly effective in a range of vertical silos including silos that are less than gastight. It is a fully controllable system enabling optimization of the concentration of phosphine, the exposure time, and the distribution throughout the grain mass. This flexibility has provided operational advantages to grain managers and has enabled compliance with stringent standards of grain quality. Trials, in a range of vertical silos, have demonstrated the efficacy of SIROFLO® and have shown that it produces safer workspace atmospheres than other phosphine fumigation methods and that emission levels are also significantly lower than other methods and generally below all known emission standards. Moreover, grain treated with this method easily satisfies residue requirements, is more cost effective than traditional phosphine application methods, and renders significant savings when compared with current grain protectant costs.

INTRODUCTION

SIROFLO®, a pressurised distribution system for fumigating grain with phosphine, was first implemented on a commercial scale in Australia in 1988 following a series of trials in different vertical silos that began in 1985. In its first year of commercial use, approximately 100,000 tonnes were fumigated with the technique. Estimates for the coming harvest indicate that the quantity of grain treated with SIROFLO® will be in excess of 2 million tonnes in an increasing number of storages that have this system installed. The rate of implementation in New South Wales that is shown in Fig.1.was high despite a series of crop failures over recent years. The rate of adoption in South Australia has been even more dramatic over the past 2 years, with permanent SIROFLO® facilities being installed in each of their 7 seaboard terminals and scheduled to be doubled within the next 12 months along with increased facilities in the country.

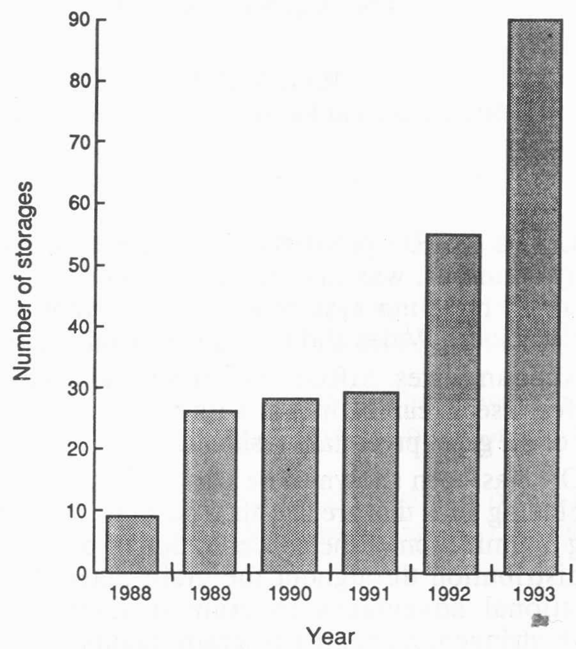

Fig. 1: Increase in number of storages equipped with SIROFLO® in New South Wales.

The total number of SIROFLO® storages cannot be specified exactly because as well as fixed installations, many fumigations are being conducted with portable equipment. In vertical storages, SIROFLO® has rapidly become the major disinfestation and grain "protection" method used in Australia. The reasons for this include:

- It may be applied in structures that are not gastight.
- It is a method that satisfies market requirements for residue-free grain.
- It offers significant advantages in terms of worker safety and is more environmentally acceptable than other fumigation methods.
- It is a method that offers maximum flexibility in terms of its operation.

- It will control a wide range of species and strains including those resistant to phosphine.
- It brings about significant cost savings when compared with other methods such as admixture of grain protectants or admixture of tablets or pellets of aluminium phosphide.

DESCRIPTION OF METHOD

SIROFLO® is a pressurised distribution system for fumigating grain with phosphine (Fig. 2) for which patents are pending. Its principal advantage is that it enables the fumigation of silos that are less than gastight and the achievements of levels of kill to be obtained that will satisfy all market requirements including "nil" tolerance. Very simply, a continuous stream of phosphine, from a cylinder source or on-site generator, is metered into an air supply introduced to the bottom of a silo. The pressurised distribution system is designed to overcome the factors that give rise to gas loss in conventional fumigations or more particularly to prevent the ingress of outside air that would otherwise dilute the phosphine concentration or create pockets of low concentration in which insects will survive.

By contrast, phosphine from cylinders has been evaluated in Britain over the past few years by continuously adding fumigant during the exposure period but without a pressurised distribution system (Bell *et al.,* 1991). Although it is claimed that this approach is "equally successful" as SIROFLO®, the results of the trials reported show that this is clearly not so. The gas distribution patterns reported are poor and no doubt account for the survival of insects reported. This is despite the much higher application rates, with associated higher costs and greater risks to fumigation personnel and to the environment. Moreover, most of the grain treated in these trials would not satisfy a "nil tolerance" standard, whereas properly applied SIROFLO® treatments consistently meet this standard and have been doing so for the past four seasons.

Many of the vertical silos in Australia are old, many dating back to a period when the only requirement for the structure was that it be grain-tight. Consequently, many of the silos built during this period are open-topped. In recent years, these silos presented particular problems, and conventional fumigations, using admixture of aluminium phosphide tablets, were at best, only partially effective. With the introduction of grain protectants in 1964, the fumigation limitations of these structures were reduced particularly if the grain was shipped out before the protectant reached the end of its effective life. However, when the industry began to phase out grain protectants, there were some industry people that believed that many of these old silos would have to be abandoned. With the advent of SIROFLO®, this situation was turned

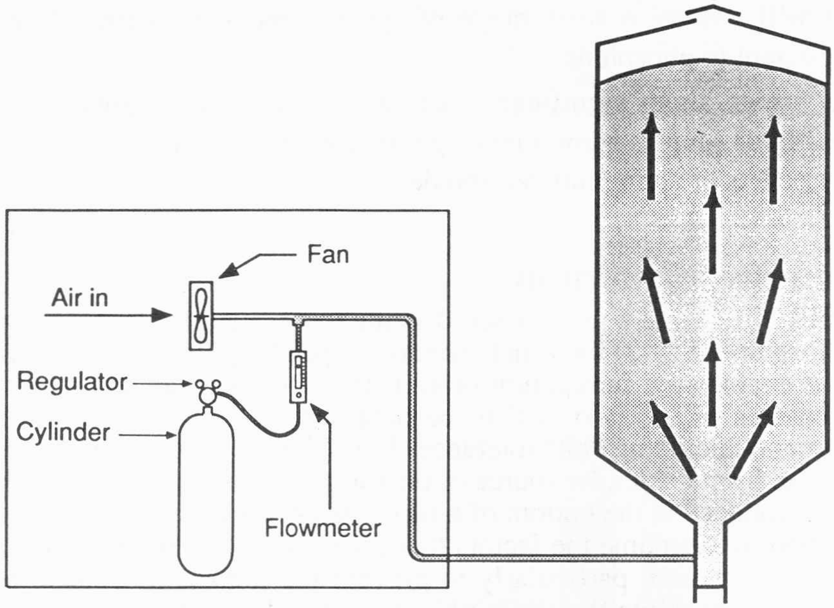

Fig. 2: Schematic diagram of the SIROFLO® system.

around and the old silos have been resurrected effectively. Indeed, there have been a number of occasions when infested grain in other storages has been transhipped through the SIROFLO® facilities in these "old" silos as a better method of fumigating the grain.

Following the early trials of SIROFLO®, it was believed that the preferred implementation would be based on portable facilities that would become part of a pest-control officer's mobile equipment. At that stage, it was believed that facilities would be used largely to cope with occasional fumigations. Very rapidly, however, the position changed and developments of SIROFLO® were aimed at implementing the technique in such a way as to provide the basis for long-term storage strategies, i.e., it was, and continues to be, developed, as an alternative to grain protectants. A program of permanent installations was launched. However, permanent installations not only increased the operational flexibility but also imposed a need to scale-up the engineering to cope with large installations in facilities that varied considerably from one another. For example, a fundamental requirement was that it would cope with the treatment of single bins or all bins in a facility, and any combination in between. This requirement largely ruled out portable units as they were designed at that stage and led to the development of permanent, manifolded systems. Manifolded systems have now been developed in a range of storage complexes starting from small 10-bin sites holding about

2,500 tonnes up to large silo complexes comprising 2,000 tonne bins with interspaces. In this context, over the past 12 months, large permanent facilities have been installed at all seaboard terminals in South Australia and represent the largest installations to date. The largest of these has a capacity of 46,500 tonnes which is soon to be doubled.

We are currently developing SIROFLO® for use in horizontal storages but so far the preferred use of the method is in vertical storages. The reason for this is largely due to the differences in the geometry of the two types of structures and how these differences influence the relative effect of gas loss processes in each structure. With horizontal storages, the major factor associated with gas loss is wind, whereas in vertical silos the dominant factor is the chimney effect. Moreover, the cost/benefit ratio currently favours vertical storages by a significant margin even though the implementation of SIROFLO® in existing horizontal storages is more cost-effective than alternative methods. It is expected that a significant number of horizontal storages in New South Wales will be fumigated with phosphine using SIROFLO® during the 1992/93 season and this number is likely to increase in future seasons.

The chimney effect in vertical storages is driven by the dynamics of the temperature gradients between the grain and the surrounding environment. When the grain is warmer than the surrounding atmosphere the air in the silo tends to rise while if the grain is cooler the reverse will occur. It is this force that is responsible for many failures (or partial failures) of phosphine fumigation in such structures. Were it not for the fact that the tolerance of the visible stages of adults and larvae is low, i.e., they are killed easily, as compared with the less visible stages of pupae and eggs, it is doubtful whether phosphine would have achieved the success that it did. Most fumigations in leaky structures, particularly vertical silos, have been associated with an illusion of success. The reason for this is quite simple: the chimney effect swept the gas out of the silo before it has had time to kill the more tolerant egg and pupal stages. It has been shown that exposure time is the more important variable of dosage with phosphine (Winks, 1984, 1986) and that exposures in excess of 7 days are required to kill all stages of the more tolerant species, such as *Sitophilus granarius,* at 25°C. In leaky vertical structures, with grain at temperatures generally greater than its surroundings, air enters through leaks in the bottom of the bin and rapidly sweeps fumigant away from these areas. In such areas, even with methods in which tablets or pellets are admixed with the grain, lethal concentrations are not achieved and insects will survive. Overall, fumigations last usually no more than 4-5 days, i.e., the concentrations fall to zero, irrespective of the application rate (Winks, 1986).

In developing SIROFLO® in vertical silos, considerable effort has been directed towards an understanding of the chimney effect and implementing the technique in such a way as to enable us to overcome this force. We are now able to predict the magnitude of the chimney effect, characterise silos in terms of their level of suitability for fumigation, and optimise SIROFLO® parameters to cope with any prevailing conditions.

RESIDUES

Many of Australia's major markets for grain require residue-free grain or "Maximum Residue Limits" (MRLs) considerably lower than those set by Codex Alimentarius. Our own domestic market falls into this category. These market requirements have encumbered the use of grain protectants. Indeed, although there are still some markets that are happy to accept protectant-treated grain, the logistics associated with grain management, some with protectant and some without, have caused most handling authorities to move rapidly towards a protectant-free system.

Phosphine-treated grain satisfies market requirements for residue-free grain particularly when methods have been used that do not leave tablet residues in the commodity. Because of the 3-5% of unreacted aluminium phosphide left in tablet residue and increasing concerns over residues generally, efforts are being made to avoid fumigations based on admixture of tablets with the commodity. Clearly, with admixture of tablets at rates as low as 2 tablets per tonne, there is a likelihood of exceeding the MRL of 0.1 ppm in cereal grain.

SIROFLO® satisfies clearly the foregoing requirement. Moreover, as Banks (1993) has indicated, the levels of phosphine left in grain immediately following treatment appear to be independent of time when low concentrations are used, such as those used with SIROFLO®, i.e., there appears to be no accumulation with time. In addition, samples from wheat and barley treated for 56 days in a SIROFLO® storage and aired with natural ventilation for about 24 hr, contained no evidence of phosphine, i.e., the level of phosphine remaining in the grain was below the detection limit of 1 ppb.

WORKER SAFETY AND THE ENVIRONMENT

Over recent years, the Australian industry has been faced with an increasing demand to minimise hazards in work-space environments and has been faced with the need to ensure that risks to the external environment are minimised. This demand, of course, is voiced now in many parts of the world. These concerns have led to a detailed examination of work practices, including those pertaining to fumigation. In the context of the external environment we have seen the emergence of environmental protection agencies that have prescribed standards for emissions of fumigants to the atmosphere.

Although the hygienic standard for the work-space atmosphere has not changed and is still 0.3 ppm v/v PH_3 in many parts of the world, greater emphasis has been directed towards the monitoring of work-space atmospheres and ensuring that practices associated with fumigation do not bring pest-control staff or other silo staff into contact with levels above the "Threshold Tolerance Limit" (TLV). There is little doubt that practices in the past were inconsistent with this philosophy and various reports are available describing phosphine fumigation practices that exposed people to levels well in excess of 0.3 ppm and no doubt to levels in excess of the prescribed excursion limit of 1 ppm for brief periods (Garry *et al.,* 1989). Workspace atmosphere levels of phosphine during SIROFLO® treatments have been shown to be consistently low. In New South Wales, atmospheres on walkways over bins being treated with SIROFLO®, have been monitored with detector tubes, such as the Dräger 0.1/a tubes, during every fumigation since 1988, and on almost all occasions phosphine levels have been below the limit of detection.

In Australia, some attention is being directed towards the setting of maximum levels in the environment surrounding silos in conjunction with maximum emission levels. In this context, levels in the external environment have been set lower than the TLV to allow for possible exposures for 24 hr as distinct from the 8 hr work shift and to allow for the possible exposure of the very young and the elderly, as distinct from the normal healthy adult, that forms the basis of the TLV for work-space atmospheres. In Germany, the environmental level is set at 20 ppb with this rationale in mind, but also with the recognition that it is necessary to be able to monitor any standard set. Twenty ppb is twice the minimum level of detection for phosphine using a commonly available, easily used device, namely, the ultra-low range Dräger tube (0.01/a).

From a number of trials involving SIROFLO®, ground-level measurements of phosphine outside the silos, at distances ranging from 2-85 m, have been generally below the limit of detection that is approximately 10 ppb using conventional methods, i.e., using either ultra-low range Dräger tubes or gas chromatography with either a photoionisation detector or a flame photometric detector. The emission model SCREEN, produced by the United States Environmental Protection Agency, calculated maximum ground level concentrations that were below 1 ppb. These calculations were based on the maximum emission from a 7 x 1500 tonne vertical silo site with simple surrounding terrain, treated with the highest SIROFLO® application rate currently used in Australia, without any allowance being made for loss due to sorption, i.e., using the maximum emission rate possible for this method of application. Apart from the fact that these observations and calculations are low, it has been reported that the life of phosphine in the atmosphere is short and in bright sunny weather its half-life can be less than 5 hr (Frank and Rippen, 1987).

OPERATIONAL FLEXIBILITY

As the demand for residue-free grain has increased, the Australian Grain handling authorities have found that it is easier to have most grain untreated rather than to "juggle" the complex logistics associated with having multiple grades and multiple residue requirements. By having most grain without grain protectant, it is possible to virtually eliminate one dimension of the array. Since phosphine-treated grain satisfies the requirements for residue-free grain, there has been an increase in the use of this material and the development of strategies that enable the use of phosphine as the major component of an alternative grain protection system. The use of SIROFLO® features prominently in this strategy in Australia, and indications are that its usage will continue to increase.

SIROFLO® has a distinct advantage over methods that require admixture of either tablets or pellets quite apart from residue considerations. The fumigation can be carried out without the need to turn the grain. This has obvious benefits:

1. Cost of turning is avoided as is the labour of adding tablets where manual methods are still employed.
2. Plant cleaning after turning is avoided with obvious labour savings.
3. Insects that create the need to fumigate are not spread throughout the plant.
4. Plant facilities can be used for other purposes, a significant factor in large installations.

Initially, it was perceived that the long exposure periods required by SIROFLO® would create difficulties for handling operations, i.e., tying up grain that was required for shipment. However, providing that a little forward planning is done, these difficulties can be overcome.

The SIROFLO® system offers additional operational benefits in that it can be easily turned on and off, something that other methods of fumigation do not permit. Thus, if grain is required in a section of the plant that has a fumigation underway, the fumigation can be stopped to provide access to nearby bins and restarted once the grain from those bins has been transferred. In many situations, the phosphine concentrations in the workspace atmospheres are so low that stopping a SIROFLO® fumigation is not required and normal operations within the vicinity of fumigated bins can continue.

A further benefit of SIROFLO® is that adjustments can be made easily during a fumigation to cope with unforeseen deficiencies in the storage structure. For example, during one of the early trials with SIROFLO®, it was found that a longitudinal crack in a silo was allowing ingress of air that lowered the concentration up that side of the bin. By adjusting the SIROFLO® airflow the internal pressures in the bin were raised sufficiently to prevent ingress of air, thereby stabilizing the concentrations throughout the bin. The ability to compensate for deficiencies in a bin during a fumigation minimises disruptions to handling programs. With other methods, where unforeseen deficiencies occur, the fumigation would probably have to be repeated.

BIOLOGICAL FLEXIBILITY

Another major benefit of SIROFLO® is the ease with which dosage parameters may be varied. Thus, it is possible to tailor the concentrations and exposure times to suit operational and biological requirements. In Australia, for example, we currently recommend exposure periods of either 14 or 28 days. However, other exposure periods are easily derived, if necessary.

The implications of phosphine resistance, in the context of phosphine usage generally and SIROFLO® usage specifically, have been studied recently in considerable detail in Australia. This study formed part of a comprehensive revision of the guidelines for registration of phosphine-generating products that are comprised largely of recommendations for effective usage in a wide range of situations. In terms of resistance, the species that predominates is *Rhyzopertha dominica*. Currently, the levels of resistance in this species are not high, and the evidence indicates that where fumigations are carried out properly, complete control will be achieved. The most tolerant, phosphine-susceptible species in Australia is *S. granarius*, and dosage rates for grain are in fact based on controlling this species.

To support the application of SIROFLO® in the field, laboratory studies have established times to population extinction over a wide range of concentrations and for all of the major species, including *S. granarius*. Moreover, we have established minimum concentrations that will eliminate populations, where time is not a constraint, including resistant strains. Recommendations for SIROFLO® dosages are not based on the concept of an application rate (input level), rather they are based on the concept of the minimum concentration at any point in the treated commodity. With this approach, operators can make judgements about the "gastightness" of the silo and the likely sorption characteristics of the commodity. If necessary, they can adjust the operational parameters of SIROFLO® to meet the minimum requirement. Other methods of phosphine fumigation do avail the fumigator with this level of control, thereby increasing the probability of failure.

SIROFLO® offers an effective solution to phosphine resistance. It will prolong the life of phosphine as an effective control agent without excessive increases in cost and will do so in structures that would be unsuitable for alternative approaches using either carbon dioxide or low-oxygen. Dosage rates for phosphine-resistant strains have been established from a number of resistant field strains of *R. dominica* and a laboratory strain selected over a number of generations.

COST BENEFITS

In Australia, the handling authorities that have invested heavily in SIROFLO® have identified significant cost savings over other methods, particularly the use of grain protectants (Fig. 3). In this context, the difference between the cost of a SIROFLO® treatment and the application of grain protectants enables the repeated use of SIROFLO® if necessary. The common practice is to fumigate the grain soon after receival and then to treat it again about one month before it is due to be shipped out. On the basis of two treatments, significant savings are achievable and the costs of installation (Fig. 4) can be recovered within a relatively short time.

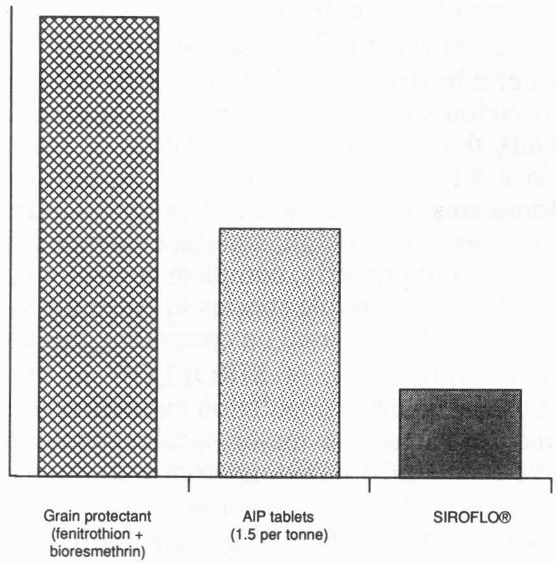

Fig. 3: Relative costs of SIROFLO® as compared with admixture of tablets at 1.5 tablets per tonne and the use of a grain protectant mixture based on fenitrothion and bioresmethrin.

SIROFLO® is also less costly to apply than methods based on admixture of tablets or pellets, since this usually involves turning the grain to treat it (Fig. 5). It is not normal practice for grain to be fumigated by admixture during receival since a "nil tolerance" is applied to all deliveries. If

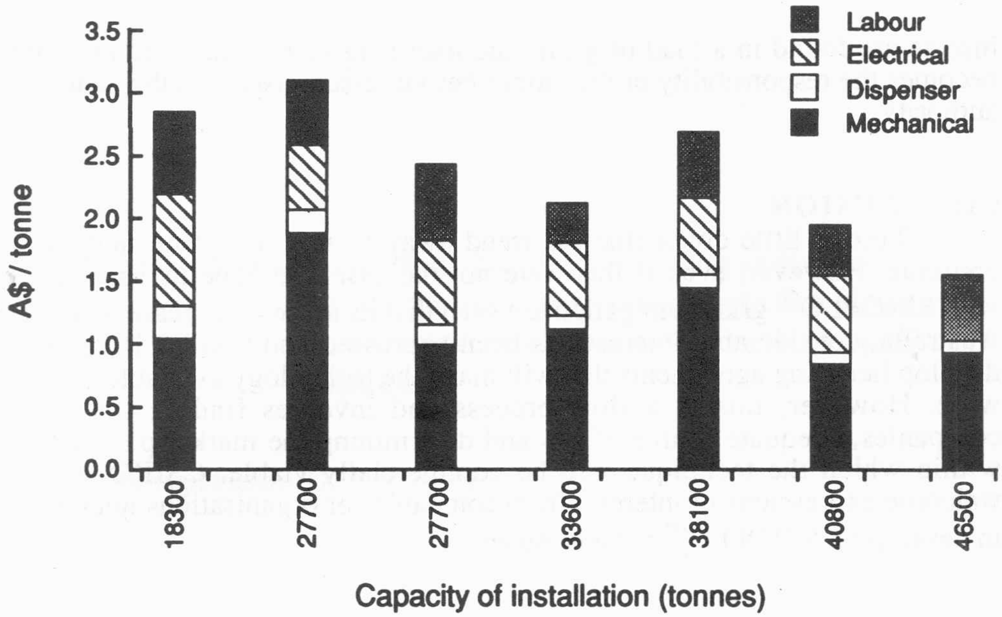

Fig. 4: Cost of installing SIROFLO® at a number of sites in Australia.

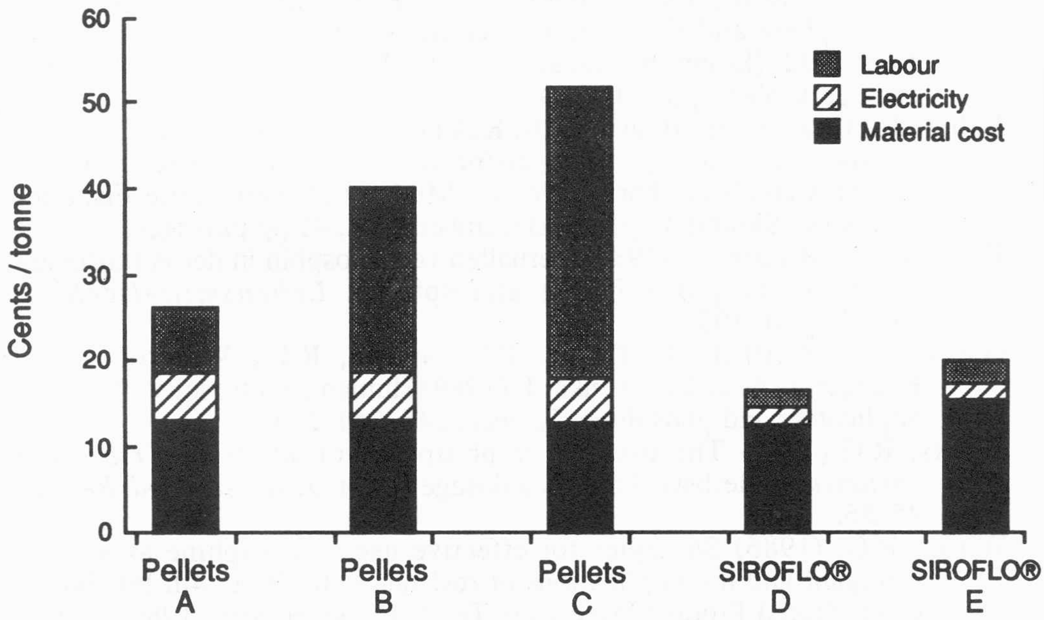

Fig. 5: Costs of SIROFLO® treatments as compared with treatments based on admixture of pellets to grain at a rate of 8 pellets per tonne: A, hopper-bottomed port silo; B, flat-bottomed port silo; C, flat-bottomed country silo; D, hopper-bottomed port silo; E, flat-bottomed country silo.

insects are found in a load of grain, the load is rejected and its fumigation becomes the responsibility of the farmer before re-submission to the handling authority.

CONCLUSION

There is little doubt that the trend away from grain protectants will continue. However, even if this were not the case, the benefits associated with SIROFLO® grain fumigation are such that its use will increase. Outside Australia, considerable interest has been expressed and CSIRO is keen to develop licensing agreements that will make the technology available world-wide. However, this is a slow process and involves finding the right companies, adequate source of gas and determining the market parameters within which the technique will be commercially viable. CSIRO would welcome expressions of interests from companies or organisations interested in developing SIROFLO® outside Australia.

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