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GRAIN STORAGE

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Start here for answers to your immediate grain storage issues

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Introduction

A.1 On-farm grain storage

On-farm grain storage is a significant component of many Australian cropping operations and growers who manage their storage facilities and operations well are being rewarded through preferred-supplier partnerships with key grain traders. Grain traders and buyers are increasingly pursuing growers who can maintain grain quality through best-practice storage management allowing savvy growers to become 'price makers' rather than 'price takers'.

On-farm storage systems are a significant investment to set up and manage. Any potential return on investment in on-farm storage should be compared to other investment options, such as buying more land or upgrading machinery, to determine the best use of capital. The interesting thing about on-farm storage is the return on investment varies for every grower depending on their scale, crops grown, access to bulk handlers and distance from domestic markets.

In the same way growers ensure they take a strategic approach to managing the production of their crops, a strategic approach to grain storage is also required for optimal end-product performance. It's no longer acceptable to empty grain into a silo at the back of the shed and forget about it for months on end. A strategic development plan for investment in grain storage provides greater opportunity to manage variable production years and crops whilst ensuring grain quality.

A key component to storing grain on farm successfully is having the knowledge of best-practice management to avoid costly quality issues and disasters. This manual aims to provide relevant information, links to other resources and contacts to enable a base understanding of how to manage on-farm storage successfully. Through an integrated pest management (IPM) approach and proactive attitude to quality control we can avoid adding to the increasing challenge and scale of phosphine-resistant pests. Ultimately our aim is to save growers and industry a significant amount of money by prolonging the life of the most cost-effective pest disinfectant available — phosphine.

Photo 1: *On-farm grain storage can be an enterprise in itself if managed well. (Source: Chris Warrick, Primary Business)*

Grain storage — planning and purchasing

VIDEOS

GCTV Mixed storage strategy

Grain storage systems come in a range of shapes and sizes to meet farm requirements and careful planning is needed to optimise an on-farm grain storage facility investment.

According to the option selected, on-farm grain storage systems can provide a short-term or long-term storage facility. Depending on the goal of on-farm storage, whether it be access to improved markets or simply to maximise harvest efficiency, there are a number of options available. Since dichlorvos is no longer available for on-farm grain treatment, reliance falls to fumigation or controlled atmospheres to treat pest infested grain making storage planning even more important.

Harvest is the ideal time to plan future grain storage system requirements, as it can help identify issues and opportunities for future harvest operations that may otherwise be forgotten once next year's crop cycle gets underway.

Photo 2: *Flat-bottom silos (photo top) and cone-base silos (photo bottom) remain the most popular on-farm grain storage options. (Source: Chris Warrick, Primary Business)*

1.1 Grain storage options

Costs and storage flexibility can vary between grain storage options as can longevity of the investment.

Table 1 identifies the major on-farm grain storage options, their advantages and disadvantages.

Silos are the most common method of storing grain in Australia, constituting 81 per cent of all on-farm grain storage facilities nationally (see Figure 1).

Silos come in a variety of configurations, including flat-bottom or cone base, and both are available as gas-tight sealable or non-sealed, aerated and non-aerated.

The balance of on-farm grain storage facilities can be split between grain storage bags (10 per cent) and bunkers or pits (9 per cent).

Grain-storage bags are increasing in popularity as a short-term storage solution to assist harvest logistics. With careful management growers can also use grain bags to provide short-term marketing opportunities.

For similar storage timeframes to grain storage bags, and where options are limited, growers can also temporarily store grain in sheds during harvest — provided they have been well prepared.

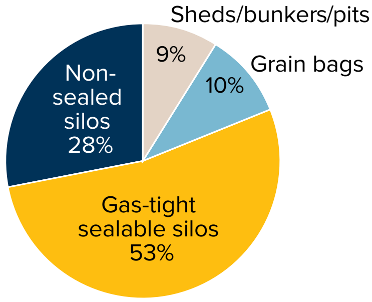

Figure 1: *On-farm grain storage*

Source: Kondinin Group NAS 2021

Table 1: Advantages and disadvantages of grain storage options

Storage type	Advantages	Disadvantages
Gas-tight sealable silo	• Gas-tight sealable status allows phosphine and controlled atmosphere options to control insects • Easily aerated with fans • Fabricated on-site or off-site and transported • Expected 30 year plus service life • Simple in-loading and out-loading • Easily administered hygiene (cone base particularly) • Can be used multiple times in-season	• Requires foundation to be constructed • Relatively high initial investment required • Seals must be regularly maintained • Access requires safety equipment and infrastructure • Requires an annual test to check gas-tight sealing
Non-sealed silo	• Can be cheaper than sealable silos	• Silo cannot be used for fumigation — see phosphine label • No insect control options, only prevention strategies such as protectants, hygiene, structural treatments and aeration cooling.

VIDEOS

Adding on-farm grain storage – considerations

VIDEOS

Storage options

Table 1 (Cont.): Advantages and disadvantages of grain storage options

Storage type	Advantages	Disadvantages
Grain storage bags	• Low initial cost • Can be laid on a prepared pad in the paddock • Provide harvest logistics support • Can provide segregation options • Are all ground operated • Can accommodate high-yielding seasons	• Requires purchase or lease of loader and unloader • Increased risk of damage beyond short-term storage • Limited insect control options, fumigation only possible under specific protocols • Requires regular inspection and maintenance which needs to be budgeted for • Must be fenced off • Prone to attack by mice, birds, foxes etc. • Limited wet weather access if stored in paddock • Need to dispose of bag after use • Single-use only
Grain storage sheds	• Can be used for dual purposes • 30 year plus service life • Low cost per stored tonne	• Aeration systems require specific design • Risk of contamination from dual purpose use • Typically cannot be used for fumigation (unless extensive sealing process is undertaken.) • Vermin control is difficult • Difficult to unload
Bunkers	• Low capital cost • Flexible size	• Requires tarp removal and replacement for loading and unloading • Difficult to unload • Typically unsuitable for fumigation unless setup to be sealable • Requires suitable location and groundworks to prevent water ingress

Source: Kondinin Group

1.1.1 Silos

Silos remain the dominant form of on-farm grain storage in either a flat-bottom or cone-base configuration. When compared with grain storage bags, sheds and storage bunkers, silos can be a significant investment, however they offer superior insect pest control via gas-tight fumigation and controlled atmospheres, flexibility in terms of size and construction, comparable longevity, along with the ability to install aeration cooling and drying to manage and maintain grain quality.

Fumigation

A gas-tight sealable silo will ensure phosphine, or other fumigants and controlled atmospheres, are maintained at a sufficient concentration to kill insects through their complete life cycle of eggs, larvae, pupae and adult.

Be aware of cunning marketing terminology such as ‘fumigatable silos’. Although such a silo might be capable of sealing with modifications, a gas-tight sealable silo needs to be tested onsite to meet Australian Standard (AS 2628–2010) after installation.

Gas-tight sealable silos also can be used for alternative methods of insect control including controlled atmospheres of inert gasses, such as carbon dioxide or nitrogen.

VIDEOS

Pressure relief valve maintenance

Size and construction

Silos can be transported fully constructed and ready to stand, or can be built onsite. Prefabricated, transportable silos are typically limited to 150 tonnes capacity due to road transport regulation limitations. Larger cone bottom silos are built on site.

Cone-bottom silos are easier to clean than flat-bottom silos due to their self-emptying design. Build on site cone-bottom silos typically range from 150–300t but can be up to 3000t and generally require a higher capital cost per tonne of storage capacity.

Flat bottom silos typically range from 800–4000t but can be up to 15,000t. The increased surface area of a larger silo requires more sheet metal joins and more load forces providing more challenges to seal to gas-tight standards.

The only way to ensure larger silos are gas-tight is to buy a reputable brand, designed and constructed to be gas-tight under Australian conditions.

Typically, increased construction quality comes at a higher price, but the longevity of the structure should pay for itself over time and provide the assurance of total insect control over extended storage periods allowing growers access to any market.

Capacity is commonly quoted in tonnes, in most cases referring to wheat. But check what wheat bulk density is being used as it does vary between manufacturers. Capacity can also be quoted as cubic metres (m^3), which can be useful when comparing quotes with different wheat bulk densities used in the calculation.

To determine tonnage capacity, multiply the cubic capacity by the volumetric density of the grain (see Table 2 for typical grain bulk densities).

Table 2: Typical grain bulk densities per cubic metre

Grain	Bulk density (t/m^3)*
Wheat	0.77
Canola	0.67
Barley	0.68
Triticale	0.68
Sorghum	0.73
Maize	0.72
Lupins	0.80
Mung beans	0.75
Sunflower seed	0.42
Cotton seed	0.40

*Note: Vary according to moisture content and variety.

Source: Kondinin Group

Photo 3: *The choice between flat or cone-bottom silos requires consideration of ease of empty, segregation, efficient size for loading and unloading and cost. (Source: Chris Warrick, Primary Business)*

Longevity

A well-built, aerated, quality gas-tight sealable silo constructed to meet the Australian standard (AS 2628–2010) with a thorough maintenance regime could be expected to provide at least 30 years of serviceable life before major repairs may be required.

Aeration cooling

Silos enable simple provisions for aeration after harvest to cool grain.

Aeration cooling of grain in storage creates uniform moisture conditions and slows or stops insect pest life cycles.

Depending on the temperature reductions achieved; this can deliver significantly-reduced insect numbers.

Photo 4: *Aeration cooling is relatively inexpensive and can offer substantial benefits. (Source: Ben White, Kondinin Group)*

For more information on aeration cooling, see Section 5 Aeration cooling.

Aeration drying

Specific drying silos are designed to maximise drying efficacy and have high air-flow rates of between 15–20 litres per second per tonne (l/s/t) of storage.

Specially-designed drying silos often have a truncated, or secondary, base cone to assist in the efficiency of drying stored grain.

Drying with ambient air requires a relative humidity below the equilibrium relative humidity of the grain. For regions where higher relative humidities are common, the addition of heat at the air intake will improve the moisture removal capacity of the air flowing through the grain, and requires higher air-flow rates over 20l/s/t.

For more information on aeration drying, see Section 7 Managing high-moisture grain.

VIDEOS

On-farm Grain Storage: Silo maintenance

Capital investment

As a permanent infrastructure fixture on a farm, silos require a high initial capital investment especially when foundation costs are included. When considering the cost of storage over the expected life of the silo however, silos are comparatively cost effective with other types of storage.

For more information on the economics of investing in silos, see Section 2 Economics of on-farm grain storage.

Safety

Working at heights can be dangerous without the appropriate safety precautions. In the case of silos, this can mean working up to 16m off the ground.

When grain is stored for longer than a month, regular inspection through the top hatch is required. Silo designs now incorporate ground-operated lids, caged ladders, platforms and top rails to minimise the risk of operators falling. Facilities for harness attachments, which should be worn by all operators climbing silos, are also fitted.

For more information on silo safety, see Section 3 Safety around grain storage.

Photo 5: *Caged and platformed access ladders improve safety when climbing the silo to inspect stored grain. (Source: Ben White, Kondinin Group)*

VIDEOS

Ladders required on silos

MORE INFORMATION

Kondinin Group: Grain Silos Research Report

VIDEOS

Pressure testing silos

GCTV2: Pressure Testing Sealed Silos

Stored Grain: Silos for fumigation

Silo buyers' checklist

- Aerated, gas-tight sealable silos should always be the preferred option.
- Ask the manufacturer to provide a guaranteed pressure test in accordance with AS2628-2010 on-site after construction or delivery. Pressure testing a storage when full of grain is also important.
- Ensure a pressure relief valve is fitted, capable of handling the maximum air-flow in and out of the silo due to ambient temperature variations.
- A tyre valve or a larger fitting may also be installed to apply air from an air compressor or leaf blower to perform a pressure test.
- Seal mechanisms on inlets and outlets should be simple to operate and provide even seal pressure.
- Seal rubbers should be quality high-density EPDM (ethylene-propylene-diene-monomer) rubber, maintain a strong memory and be UV resistant.
- Look for ground-operated lids that provide an even seal on the silo inlet. High-quality ground-opening lids will provide a gas-tight seal, but some will still require a climb to the top of the silo to lock down the lid for fumigation.
- For silos lager than 150t capacity a sealed, powered recirculation system aids phosphine distribution through the grain. Ensure plumbing is UV stable and sturdy construction not to compromise the sealablitiy of the silo in time.
- Aeration cooling fans with an automatic controller provide significant benefits for stored grain. Buy these with the silo or as an aftermarket accessory and specify airflow rates of at least 2–4l/s for every tonne of grain storage capacity of the silo.
- Aeration drying silos are an option and are specifically designed to maximise drying efficiency. Drying fans need to deliver between 15 and 20l/s for every tonne of grain storage capacity of the silo and additional sealable venting in the roof should be fitted.
- Outlet access for unloading should be simple to operate and permit ample auger access.
- Look for a sturdy base and frame on elevated cone base silos with quality weldments. Galvanised tubing has a heavier coating than galvanised rolled hollow section (RHS) but is more difficult to shape and weld joins.
- Ensure wall sections incorporate a positive seal between sheets and sealed riveting where rivets are exposed.
- Always consider access and safety features, including roof rails, ladder lockouts, platforms and ladder cages. It can be argued that a ladder should always be fitted, as inspection of the grain in the top of the silo should be carried out regularly.
- A quality outside finish will provide a superior life. White paint reduces heating of grain in storage. It comes at a cost premium but is superior to zincalume finishes over time.
- A chalk-board patch painted on the silo base can be useful for recording grain and treatment details.
- Check silo design inside and outside for ease of cleaning. Check walls and aeration ducting including the floor for grain trap points.
- Consider grain segregation requirements when determining silo size. Smaller silos allow better segregation but require more frequent auger moves. A variation of sizes often works well.
- Ensure adequate venting is fitted to the roof of silos with aeration fans to permit adequate air-flow without restriction. These vents should be easy to clean and near the roof access ladder to enable maintenance. Check seals and lock down if it is a sealable silo.

1.1.2 Grain storage bags

Since their introduction to Australian in the early 2000's, many lessons have been learnt to improve the longevity of bag storage. They can be used as short-term storage in the paddock or medium term storage if regularly maintained at well prepared, centralised sites.

Capacity

Typical storage capacity is around 240t, but other sizes including up to 500t bags are also available.

Take care when buying bags. Quality of bag materials varies and using bags for grain storage that have been designed for silage storage is not recommended as they are likely to fail.

Using grain storage bags successfully

Successful use of grain bags as an on-farm grain storage option requires a carefully-prepared site. An elevated, compacted, well-drained pad provides optimal results where no stubble (which can harbour vermin) or rocks can tear the grain storage bags as they are being filled and unloaded. Combining bags to centralized, purpose built sites has many advantages in managing, maintaining and outload, therefore extending the likely storage period before issues arise.

Fill rates can be as quick as 10–12 tonnes per minute. Always fill bags on firm compacted ground and ensure brake settings on the filler are set to ensure the appropriate stretch of the bag is achieved. While typically a 10 per cent stretch, this can be adjusted down for hot weather conditions or up for cool ambient weather. Check filled bags regularly and vigilantly for cuts, nicks and holes and patch these with silicon or bag adhesive tape available from the bag supplier.

Capital investment

The two pieces of equipment required for loading and unloading grain storage bags cost around $50,000–80,000 each.

This equipment can be hired, although owning it can reduce the pressure of having to get grain in and out of the bags within a specified timeframe as demand for this hire equipment is high at the peak of harvest.

The bags themselves are single-use and cost around $5–$6 per tonne stored.

Consider site-preparation, including any earthworks and fencing requirements, time and labour costs for maintenance when calculating the comparative costs of using grain bags.

Longevity

While longer-term storage is possible in bags if well managed, they are best suited to short-term storage of a few months. Beyond this, the risk of grain losses and spoilage increases significantly.

VIDEOS

GCTV: Grain bags – Fumigation

GCTV: Grain bags — A grower's perspective

GCTV: Grain bags — Best practice

Pest and insect control in grain bags

Fumigation in bags has been proven in Australia as an option if the correct method of application and venting is followed. Success relies on the bag not being compromised with holes. Phosphine meters are required to monitor gas concentration during the fumigation and venting periods.

Trials indicate phosphine placement must be no more than seven metres apart along the bag, inserted in such a way that the bag can be resealed during fumigation and removed so grain is not contaminated with residue. One metre lengths of PVC pipe with with a series of 1mm slots cut along the top and inserted horizontally has been proven to evenly distribute gas over a 10 day period.

Venting methods trialed have included propping open the finish end of the bag and inserting the suction side of a fan into the start end of the bag to draw the gas out. A passive ventilation option is to use 50mm slotted PVC pipe inserted every 7m along the bag on alternate sides, with the ends of the pipe left open after the phosphine is removed.

If 0.3 parts per million phosphine is the required clearance level, expect the fan method to take two or more days, and the passive method to take at least 35 days to vent.

Paying a commercial fumigator to use Sulfuryl Fluoride is another option for fumigating grain bags. Allow at least 20 days for complete life-cycle control and passive venting.

In addition to insects, vermin including mice and birds can attack grain bags. Outside baiting, reducing habitat provision and food sources (including regular checking and patching of bags where required) is the best way to reduce vermin risk.

Access

One often-overlooked aspect of using grain-storage bags in the paddock is their accessibility after harvest. Unless the bags are placed on, or near, an all-weather access road, they can be difficult to unload if wet weather conditions prevail post-harvest. The pad site needs to be large enough for trucks and machinery for bag unloading and allow access in wet conditions.

1.1.3 Sheds and bunkers

Photo 6: *Grain storage sheds can provide dual functionality but hygiene is imperative to avoid contamination. (Source: Source: Chris Warrick, Primary Business)*

Bunkers are commonly used by bulk handling companies, but require careful site preparation, labour for handling large tarp covers and machinery to move grain on and off the grain stack. An elevated site is required that can be graded to a camber shape to run water away. Bunker walls can vary from none to half-meter pile of soil to purpose built concrete with clamps to hold tarps down.

It is difficult to treat insect infestations in sheds and bunkers effectively.

VIDEOS

Bunker Storage Setup

MORE INFORMATION

Ground Level Grain Storage (Kondinin Group Research Report 2024)

Sheds and bunkers can provide dual-purpose functionality for storage of other products including fertiliser and machinery, but the risk of grain contamination requires a focus on impeccable hygiene practices.

Specialist grain-storage sheds can be constructed to make filling and unloading simpler. Consider aeration and sealing methods for fumigations early in the design phase.

Sheds and bunkers are most useful as a short-term storage solution to assist harvest logistics. They can be a useful component of an on-farm grain storage system that incorporates other gas-tight sealable grain storage facilities.

Capital investment

The cost of grain storage in sheds varies widely depending on footing and slab requirements as determined by soil type. Bunkers are arguably one of the lowest capital cost storage options but will require more labour and equipment for outloading. Method of construction and alternative uses can also vary the cost of construction.

Aeration cooling

Aerating grain stored in a shed is difficult due to the variation in grain depth. Specialised suppliers can setup aeration systems for sheds, which usually involve ducting in sections that can be removed as the shed is emptied to allow loader access.

Pest and insect control

Given the open nature of most sheds on-farm, pest and insect control presents some challenges. Fumigation with gas-proof sheeting placed over the stack is difficult to seal. Bulk handlers, including CBH in Western Australia, have invested heavily in sealing gas-tight bulk storage sheds to permit fumigation. Protectants are available in the eastern states of Australia (and some in Western Australia) to assist pest prevention in cereal grains but buyers should be consulted before applying any products to grain. Mice, birds and other vermin can also be challenge to control around sheds and bunkers.

Photo 7: *The success of a bunker relies on careful site selection and preparation, quality tarps and equipment for managing tarps and outloading. (Source: GRDC)*

Loading and unloading

One of the biggest drawbacks of sheds used for grain storage is the difficulty getting grain in and out. Using an auger or belt conveyor to fill the shed from the truck is common practice.

For out-loading, some operators opt for bulk-handling buckets on front-end-loaders or telehandlers to fill direct into trucks or large hoppers mounted over an auger or conveyor. Some grain trade operators use this approach to minimise grain damage when handling grains prone to splitting, such as legumes.

Grain vacuums can also be used to out-load grain from sheds. Regardless of the out-loading options, inevitably, a final clean is performed with a broom and grain shovel, which can take time if hygiene is to be maintained.

1.1.4 Underground pits

Photo 8: *Grain storage pits are usually covered with a tarp, held down by a layer of soil. A narrow pit enables a telehandler to be used for adding and removing the soil, without driving too close to the edge. (Source: Mark Mortimer)*

Underground pits can be an effective, low-cost method of storing grain for the long-term. Pit storages are most commonly used on farm for storing drought feed reserves. Feed grain has been recovered in good condition after more than 10 years.

The main drawback of underground storage is the difficulty of removing grain.

Size and construction

Careful preparation is essential for underground storage to be successful.

Locate the pit on a well-drained site above the water table, with the immediate surrounds graded to prevent rainfall run-off collecting in the pit area. If constructing multiple pits, leave at least 10 metres between pits to prevent seepage from an empty pit into a full pit.

Keep each storage pit no more than three metres wide to allow the covering soil to be placed and removed by a telehandler without having to drive close to the edge of the pit. The depth will be determined by the unloading facilities.

Match pit capacity to available silo and truck capacity so the pit can be completely emptied after it is opened.

A pit may be unlined if the floor and walls can be made firm and clean. Plastic lining is often used and should be laid at the starting end just before loading starts.

The lining can be unrolled as filling progresses. Fill the pit until the grain forms a slight ridge along the centre.

Loading

Grain moisture content must be less than 12% to reduce the risk of spoilage.

Filling can be done either by driving into the pit, or using an auger from the side. Avoid driving too close to the edges of the pit — keep heavy machinery, such as trucks and tractors, away from the pit edge by a distance at least equal to the depth of the pit.

After filling a pit, cover the grain with plastic sheeting and soil. A layer of soil about 0.5 metres thick will provide adequate protection from weather and pests. An initial layer of sand will prevent rocks or hard clods from damaging the top cover. Shape the soil to facilitate run-off. Mark the location of the pit with a peg at each corner.

MORE INFORMATION

DAF QLD note Grain Storage — Underground pit storage of grain

DPIRD Farmnote Stored grain management: Underground storage of grain

Pest and insect control in bunkers

A well-constructed pit storage is air-tight and oxygen levels gradually reduce over time. The low oxygen levels prevent development of damaging numbers of grain insects. If in doubt about the gas-tightness of the pit, grain protectants can be applied to cereal grain when it is placed in storage to prevent insect pests at least for the first few months of storage.

Unloading

To unload the pit, it is necessary to be able to remove all the covering soil without contaminating the grain. This can be difficult and is the reason for using narrow pits.

Always unload the entire contents once the pit is open, otherwise losses due to drainage problems are likely.

Grain vacuum machines are ideal for emptying pit storages, and allow much easier final clean-up of grain than other methods. Mobile augers or belt conveyors with fixed and guarded cross-sweeps, or a front-end loader can be used to empty the pit.

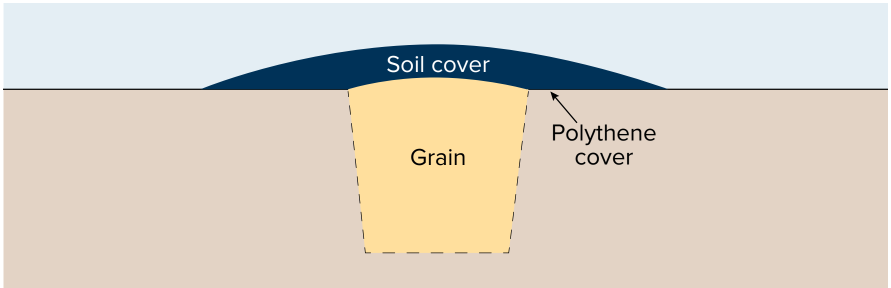

Figure 2: *Cross section of underground grain storage pit*
Source DPIRD

1.2 Grain storage considerations

When investing in and planning a grain-storage facility there is a range of factors to consider, regardless of the storage type.

1.2.1 Access for in-loading and out-loading

Continuous loop roads around the grain-storage facility requiring minimal, or no, reversing are ideal and can dramatically improve loading and out-loading rates while minimising damage to equipment through accidental collision.

Dedicate an ample-sized pad to permit auger or grain conveyor access and ease of shifting grain loads.

Where steeper slopes exist, some growers have terraced the slope with a retaining wall, to allow them to reduce the lift height (and auger size) for loading the silo.

Where retaining walls exceed 1m in height, consider guard rails and access steps.

1.2.2 Proximity to resources (power sources — electricity and fuel)

Whether the facility is to be powered for aeration, i.e. using diesel or electricity, consider the proximity to these resources, particularly if the facility will be built in stages as each stage becomes affordable.

Connection to mains power can be expensive depending on the distance to the line. Some large fans also require three-phase power which requires a specific pole transformer.

With augers, machinery and tipping trucks in use around the facility, placing power underground is expensive, but can significantly improve safety.

It is worth considering fuel sources and fuel lines for dryer installations, or future dryer installations, when planning the facility layout and constructing the pad.

1.2.3 Health and safety considerations

Operational safety considerations should be key to the facility design. Allow plenty of space for auger transport and movement around the facility.

Ensure overhead power-lines are located nowhere near the pad where augers, conveyors or trucks might be operating — ideally locate power underground. As a minimum, have signs and markers installed to alert operators to overhead powerlines.

Construct pads that are flat, hard-packed stands, which allow tipping trucks to elevate without risk of toppling over sideways.

Minimise any slopes and ensure they are of a constant grade. Position drainage lines and holes away from high-traffic areas to reduce the risk of equipment falling through, while maximising drainage effectiveness. Incorporate residual current devices (RCDs) into electrical switchboards to prevent electrical shock if, for example, an electrical cable was accidentally cut. A qualified technician is required to carry out any 240-volt electrical work. They will ensure the components are safe to use in areas where combustible dusts are present.

For more information on silo safety, see Section 3 Storage safety.

1.2.4 Road access

The ability to get trucks in and around the grain-storage facility is paramount to its success. Sealed or hard, all-weather roads to the site from a main road are essential for year-round out-loading, which will ensure grain sale contracts are met in a timely manner and can deliver marketing advantages.

1.2.5 Proximity to trees and insect or bird havens

Avoid locating storage facilities near trees, haystacks and haysheds — all are havens for insects and birds, making migration from nature to the grain stored in the facility easier. Similarly, water sources are attractions for vermin and birds. Avoid water sources when selecting a site for a grain storage facility.

1.2.6 Proximity to harvest locations

One of the most important considerations of facility placement and layout is harvest logistics to make the busiest time of use most efficient.

While placing silos close to a house or existing infrastructure is most common, it may not be the most efficient placement from a logistics perspective. Ultimately the location will be a balance between harvest efficiency, proximity to power access but away from houses to reduce dust and noise from aeration fans running all hours.

1.2.7 Determining storage capacity requirements

Calculating ‘adequate storage capacity’ can involve an enormous range of variables. Consider what would be the ’ultimate‘ in on-farm storage capacity for the farm and then plan a series of stages to achieve this ultimate goal.

For some growers, ultimate storage capacity is 100 per cent of their harvest, while others will always use an external bulk handling system to some extent. This is likely to vary between State bulk handling operators, dominant crop types, target markets and distance from the farm to bulk handlers.

As an initial step, aim for a reasonable proportion of the total harvest and plan to expand the facility from there. Consider investing in a number of small silos as the first step and buy larger silos as the business expands.

Smaller silos, for example around 70 to 100 tonnes, will always be valuable for segregation and blending or insect control in small parcels of grain.

Commonly, a variation of storage sizes and types provides flexibility - cone silos for segregation, large flat bottoms for efficiency, temporary storage for extra capacity when needed.

1.2.8 Determining out-loading throughput rates

A standard out-loading rate is around 3–4 tonnes per minute and anything exceeding that will enable the driver to get back on the road to their delivery port quicker.

1.2.9 Weighbridges

With fines for overloading increasing in severity and occurrence in most States, using a weighbridge could pay for itself quickly. Weighbridges can be incorporated into the silo load-and-unload loop with effective installations providing readouts for the driver when approaching from both sides. The alternative but not as reliable option is using truck airbag readings.

Photo 9: *The addition of a weighbridge can help maximise truck carrying efficiency and avoiding overloading fines. (Source: Ben White, Kondinin Group)*

1.2.10 Blending abilities

The ability to blend grains and optimise specifications is one of the primary benefits of an on-farm storage facility. The ease of out-loading for blending is greatly improved by adding a belt or drag-chain grain conveyor and elevator system to the facility. This addition also requires remote operated silo outlets, a seal off system to isolate silos when they require fumigation and a method for cleaning the conveyor system to maintain meticulous hygiene.

1.2.11 Sampling abilities

Keeping a record and sample of grain stored on-farm can be useful for subsequent testing and quality assurance.

Owners of larger on-farm, grain-storage facilities commonly add a sampling shed where grain-quality specifications are collected and stored. Taking the sample from silos can be easier if sealable silo ports for sample collection can be easily accessed to obtain a cross section of the stored product. Truck sampling options include push spears and vacuum spears, which are designed to take a profile section of the load. Collecting running samples during loading is another option providing a full cross section of the grain flow is collected.

If adding an elevated platform to the facility, remember to add compliant handrails and stairs to minimise the risk of falling.

1.2.12 Cleaning and facility maintenance

Maintaining thorough site hygiene is easier with a quality hard surface. Concrete pads are essential for silos to sit on but extended aprons can also assist cleaning grain spilt during loading and unloading.

Common grain trap points include dump-pits, drainage or aeration channels and around silo bases.

Clean all grain off the site on a regular basis to avoid harbouring insects, which may infest stored grain. Ensure a water point is accessible for washing out cone bottom silos after they are emptied. Grain vacuums are popular with owners of flat-bottomed silos to remove residual grain where sweep augers have not been able to reach.

For more information on grain storage hygiene, see Section 5 Hygiene and structural treatments.

1.2.13 Facility earthworks

When determining the requirement for earthworks, always allow a buffer around the pad for construction-vehicle movement. Raised pads are most common as they minimise the potential for water damage to the facility and stored grain. The height of the pad will typically vary according to the overall topography of the site relative to the landscape but 500mm above average topographic level is not uncommon.

Soil type impacts

Soil type can have a huge bearing on silo foundation thickness and requirements for facility earthworks. Foundations are normally engineered with depth of footing and reinforcing determined according to the physical properties of the soil. Highly-reactive soils shrink and swell according to their level of moisture and typically require additional foundation engineering and reinforcing, which comes at a greater cost. As a rule of thumb, experienced silo-pad concreters assume soil type according to region for quoting purposes with slight variations dependent upon on-site requirements.

Drainage

In addition to maintaining a raised, firm pad for the storage facility, plan for drainage to handle and direct run-off away from the pad. In some cases the natural topography of the site may assist free drainage while on flat sites, drainage channels may have to be formed to carry water away from the site. A well-designed pad for transportable cone-bottom silos will ensure water does not pool near the base structure, which can quickly rust out.

1.2.14 Lighting

Loading and out-loading is often carried out at night during harvest and effective lighting not only makes the job easier for drivers but also improves safety at the site.

Efficient and robust forms of lighting, including LED, are suitable choices for short-throw requirements.

If laying electrical cables underground, for aeration or auger drives, consider laying electrical cables for lighting at the same time.

1.2.15 Communications

With numerous market opportunities and volumes of information and data detailing specifications of stored grain increasing, facilities for data transfer and communication add value to any site plan, particularly if the site is to be equipped with a sampling and testing shed.

1.2.16 Planning to expand

It is rare that any grower would set out to build a complete on-farm grain storage system from scratch. The capital requirement would be enormous and in most cases grain storage facilities grow with increasing farm productivity.

Carefully planning for a facility to be built in stages can ensure design aspects of the larger site are not overlooked when constructing these stages. It can also lead to savings through coordinated placement of pipes, electricals and concrete pads.

Expansion is most commonly, and simplistically, an extension of a single line of silos, although variations include circles with a central receival and out-loading point. Single lines of silos offer the ability to run a single out-loading belt, which can feed grain into an elevator for out-loading or transfer to other silos.

When planning to expand, consider drying options including the ability to undertake batch drying or dedicated drying silos with ample airflow rates.

Also plan for aeration controller placement and associated electricals.

1.2.17 Staking out the facility

Everything can look good on plans, but it is important to physically stake out the site of grain facilities to ensure proportions have not been underestimated or overlooked. Driving pegs onto the site to indicate silo placement, pad borders and the positioning of roads and weighbridges can help visualise the suitability of the plan for the site.

1.2.18 Adapting existing facilities

In many cases, existing infrastructure is worked into the design.

Upgrading, including retro-sealing silos and sheds, can be an option to reduce the overall cost of storage per tonne, but remember retro-sealing is only useful if it passes the Australian Standard 2628 half-life pressure-test. Also budget for ongoing maintenance costs for retro-sealed facilities.

Offset placement of silos in lines parallel to lines of existing silos can be an option and can offer out-loading efficiencies. Apart from fitting in around older storages, the first modification to older silos should be the installation of an appropriately sized aeration fan and ducting.

1.2.19 On-site office and sampling sheds

An on-site office is ideal for keeping records and samples of stored grain. It can house expensive, sensitive testing equipment and be used as a crib-room for drivers and employees.

Portable site offices are a common choice as they can be fitted with air-conditioning and are often pre-wired for electrical outlets. Used site offices regularly come up for sale on mining sites and can be bought at a fraction of the new price.

As a minimal alternative, an on-site cabinet for load documentation and records will ensure hard copies of silo contents and load specification details are kept on site.

MORE INFORMATION

Smart Storage Setups (Kondinin Group 2021)

Slick Storage Setups (Kondinin Group 2013)

1.2.20 Dump pits

Dump pits can be installed in combination with paddle or drag conveyors to quickly and easily take and elevate grain to load silos.

Carefully cover dump pits when not in use to keep water out and keep pits and surrounding areas clean to minimise contamination and spoilt grain. Easy cleaning is a key consideration to avoid cross contamination and grain trap points to harbour insects.

1.2.21 Conveyor types

Numerous options for shifting grain around the site are available and each has benefits and disadvantages.

Maximum angles of elevation vary between conveyors according to grain but figures are usually quoted for wheat.

Augers are most common due to their portability and are one of the cheapest methods of elevating grain into a number of silos. In addition to diameter, elevation angle and flight turn speed have a bearing on flow rates with higher elevation angles reducing throughput.

Augers can occasionally damage split-prone grain — particularly old augers with worn flighting. Belted conveyors are the second most-commonly-used grain transfer method and are preferred by operators transferring damage-prone grain. Being a transportable unit, elevation angle is limited to the angle of repose of the grain. The angle of repose is a physical stacking property of a grain and varies between grain types. The repose angle is a measure of the angle of the sides of a conical grain pile from horizontal.

For example, the angle of repose for wheat is 27 degrees while canola is 22 degrees. Flow rates reduce as the angle of elevation increases to approach the repose angle. Belts are often cupped along the conveyor length to accommodate grain and hygiene is excellent with the design of a belted conveyor being self-cleaning. Bucket elevators are predominantly used to elevate grain vertically and are commonly used together with belted conveyors transferring grain horizontally, or splitters diverting grain down chutes through a gated manifold.

Bucket elevators are self-cleaning by design and are typically fixed position equipment. Drag-chain conveyors or paddle conveyors use a series of paddles fixed to a loop of chain moving inside a conduit. Drag chains can elevate at any angle, including horizontal, and are largely self-cleaning, although corners of the chain-loop will normally require attention. Drag-chain conveyors are a permanent installation but are extendable for facility expansion.

Economics of on-farm storage

As the use of on-farm grain storage across Australia expands, the question of economic viability gains significance.

There are many examples of growers investing in on-farm grain storage and paying for it in one or two years because they struck the market at the right time, but these examples are not enough to justify greater expansion of on-farm grain storage.

To make a sound financial decision, compare the expected returns from grain storage vs expected returns from other farm business investments, such as more land, more harvest equipment, wider machinery, more trucks or paying off debt. Calculating the costs and benefits of on-farm storage enables a return-on investment (ROI) figure, which can be compared with other investment choices.

Use the *Grain storage cost–benefit analysis template* (Table 1) to compare different storage types or varying storage scenarios.

The key to a useful cost–benefit analysis is identifying which financial benefits to plan for and costing an appropriate storage to suit that plan. If the plan includes the potential to store grain for longer periods, then consider the storage type best suited will likely be gas-tight, sealable silos to enable fumigation.

When considering temporary storage types for shorter term storage, give thought to the business' labour availability to fill, manage and empty those storages.

Being realistic about your attentiveness to detail when it comes to setting up and managing temporary storages meticulously could avoid an inevitable disaster of damaged grain.

Often a combination of storage types works well. Cost them each out individually before combining the results to provide an overall return on investment for the proposed system. To compare the benefits and costs in the same form, work everything out on a basis of dollars per tonne ($/t). When comparing manufacturer quoted tonnes of storage capacity, check the grain bulk density weight used is consistent with the grain you intend to store. It is also helpful to reality check each figure as during the calculation process — ensure the numbers are realistic.

Don't get caught up on figures that need to be estimated such as grain market figures. A productive approach is to use averages based on medium-term to long-term trends.

MORE INFORMATION

Economics of grain storage

Table 1: *Grain storage cost-benefit analysis template*

	Financial gains from storage		Example ($/t)
A	Harvest logistics/ timeliness	Grain price x reduction in value after damage % x probability of damage %	20.40
B	Seasonal trends in market	Post harvest grain price – harvest grain price	30.00
C	Local market gain (feed to feedlot)	Post harvest grain price – harvest grain price	
D	Freight (peak vs out-of-season rate)	Peak rate $/t – post harvest rate $/t	5.00
E	Cleaning to improve the grade	Clean grain price – original grain price – cleaning costs – shrinkage	
F	Blending to lift average grade	Blended price – ((low grade price x %mix) + (high grade price x %mix))	
G	Drying for early harvest	Grain price x reduction in value after damage % x probability of damage %	
H	Other benefits		
I	**Total benefits**	Sum of benefits	55.40
J	Capital cost	Infrastructure cost ÷ storage capacity	225.00
	Fixed costs		
K	Annualised depreciation cost	Capital cost $/t ÷ expected life of storage eg 30yrs	7.50
L	Opportunity cost on capital	Capital cost $/t x opportunity or interest rate eg 6% ÷ 2	6.75
M	**Total fixed costs**	Sum of fixed costs	14.25
	Variable costs		
N	Storage hygiene	(Labour rate $/hr x time to clean hrs ÷ storage capacity) + structural treatment	0.31
O	Aeration cooling	Indicatively 50c for the first month then 20c per month /t	1.18
P	Repairs and maintenance	Estimate eg. capital cost $/t x 0.25%	0.56
Q	Inload/outload time and fuel	Labour rate $/hr ÷ 60 minutes ÷ auger rate t/m x 3	1.13
R	Time to monitor and manage	Labour rate $/hr x total time to manage hrs ÷ storage capacity	0.36
S	Opportunity cost of stored grain	Grain price x opportunity or interest rate eg 6% ÷ 12 months x No. months stored	10.20
T	Insect treatment cost	Treatment cost $/t x No. of treatments	0.40
U	Cost of bags or bunker tarp	Price of bag ÷ bag capacity tonne	
V	Shrinkage (spilt/lost grain)	Grain price $/t x percentage lost eg 0.2%	
W	Drying costs (optional)	Total drying costs ÷ total tonne dried	
X	**Total variable costs**	Sum of variable costs	14.71
Y	**Total cost of storage**	Total fixed costs + total variable costs	28.96
Z	**Profit/Loss on storage**	Total benefits - total costs of storage	27.01
	Return on investment	Profit or loss ÷ capital cost x 100	12.0%
	Payback period years	Capital cost ÷ profit or loss on storage	9 years

Grain storage cost–benefit analysis template
(Source: GRDC Economics of on-farm grain storage)

2.1 Calculating the costs — key considerations

The following colour-coded letters and text correspond to each of the coloured lines in the *Grain storage cost–benefit analysis template2* (Table 1).

The following examples are not necessarily all related to the same situation.

When entering percentage figures into a calculator, first divide by 100. For example, enter 35% into the calculator as 0.35 and enter 5% as 0.05.

When carrying out calculations with multiple operations (for example x, ÷, +, - and brackets) follow 'BOMDAS' which is an acronym for 'brackets, orders multiplication, division, addition, subtraction'. This means calculate anything in brackets first, then calculate orders then multiplication then division then addition then subtraction. If unsure, follow an example to check you get the same answer.

2.1.1 Financial benefits

A Harvest logistics

One financial benefit almost every grower can gain from through on-farm storage is improved harvest logistics or timeliness — aiming to reduce the amount of time the harvester is stopped because trucks can't keep up carting the grain away.

If this is the case, ensure the planned grain storage has capacity for fast and efficient in-loading during harvest. The probability part of the calculation refers to how often a weather event damages grain. For example if rain damages ripe crops on average twice every 10 years then the probability is 20%.

Market opportunity can provide a return for storing grain to sell after harvest. In the short term, storing on-farm might give time to market the grain to the best receival site.

A CALCULATION

Grain price x reduction in value after weather damage x probability of weather damage %.

Example:
$340/t x 30% x 20% = $17.40/t

B Seasonal market trend

Consider whether you are aiming to capture a seasonal price trend for the commodity, or identify whether there is a specific, local market that will pay a premium to store grain.

Various marketing organizations do analysis on seasonal trends of grain prices for each region meaning they can guide us on the best time of year to sell each commodity according to history. This information is useful as a long term guide to determine how long we are likely to have to store grain for and what price premium we should budget on getting for holding it.

If this is a benefit relevant to your grain storage plan, it will be important to maintain grain quality for the expected storage period, which means matching the storage type to the plan. Anything longer than a few months storage will require pest control at some point to ensure insect free grain can be delivered.

VIDEOS

On-farm storage in the SA Mallee with Corey Blacksell

C Local market

If you are aiming for a local market, such as a feedlot or dairy, consider the length of time you are likely to need to store the grain and what premium the local market is likely to pay for storage (if any).

Whether aiming for a seasonal price trend or a local market trend, the benefit calculation is the same.

B & C CALCULATION

Post-harvest grain price – harvest grain price

Example: $370/t – $340/t = $20/t

MORE INFORMATION

GRDC Ground Cover Case Study: Storage smooths the harvest and quality control

D CALCULATION

To local site: peak freight rate – post-harvest freight rate

Example to local site:
$22/t – $18/t = $5/t

Or

To port: port price – freight farm to port post harvest – local receival price + freight farm to local site at harvest

Example to port: $372/t – $25/t – $340/t + $18/t = $25/t

E CALCULATION

Cleaner cost: (depreciation + opportunity cost of capital + repairs and maintenance) ÷ average throughput tonnes per year + fuel + labour.

Example of own cleaner costs:
($1000 + $100 + $400) ÷ 800t + $0.30 + $3.00 = $6.30/t

Cleaning benefit: clean grain price – original grain price – cleaning costs – shrinkage

Example of cleaning benefit:
$340/t – $300/t – $6.30/t – ($300/t x 5%) = $18.70/t

Photo 1: *A planned approach to grain storage greatly increases the chance of making money out of it, rather than hoping for the best and expecting it to be profitable. (Source: Chris Warrick, Primary Business)*

D Freight

In some regions, freight at harvest is charged at a premium due to high demand and long queues at receival sites. Holding grain on farm to cart after harvest can create a financial benefit by getting cheaper freight rates to the local receival site, or having time to cart directly to port and bypass local bulk handler charges.

E Cleaning

Having access to a grain cleaner can achieve benefits if it means you can meet the criteria of a higher grade. In most cases, this involves storing grain on farm to clean after harvest, or on a wet day, when the pressure is off.

The calculation requires a cleaning cost, which can be based on a contract rate or by totalling the cost of owning and running a cleaner.

The example opposite demonstrates one way to calculate the cost of using your own cleaner.

F CALCULATION

Blended price – (low grade price x % of mix) - (high grade price x % of mix)

Example: $320/t – ($300/t x 70%) - (340 x 30%) = $8/t

G CALCULATION

Grain price x reduction in value after weather damage x probability of damage.

Example: $340 x 30% x 20% = $20.40/t

F Blending

In some cases, grain of varying qualities can be blended to lift the overall grade. This can provide a financial benefit if a small portion of higher-grade grain can be blended to lift the larger portion of lower-grade grain and the price difference for the grade is significant.

G Drying

Where grain drying facilities are available grain can be harvested earlier in the season or harvesting can start earlier each day and extend later each evening. This can potentially lead to a financial benefit if more grain can be harvested and stored to reduce the amount lost from a weather event during harvest. Practically there is a limit to the volume of grain that can be harvested early or at higher moisture content, so the benefit may only apply to a portion of the storage facility's total capacity.

If using drying for early harvest in your calculation, remember to include the cost of drying the grain and include aeration cooling and drying in the capital cost.

The probability part of the calculation refers to how often a weather event damages grain. For example if rain damages ripe crops on average twice every 10 years then the probability is 20%.

H Other benefits

In addition to the benefits already covered, there may be location-specific benefits or opportunities to value-add to grain after storing it on farm.

One example of limited quantity would be stored planting seed, the benefit being the difference in the price to buy in seed less the price grain could be sold for at harvest, less cleaning and treatment costs.

Calculate any other benefits in the same way; on a dollar-per-tonne basis and remember to account for any associated fixed or variable costs.

I Total benefits

In many cases, it is worth aiming for more than one benefit to make storage pay.

For example, relying on seasonal market trends alone in many cases won't cover the costs of storage, but when combined with avoiding peak freight rates it might be feasible.

At the same time, it would be unrealistic to expect to get all the possible benefits in any one year.

Select the most locally relevant and reliable benefits for your operation and add them up to get the total benefit in dollars per tonne.

2.1.2 Fixed costs of on-farm storage

The costs of grain storage can be allocated into two groups — *fixed costs* and *variable costs*.

Fixed costs don't vary from year to year and are the same whether the storage is used or not.

It is important to match the storage type to the storage plan. For example, if you are planning to hold grain for several months to capture a market trend, ensure you can control insects and maintain grain quality during that period. If phosphine or another fumigant is part of your insect control strategy, a gas-tight sealable storage is required.

J Capital cost

J CALCULATION

Infrastructure costs ÷ storage capacity

Example for silos: (silos $540,000 + ground works and concrete $40,000 + aeration controller installed $15,000 + auger $80,000) ÷ storage capacity 3000t = $225/t

Example for grain bags: (in-loading machine $50,000 + out-loading machine $80,000 + permanent site preparation $2000) ÷ storage capacity 1500t = $88/t

To determine the fixed costs of storage, first calculate the capital cost — all the infrastructure, site works, concrete, equipment and labour to set up the storage. Remember to include augers or conveyors for loading and unloading as well as aeration cooling systems and electrical work if planned to be part of the build.

Divide the capital costs by the storage capacity to give a capital cost per tonne.

In the case of grain bags and bunkers, the capital costs are significantly less as they consist of the in-loading and out-loading machines, permanent site works and any other associated equipment required.

Always match the storage type with the storage plan.

For storages that can be used multiple times per year, such as silos used for winter and summer crops, or filled twice a season to aid harvest logistics, the fixed costs per tonne can be halved because the cost is spread over twice the volume of grain each year.

The most significant fixed costs for grain bags are the in-loading and out-loading machines, so the more grain they are used to store each year, the lower the fixed costs on a per tonne basis.

If there is not a lot of grain to store in bags, consider reducing the capital cost by owning half the machinery in partnership with a neighbour, or hiring the machinery so it becomes a variable cost.

K Depreciation

K CALCULATION

Capital cost ÷ expected life of the storage or inload and outloading machines

Example for silos:
$225/t ÷ 30 years = $7.50/t

Example for grain bags:
$88/t ÷ 15 years = $5.86/t

After establishing the capital costs, the first fixed cost — depreciation — can be determined.

Annualised depreciation is the capital cost spread across the expected life of the storage. The expected life of a storage is the period of time during which it will function reliably without needing major repairs.

For gas-tight silos the estimate is 30 years, for machinery it would be less and will depend on the usage.

L Opportunity cost on capital

L CALCULATION

Capital cost x opportunity cost or interest rate ÷ 2

Example for silos:
$225/t x 6% ÷ 2 = $6.75/t

Example for grain bags:
$88/t x 6% ÷ 2 = $2.64/t

Opportunity cost on capital is an allowance for what the capital could be earning or saving if it was used elsewhere.

If an alternative use of the funds is to invest in the share market you might use 10–15%, but if the alternative is to pay off debt then you might use the finance interest rate.

Divide the opportunity cost by two to account for the fact that the storage will hopefully be paid off over time, so the interest payable will also reduce over time. Remember to use the same opportunity cost rate and method between the various investments being compared.

M

Total fixed costs

The annualised depreciation and the opportunity cost of capital added together give the total fixed costs of storage. This is the cost of on-farm storage every year before it is even used. It is the cost of the privilege of having storage on site whether it's used or not.

Photo 2: *Bunkers may have lower fixed costs than other storage options but often have higher variable costs and limited flexibility. (Source: Chris Warrick, Primary Business)*

2.1.3 Variable costs of on-farm storage

Costs that vary by the amount of grain stored each year or by how long grain is held in storage are *variable costs*.

Some variable costs vary according to the type of storage used, while others will be the same for any storage type. For example, in-load and out-load time as well as shrinkage will be different for a cone-bottom silo compared with a bunker that requires tarps and a front-end loader.

Time to monitor and manage will be different for a silo compared with grain bags, which require more frequent checking and patching.

Always be realistic with calculations. If planning to store grain in bags for a few months and deliver the same quality grain, include enough time to check and repair the bags at least weekly.

The opportunity cost of stored grain on the other hand will be the same for any storage type if the grain is held for the same length of time, including if comparing to using a bulk handler or contract storage facility.

N

Hygiene

Storage hygiene is a minor cost relative to other costs. However it is worth calculating to highlight how little extra it costs for such a significant benefit in having a pest-free storage to start with and not having grain laying around that attracts pests to the site. For more information on storage hygiene, see Section 5 Hygiene and structural treatments.

N CALCULATION

(Labour rate x time to clean ÷ storage capacity) + structural treatment cost

Example: ($45/hr x 5 hrs ÷ 1,000t) + $0.08/t = $0.31/t

O Aeration cooling

Aeration cooling is another variable cost that is trivial in the economic outcome of storing grain, but has a significant effect on grain quality and insect activity. This calculation highlights how little it costs for a substantial benefit. Indicatively, aeration cooling fans delivering 2–3 litres per second per tonne will cost about $0.50/t for the first month in storage while the grain temperature is reduced, then $0.20/t per month to maintain a cool grain temperature. This is based on an automatic aeration controller running the fans continuously for the first five days, then 12 hours per day for seven days, then 100 hours per month for maintenance. An example calculation is shown opposite, but the indicative cost of $0.50/t plus $0.20/t/month is accurate enough for most scenarios.

If a generator is used to power aeration fans, add the purchase and installation to the capital costs at 'J' and use the following formula to calculate running costs. Fuel consumption (L/hr) x fuel price ($/L) x run time (hrs) / storage capacity (t).

For more information on aeration cooling during storage, see Section 5.4 Aeration cooling for pest and quality control.

O CALCULATION

Fan motor size x electricity cost x run time ÷ storage capacity

Example: 0.5kW x $0.30/kWh x (120hrs + 84hrs + (100hrs/month x 5 months) ÷80t = $1.18/t

P Repairs and maintenance

Repairs and maintenance vary with each storage type. Grain bags require in-loading and out-loading machines to be maintained, silos require seals to be maintained to ensure they remain gas-tight sealable, bunkers require repairs to tarps and walls and augers take a small amount of upkeep to increase their working life.

If storage facilities already exist, check financial records to find repairs and maintenance costs on average each year, otherwise use a percentage of capital cost to estimate an allowance.

As with hygiene, maintenance is a relatively small cost with significant benefits, enabling smooth operation and maintaining grain quality.

P CALCULATION

Capital cost x 0.5%

Example: $225/t x 0.25% = $0.56/t

Q In-loading and outloading

In-load and out-load time accounts for the labour required to fill and empty the storage. There is a tendency for growers to overlook the cost time, but it needs to be accounted for because it is time that could be used to earn money doing something else.

As a minimum, use a labour rate that would be required to pay a worker to do the job at that time of the year. If you know how long it takes to fill and empty the storage then simply divide that time by the storage capacity and multiply it by the labour rate.

The calculation shown is one way to estimate the time and associated cost, accounting for time to fill and empty with the auger as well as time to line up the truck.

Q CALCULATION

Labour rate ÷ 60 minutes ÷ auger rate x 3

Example: $45/hr ÷ 60 minutes ÷ 2t/min x 3 = $1.13/t

R Monitoring and management

The time to monitor and manage grain in storage varies with the type of storage and length of time grain is stored.

Grain in silos requires fortnightly monitoring during the warmer months and monthly monitoring during the cooler seasons to ensure issues are dealt with quickly to keep damage to a minimum.

Grain stored in bags or bunkers needs to be monitored more frequently. There is a higher risk of holes forming and exposing grain to water, leading to mould growth and insect infestation.

Monitoring is another relatively small cost, but has potentially disastrous consequences if not carried out regularly.

R CALCULATION

Labour rate x total time to manage ÷ storage capacity

Example: $45/hr x 2hr per month x 4 months ÷ 1000t = $0.36/t

VIDEOS

On-farm Grain Storage: Economics of aeration

S CALCULATION

Grain price at harvest x opportunity cost or interest rate ÷ 12 months to get a monthly rate x number of months grain is stored.

Example: $340/t x 6% ÷ 12months x 6 months = $10.20/t

T CALCULATION

Treatment cost x number of treatments

Example: $0.40 x 1 treatment = $0.40/t

U CALCULATION

Price of bag ÷ bag capacity
Example for bags: $1300 ÷ 240t = $5.42/t

Example for bunker tarps:
$10,500 ÷ 1000t ÷ 3 uses = $3.50/t

S Opportunity cost of stored grain

The opportunity cost of stored grain is an allowance for what the value of the grain could be earning or saving if it was used elsewhere.

Like the opportunity cost of capital, the rate could be based on an alternative investment or the debt finance rate during the same period grain is stored. For example, if the grain was sold at harvest the funds could be used to pay off debt rather than waiting for the grain payment some months after it has been stored.

The rate used needs to be consistent for the opportunity cost of capital and the opportunity cost of the stored grain as well as the rate used for comparing grain storage with other farm investment options.

T Insect treatment

While strict hygiene and aeration cooling can reduce the need for insect pest treatments, it would be optimistic budgeting not to include a treatment cost for grain stored longer than a couple of months.

The treatment cost will vary according to the length of time grain is stored and the product that can be used in each type of storage.

If budgeting on using phosphine (or any other fumigant or controlled atmosphere) then a gas-tight silo is required for reliable fumigation that prevents resistance developing in pest species.

For more information grain storage insect pest control, see Section 4 Grain storage insect pest identification and management.

Photo 3: *Insect control: If the plan is to store grain for longer than a couple of months, an insect control option will be required at some stage. (Source: Chris Warrick, Primary Business)*

U Bags and bunker tarps

The cost of grain bags is a simple calculation as they are a single-use item with a known storage capacity. Bunker tarps may require some estimation to account for tarps that can be used more than once.

Photo 4: *Consider the cost of hiring or owning the inloading and outloading machines. (Source: Tim Sait)*

V Shrinkage

Shrinkage is an allowance for grain spilt or lost during storage. The amount lost depends entirely on the type of storage infrastructure and care taken by the operator.

For example, bunkers, pits or sheds are likely to have more losses than cone bottom silos.

V CALCULATION

Grain price x percentage lost

Example: $340/t x 0.2% = $0.68/t

W Drying

If one of the aims of on-farm storage is drying for early harvest then a drying cost needs to be accounted for.

There will be several ways to calculate drying cost depending on the drying method, the amount of moisture being removed from the grain and the ambient conditions at the time.

In-storage aeration drying requires airflow rates of at least 15–25l/s/t, usually delivered by large fans with 7.5kw, three-phase electric motors. Ambient relative humidity and fan airflow will vary the fan hours required, so the cost of aeration drying will vary, but an example is provided below. For more information on aeration drying, see Section 7 Managing high moisture grain.

W CALCULATION

Contract dryer: total drying cost or hire cost ÷ total tonnes dried = cost $/t

Example for contract dryer: $20,000 ÷ 1000t = $20/t

Batch dryer: ((annual depreciation and repairs and maintenance + opportunity cost of capital) ÷ annual tonne throughput) + ((fuel cost/hr + labour rate/hr) ÷ throughput t/hr)

Example for batch dryer:
Step one: ((($160,000 x 7%) + ($160,000 x 6%)) ÷ 1500t/yr) + (($100/hr + $45/hr) ÷ 20t/hr)

Step two: (($11,200 + $9600) ÷ 1500t/yr) + ($145/hr ÷ 20t/hr)

Step three: ($20,800 ÷ 1500t/yr) + $7.25/t

Step four: $13.87/t + $7.25/t = $21.12/t

Calculation for aeration drying: ((fan motor size x electricity cost x run time) + (labour rate x time to manage drying process)) ÷ storage capacity

Example for aeration drying: ((7.5kw x $0.30/kwh x 240hrs) + ($45/hr x 5hrs)) ÷ 50t = $5.94/t

X Total variable costs

Adding up all the variable costs determines the cost of storing each tonne of grain on farm. If the storage already exists, then knowing the variable costs can help with the decision at harvest time whether to store on-farm or deliver straight to the bulk handler.

Any positive difference between the benefits and the variable costs essentially goes towards paying the fixed costs which we spent when the storage was purchased.

Y Total cost of storage

Adding the fixed costs and variable costs together gives the total cost of the on-farm storage facility. This reveals the return required, from storing grain, to cover all the associated costs of on-farm storage.

Z Profit or loss on storage

The budgeted gain or loss of storing grain on farm can be determined by subtracting the total costs from the total benefits. A positive figure is profit, a negative figure means storing grain on farm is likely to cost money rather than make money.

This profit/loss figure can also be used to compare on-farm storage with the benefits vs costs of marketing options such as warehousing.

2.2 The analysis

2.2.1 Return on investment

Providing storage is profitable, the margin ($/t) divided by the capital cost of the storage ($/t) multiplied by 100 is the percentage return on investment (ROI).

An ROI is simply the return or income as a percentage of the capital invested so is a practical way to compare like with like.

Use this ROI figure to compare grain storage to other investment options.

CALCULATION

Profit on storage ÷ capital cost of storage x 100

Example: $27.01/t ÷ $225/t x 100 = 12% ROI

2.2.2 Payback period

An alternative to using ROI is to calculate the payback period. That is, assuming the budgeted figures are achieved, how many years will it take for the storage to pay for itself.

CALCULATION

Capital cost ÷ profit on storage

Example: $225/t ÷ $27.01/t = 9 years

2.2.3 The decision — to invest or not to invest

While it's difficult to put an exact dollar value on each of the potential benefits and costs, a calculated estimate will determine if it's worth more thorough investigation.

If the investment of on-farm grain storage is compared with other investments and the result is similar, consider revisiting the numbers and working on increasing their accuracy.

If the return is not even in the ball park, a costly mistake has potentially been avoided.

On the contrary, if the return is favourable, it is worth proceeding with the investment confidently.

Evidently the financial implications are not the only factor to consider in deciding between investment options.

Labour availability, knowledge and area of interest will also play a part in the success or otherwise of the storage.

If the figures do add up to be the best financial investment option, the ultimate test is to consider if on-farm storage is going to get the business closer to achieving its strategic goals.

Grain storage investment checklist

If the calculation doesn't produce the answer you were expecting, try following this checklist:

- ✓ Carry out a reality check on the assumptions/estimates used.
- ✓ Check each of the benefits and costs have been calculated correctly making sure they yield a benefit or cost per tonne.
- ✓ Check the costs and benefits have been totaled then subtracted correctly
- ✓ Check the ROI calculation has been done following the example provided.
- ✓ Ensure you are looking at the investment objectively, putting aside preconceived expectations (and pride if the investment has already been made).
- ✓ Try varying the cost and/or benefits to see what effect they have on the outcome. A useful one to start with is the length of time in storage, which affects the opportunity cost of grain in storage. Remember to alter the benefits in line with the time held in storage.
- ✓ Do the calculation on a different storage type for a comparison.
- ✓ Contact one of the grain storage specialists for assistance.
  info@storedgrain.com.au
  1800 WEEVIL

Safety around grain storage

The fundamental approach to grain storage safety is the same as for all other farming activities. The aim is to have a safe workplace for everyone on the farm, including workers, contractors, families, visitors and the owner/managers.

Start by identifying any hazards associated with the grain storage site. This involves talking with workers who use the site, taking time to thoroughly inspect the site and equipment and seeking advice and information from industry and workplace health and safety (WHS) organisations to help identify risks that may not be initially apparent.

Secondly, assess the risk of each hazard in terms of its potential severity. If an accident occurred due to the identified hazard, would it result in scratches and bruises or is there potential for someone to be seriously injured or killed?

The third step is to address the hazard, starting with the highest-risk hazards first. The ultimate aim is to totally remove the risk, but where that's not possible, find a way to control it. This could mean altering the way activities are carried out or providing protective equipment.

After controlling the risk as much as possible, it is important to develop a plan of action in the event an accident does occur. For example, if a worker is exposed to phosphine gas, or another harmful chemical, ensure emergency phone numbers are readily available to get medical help.

Training for everyone who works around grain storage is required and may be performed by a mixture of experienced operators and qualified, specialist trainers. Safety topics include; Identifying and managing risks, operating grain handling machinery and storages, grain testing and record keeping, working from heights, working in confined space, chemical handling and fumigation.

3.1 Designing a safe storage facility

Regardless of the type of grain storage used, selecting a suitable site is the first consideration when designing a safe grain storage system.

If the storage site is already established, assess the site for the following safety considerations and potential for improvement.

If considering future expansion, it may be beneficial to build a new site and decommission the current site when it reaches the end of its working life.

Site safety considerations include:

- *Surroundings* — locate the storage site away from overhead powerlines, houses where children might play, or houses or work areas that will be affected by dust and noise from grain storage activities.
- *Access* — ensure safe access for trucks turning into and out of the site from public roads without endangering other road users.
- *Expansion* — ensure the site is clear of trees, sheds and permanent structures to allow for expansion without having to manoeuvre trucks and augers in a cramped area.
- *Drainage* — select a relatively level site for easy and safe manoeuvring of augers and trucks, but ensure sufficient drainage is available to prevent having to work in wet, slippery and boggy conditions.

For more information on silo safety, see Section 1.2 Grain storage considerations.

MORE INFORMATION

RIRDC: OH&S Managing Grain Production Safely

AgriFutures Australia: WHS for grain farms

VIDEOS

GCTV Stored Grain: Stay Safe Around Grain Storage

3.2 Smart storage selection

Choose storage that is cost effective and practical for the volume of grain to be stored. Considering safety in the mix makes for the ultimate storage result.

Sheds and bunkers are cost-efficient options for large quantities of grain, but require a considerable amount of manual labour and dedicated equipment to empty.

Silos are comparatively less labour intensive, although the amount of manual shovelling to completely empty silos is significantly reduced by choosing cone-bottom silos or flat-bottom silos with well designed sweep augers.

Cone-bottom silos are the obvious choice for easy and safe out-loading. They are particularly beneficial if filled more than once a year — used as a buffer for harvest logistics.

Granular fertiliser, high-moisture grain and grain with a high percentage of screenings does not empty from standard silos very well, which commonly leads to people being tempted to climb into the silo to shovel out the stubborn grain. It is better to only store these types of commodities in silos with steeper cone bottoms or sheds where they can be out-loaded with a front-end loader.

Manufacturers are well placed to provide advice on choosing suitable storage types for various commodities.

3.3 Safety features on silos

Before buying a silo, consider the safety features on offer.

In most cases ladders are still required for monitoring grain in the top of the silo. State-based WHS requirements for ladders exist, but as a guide look for ladders with a safety cage and platforms every two metres, handrails on the top of the silo and a system that prevents children climbing the ladder. Consider an elevated walkway to access the top of a line of silos rather than a ladder on each silo.

Features that limit the need to climb the ladder are a valuable addition to silos and include:

- sight glasses or a device to indicate the level of grain inside the silo;
- a system for applying fumigation at ground level, which will distribute the gas to the head space in the silo;
- lids that can be opened and closed from the ground. (Be aware that few ground-operated lids can be closed and latched tight enough to be gas-tight for fumigation. Most lids still require a climb to the top of the silo to inspect rubber seals and latch the lid before the silo will meet a half-life pressure test, required for effective fumigation. When checking this point with manufacturers, refer to AS2628 — the Australian Standard for gas-tight silos.)

Photo 1: *Silos require safe access to the top for monitoring and maintenance. (photo left). (Source: Ben White, Kondinin Group). Place warning stickers on silos near the ladder, where operators will easily see them (photo right). (Source: Chris Warrick, Primary Business)*

VIDEOS

CASA-ACSA: Grain Entrapment

3.4 Safety on the inside

When working in a potentially dangerous environment, such as inside a silo to clean it out after emptying, it is essential to have another person outside to call if help is needed.

Before entering the silo, ensure you are well hydrated and wearing suitable clothing to do the job (for example, sturdy, enclosed footwear).

Avoid heat stress by carrying out the job during a cool time of the day so the internal silo temperature is more comfortable.

Before entering a silo:

- Open all lids and ventilation points well before entering to allow as much free-flowing air as possible. Damp grain, especially canola, will produce carbon dioxide and carbon monoxide at toxic levels. Monitors are available to test for these gases.
- Ensure all augers or conveyers filling or emptying the silo are stopped and cannot be started by someone else while you are in the silo.
- Stop and think if there is any way the job can be done from outside the silo.
- If entry is not through an access door at ground level, ensure the ladder has an appropriate safety cage. If not, a certified safety harness must be worn.
- Check for bridged or lodged grain that could collapse and do not enter under these circumstances.

While working inside a silo:

- Have someone outside the silo to assist and get help if required.
- Wear an appropriate dust mask to prevent fine dust particles entering your lungs.
- If you become trapped under grain, avoid movement and don't panic as this will worsen the problem — try to remain calm and call for help

3.5 Filling and emptying

Always fill and empty silos from the middle. Filling or emptying a silo from the sides will cause uneven loading on the silo, potentially causing a structural failure. Ensure augers and conveyors are fitted with adequate guarding.

Wear high-visibility clothing while working around moving machinery to reduce the chance of being run over. Ensure all workers are trained to safely operate the grain storage facilities, filling and emptying equipment and associated machinery.

Fatigue and stress are common during harvest; ensure all operators get enough rest or downtime to avoid fatigue and stress-related accidents.

Photo 2: *Having a large gravelled area around silos enables machinery to be moved into position safely. Always fill silos from the centre to avoid uneven loading. (Source: Chris Warrick, Primary Business)*

VIDEOS

GCTV Stored Grain: Fumigation safety

Masks for phosphine

3.6 Stored grain fumigants and chemicals

Even though alternative fumigants are becoming more readily available, phosphine is still widely relied upon to control pests in stored grain.

Phosphine is potentially one of the most dangerous products used on farm, which is why it is classed as a schedule seven poison, indicated on the label — DANGEROUS POISON.

As a minimum requirement, the label directs the use of elbow-length PVC gloves and a full-face breathing respirator with a combined dust and gas cartridge.

Never rely on the odour of phosphine to determine if the atmosphere is safe. The odour threshold of phosphine (for those that can smell it) is two parts per million (ppm). The threshold limit value for a time weighted average is 0.3ppm and the short-term exposure limit is 1ppm. This means by the time workers can smell phosphine (2ppm) the gas concentration level is already exceeding the safe exposure limits.

Always read the product label and Material Safety Data Sheet (MSDS) for safety information and required personal protection equipment (PPE). The respirator must be fitted with a combined dust and gas cartridge (canister) suitable for inorganic gas. Be aware that cartridges have a limited lifespan as they contain activated carbon. Store in a sealed container when not in use and follow manufacturer directions for replacement.

Personal phosphine monitors are available and easy to use. The monitors simply clip onto the operator's collar or top pocket (close to their nose and mouth) and will sound an alarm if more than 0.3ppm is detected and sound another alarm if more than 0.6ppm is detected. Price may deter growers who only use phosphine occasionally, but these handy devices can potentially save a life, so are worth serious consideration.

Place a warning sign on the silo to tell others to stay away. The sign must contain the words DANGER — POISONOUS GAS, KEEP AWAY.

For more information on fumigation, see Section 6 Fumigating with phosphine.

Photo 3: *A full-face breathing respirator is required for handling phosphine. The respirator must be fitted with a combined dust and gas cartridge (canister) suitable for inorganic gas. (Source: Ben White, Kondinin Group)*

3.7 State Worksafe organisations and government WHS contacts

Safe Work Australia

Safe Work Australia

W www.safeworkaustralia.gov.au

SafeWork NSW

W www.safework.nsw.gov.au
T 13 10 50

SafeWork SA

W www.safework.sa.gov.au
T 1300 365 255

Workplace Health and Safety QLD

W www.worksafe.qld.gov.au
T 1300 362 128

WorkSafe Tasmania

W www.worksafe.tas.gov.au
T 1300 366 322

NT WorkSafe

W worksafe.nt.gov.au
T 1800 019 115

WorkSafe Victoria

W www.worksafe.vic.gov.au
T 1800 136 089

WorkSafe WA

W www.commerce.wa.gov.au/worksafe
T 1300 307 877

WorkSafe ACT

W www.worksafe.act.gov.au
T 13 22 81

MORE INFORMATION

QDAF Fact Sheet: Identification of the flat grain beetles (*Cryptolestes* spp.) of Australia

MORE INFORMATION

Insect resistance testing contact details

Grain storage insect pest identification and management

If stored grain is not properly managed there it can become infested with stored grain pests. Grain for domestic human consumption, and especially grain for export, must not contain live insects.

Regular storage inspections, by sieving grain from the top and bottom of silos, will provide an early warning of insect infestations.

Probe traps installed in the top of the grain store will show insects are active long before they are seen on the surface of the grain.

Protecting any stored grain from insect attack makes economic sense, because even feed grain can lose value though loss of protein or palatability, affecting livestock growth rates.

Seed grain is next year's investment and if boring insects are present they will destroy the germ of the grain.

For assistance identifying grain storage insects or to have a sample tested for resistance, use the link opposite to contact your nearest laboratory.

4.1 Key pest species

The most common insect pests of stored cereal grains in Australia are:

- Lesser Grain Borer: (*Rhyzopertha dominica*)
- Rust-Red Flour Beetle: (*Tribolium* spp.)
- Rice Weevil: (Sitophilus spp.)
- Flat Grain Beetle: (*Cryptolestes* spp.)
- Saw-Toothed Grain Beetle (*Oryzaephilus surinamensis*)
- Psocids *(Liposcelis* spp.*)* – Booklice
- Bruchids: Cowpea weevils (*Callosobruchus* spp)
- Pea Weevil (*Bruchus pisorum*)

MOTHS:

- Angoumois Grain Moth (*Sitotroga cerealella*)
- Indian Meal Moth (*Plodia interpunctella*)
- Warehouse Moth (*Ephestia* spp.)

Figure 1 provides a useful guide for identifying the most common five grain pests.

VIDEOS

GCTV2: Grain Storage Insect ID

QDAFF: Diagnosing pest using digital microscopes

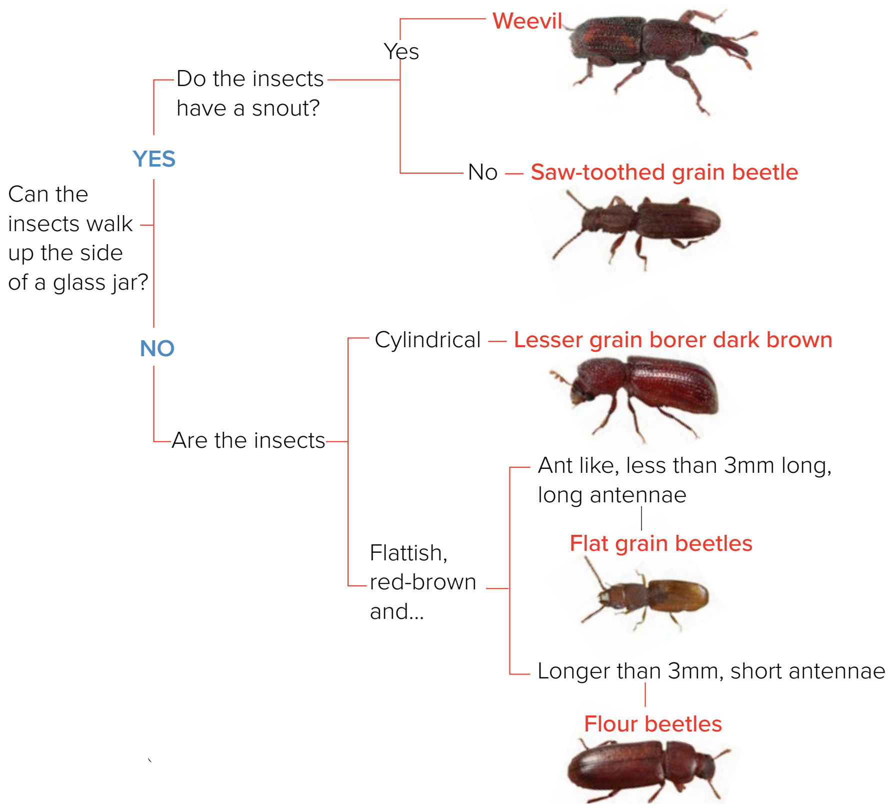

Figure 1: *Identification of common pests of stored grain*
Source: DAF, QLD

4.1.1 Lesser grain borer (*Rhyzopertha dominica*)

Photo 1: *Lesser grain borer (*Rhyzopertha dominica*) (Source: DAF, QLD)*

A serious pest of most stored grains: the Lesser Grain Borer has developed resistance to a number of grain insecticides.

Key Features:

- Dark brown cylindrical shaped beetle (up to 3mm long) with club-like antennae
- Viewed from the side the beetle's mouth parts and eyes are tucked underneath the thorax (chest)
- Adult beetles are strong flyers.

Life cycle:

- Life cycle completed in four weeks at 35°C and seven weeks at 22°C. Breeding stops below 18°C
- Females lay between 200–400 eggs on grain surface. Young larvae (white with brown heads) initially feed outside then bore into the grain
- Adults live for 2–3 months.

Detection:

- Their habit is to remain hidden in grain. Regular sampling and sieving is required for detection.

4.1.2 Rust-red flour beetle (*Tribolium castaneum*)

Photo 2: *Rust-red flour beetle (*Tribolium castaneum*) (Source: DAF, QLD)*

Commonly found in stored cereal grain, processed grain products, oilseeds, nuts and dried fruit.

Key Features:

- Adult beetles (3–4.5mm long) bright reddish-brown in colour when young and a darker brown when older
- Three larger segments on end of end of antennae
- Similar species: Tribolium confusum – confused flour beetle, more common in cool, temperate regions.

Life cycle:

- Life cycle completed in 4 weeks at 30°C, 11 weeks at 22°C and reproduction stops below 20°C
- Adults live from 200 days to 2 years and fly in warm conditions
- Up to 1000 eggs per female, loosely scattered throughout the commodity
- Cream-coloured larvae feed externally on damaged grain
- Beetles infest whole grain, but breed more successfully on processed products (i.e. flour).

Detection:

- Beetles move quickly and are strong flyers. When in low numbers use sieving and probe traps to detect
- Prefered habit is around storage areas with poor hygiene, broken grain, gradings or bulk cottonseed.

4.1.3 Rice weevil (*Sitophilus oryzae*)

Photo 3: *Rice weevil (*Sitophilus oryzae*) (Source: DAF, QLD)*

Major pest of whole cereal grains.

Key Features:

- Adults are dark brownish black (2 – 4mm long) with a long weevil 'snout'
- Have four small light coloured patches on its rear wing covers
- Rarely flies, but climbs vertical surfaces (e.g. glass jar)
- Similar species: Sitophilus zeamais – maize weevil, and Sitophilus granarius – granary weevil.

Life cycle:

- Adults live 2-3 months
- Larvae generally not seen – they feed and develop inside single grains
- Life cycle completed in four weeks at 30°C, 15 weeks at 18°C, breeding stops below 15°C.

Detection:

- Under warm conditions or when grain is moved rice weevils are often observed climbing out of grain up vertical surfaces. Sieving & probe traps recommended to detect low numbers.

4.1.4 Flat grain beetles (*Cryptolestes* spp.)

Photo 4: *Flat grain beetle (*Cryptolestes *spp.) (Source: DAF, QLD)*

Infests most stored grain and feeds on damaged grain. Some populations have high levels of phosphine resistance.

Key Features:

- Smaller than other major stored grain pests (2mm long), very flat,reddish brown colour with long thin antennae
- Fast moving, seeking cover under grain or trash
- Adults fly readily and can live for several months
- C. ferrugineus most common in Australia, but there are several closely related Cryptolestes species with similar appearance.

Life cycle:

- Life cycle completed in 4 weeks at 30–35°C with moist conditions, 13 weeks at 20°C, breeding stops at 17.5°C
- Larvae, with characteristic tail and horns, feed and develop externally on damaged grains
- Females lay up to 300 eggs loosely in the grain stack.

Detection:

- Sieving and probe traps usually required for detection
- Some populations of flat grain beetles have developed very high levels of phosphine resistance. Send in insect samples for testing after a fumigation failure.

4.1.5 Saw-toothed grain beetle (*Oryzaephilus surinamensis*)

Photo 5: *Saw-toothed grain beetle (*Oryzaephilus surinamensis*) (Source: DAF, QLD)*

Infests cereal grains, oilseeds, processed products, peanuts and dried fruits.

Key Features:

- Dark brown-black beetle (up to 3mm long), fast moving
- Thorax (chest) has saw-toothed pattern on each side and three distinct ridge lines on top
- Adults climb vertical surfaces (glass jar) and fly in warm conditions.

Life cycle:

- Prefers damaged or processed grain to establish in significant numbers
- Adults can live for several months, females laying 300 – 400 eggs loosely throughout the grain. White larvae feed and develop externally
- Life cycle completed in 3 weeks at 30–33°C, 17 weeks at 20°C, reproduction stops below 17.5°C.

Detection:

- Sieving and probe traps are recommended for detection
- Has developed resistance to a number of grain insecticides.

4.1.6 Psocids (*Liposcelis* spp.), booklice

Photo 6: *Psocids (*Liposcelis *spp.), booklice (photos left and right). (Source: DAF, QLD)*

Infests a wide range of grains, commodities and storage facilities.

Key Features:

- Very small, soft-bodied and opaque, pale coloured (up to 1mm long), often appear as a 'moving carpet of dust' on grain or storage structures
- A secondary pest, feeding on damaged grain and moulds
- There are three main species of psocids in Australia, often in mixed populations.

Life cycle:

- Thrive under warm, moist conditions – optimum 25°C and 75% relative humidity. Life cycle 21 days
- Eggs are laid on grain surface, hatching to nymphs that moult through to adult stage.

Detection:

- Warm, humid conditions increases activity. Usually observed in storage or on grain surfaces. Sample and sieve to detect when in low numbers.

4.1.7 Bruchids: Cowpea weevils

Photo 7: *Cowpea weevil (*Callosobruchus *spp) (Source: DAF, QLD)*

Callosobruchus spp are pests of most pulse crops, including mungbeans, cowpeas, field peas, chickpeas, soybeans and lentils.

Key Features:

- Adults (up to 4mm long), emerge through perfectly round holes in the seed
- Globular, tear-shaped body is reddish brown with black and grey markings
- Wing covers (elytra) do not fully cover the abdomen
- Adults have long antennae, climb vertical surfaces (glass jar) and are strong flyers.

Life cycle:

- Adults do not feed, but lay 100 white eggs clearly visible on the outside of seed. Adult short lifespan 10 –12 days. Unlike most storage pests, adults may also lay eggs on mature seed pods in a standing crop
- Larvae feed and develop within individual seeds and emerge as adults leaving a neat round hole.

Detection:

- A common problem in warmer months for mungbeans.
- Fortnightly thorough sampling and sieving is important to prevent serious losses.

4.1.8 Pea Weevil (*Bruchus pisorum*)

Photo 8: *Pea weevil (*(Bruchus pisorum)*) (Source: SARDI ENTOMOLOGY)*

Both a field pest and storage pest (appears in storage after emergence). In WA it is a major pest of field peas.

Key Features:

- Adult globular body length (4–5mm long) with long legs and antennae
- Wings (elytra) are patterned with white/cream spots
- Do not breed in stored dry peas, adults lay and glue eggs onto pods in standing pea crops before harvest
- Adult emerges through a neat round hole in the seed
- Adults are strong flyers, they reappear in spring to visit flowers to feed on the nectar then seek out new field peas crops to lay eggs.

Life cycle:

- Hatching larvae bore through the seed pod and into a single seed where they feed, grow and pupate
- Breed one generation per year. Adult is long-lived and overwinters but does not feed on field peas.

Detection:

- Adults migrate into crops from seed sources and nearby trees where they shelter under the bark
- Field peas should be regularly checked, in and around the crop edges when first pods are forming using a sweep net when temperatures are above 18°C
- Check pea seed for neat round holes (evidence that adults have emerged).

MOTHS:

Angoumois Grain Moth (*Sitotroga cerealella*)

Photo 9: *Angoumois Grain Moth (*Sitotroga cerealella*) (Source: CSIRO)*

A pest of whole cereal grains which only infests surface layers of bulk-stored grains. Infestation of standing maize crops before harvest is quite common, occasionally in other cereal crops.

Key Features:

- Silvery grey to grey brown wings which taper to a point
- Wings have a long fringe of fine hairs along the posterior edge
- Adults (5–7mm long) are unable to penetrate grain, therefore only infest surface layers of bulk grain.

Life cycle:

- Adult moths do not feed but lay 150–300 eggs on or near the grain surface. This pest does not create webbing
- Larvae burrow into a single grain and feed and develop until the adult moth emerges in 10–14 days through a visible hole
- Life cycle takes around 5–7 weeks in warm conditions.

Detection:

- Take regular monthly samples and look for moths near grain surface. When adults emerge pupal cases are often found protruding from grain.

Indian Meal Moth (Plodia interpunctella)

Photo 10: *Indian Meal Moth larvae (*Plodia interpunctella*) (Source: CSIRO)*

A pest in flour mills, processing plants, dried fruit and on the surface of all types of grains.

Key Features:

- Adults (5–7mm long), distinctive bicoloured wings – dark reddish brown on rear half of the wing and grey at the front.

Life cycle:

- Female month lay 200–400 eggs on the foodstuff
- Larvae create webbing as they feed. They then pupate in several grains webbed together in a clump
- In summer life cycle takes about 4 weeks.

Detection:

- Take regular monthly samples and look for webbing and moths near grain surface
- Also check in residues on grain harvesting and handling equipment.

Warehouse Moths (*Ephestia* spp)

Photo 11: *Warehouse Moths larva (*Ephestia *spp) (Source: CSIRO)*

A pest of flour mills, food processing plants, cereal grains and oilseeds.

Key Features:

- Adult moth body length is 8 – 10mm
- Moth has grey wings with many fine, dark wavy markings, including lighter stripes extending horizontally across each forewing
- Extensive webbing created by larvae is visible on the grain surface.

Life cycle:

- Adult moths do not feed and are short-lived. Female lays between 100 – 270 eggs over a two week period on or near grain
- Caterpillar is coloured light pink with a small black spot at the base of each hair
- Full life cycle 30 days under ideal conditions, 30°C and 75% relative humidity.

Detection:

- Take regular monthly samples and look for webbing and moths near grain surface. All moths are typically active at dusk and dawn.

Phosphine-Resistant Insects

- Saw-Toothed Grain Beetle and Lesser Grain Borer have developed some resistance to a number of grain insecticides.
- Flat Grain Beetle: some populations (Rusty Grain Beetle) have developed high level of phosphine resistance.
- A range of stored grain insects are becoming harder to kill with phosphine fumigations.
- Threatens exports, as phosphine may become ineffective against some pests.
- Poor fumigation practices increase resistance (e.g. repeated fumigations in unsealed or poorly sealed storages).
- Strong phosphine resistance is also found in overseas countries.
- Live insects detected following fumigation should be tested for resistance.
- Resistant insects can fly between stores or be transported in machinery.

Exotic pests: Not present in Australia – be on the lookout

The following pests have serious potential impact on the value of grain if detected in Australia. If you see anything unusual, report it to your local state department of primary industries or phone the Exotic Plant Pest Hotline, 1800 084 881

Karnal bunt (*Tilletia indica*)

Photo 12: *Karnal bunt (*Tilletia indica*) (Source: PaDIL)*

- Can infect wheat, durum and triticale.
- Usually only part of each grain is affected. Infected stored grain will have a sooty appearance and will crush easily, leaving a black powder.
- Infected grain often has a rotten fish smell, flour quality is seriously reduced.
- Symptoms are similar to common bunt.

Khapra beetle (*Trogoderma granarium*)

Photo 13: *Khapra beetle (*Trogoderma granarium*). (Source: Ministry of Ag. and Regional Development)*

- Attacks most stored grains.
- Larvae are covered in fine hairs.
- Looks identical to the warehouse beetle to the naked eye.
- Causes grain loss in storage.
- Larvae skins contaminate grain and cause allergies on consumption.
- Phosphine fumigation is not reliably effective.

4.2 Monitoring for insect pests

Regular monitoring means problems are detected early and can be managed before significant grain damage occurs. It also avoids surprises at out-loading, prevents costly rejections from grain buyers and maintains your reputation for supplying quality grain.

To maintain grain quality and to select the correct treatments, identify pests early by sampling monthly. In warm conditions (>30°C) many grain pests can complete their life cycle in as little as 3–4 weeks causing significant damage.

Grain kept for seed or stockfeed is a common breeding ground for pests so monitor all grain storages every two weeks during warmer periods of the year.

Use grain insect sieves and probe traps to monitor for pests in all stored grain and regularly check grain handling equipment during the off season.

Finding grain pests early allows them to be identified, treated appropriately and removed before they spread and become a much larger problem, which may be more difficult to treat.

It's useful to understand that for every live adult insect found, there is typically a ratio of 90 insects in immature life stages (egg, larvae and pupae), which will infest the grain when conditions enable them to develop.

For more information on grain storage insect pest control, see Section 5 Preventing insect pests from entering grain storage.

4.2.1 Sampling stored grain

Collect samples from the areas where insects are most likely to establish first. These areas are generally around openings — hatches, doors, aeration fan inlets, filling and emptying points.

The most common place for insects in a silo is at the top, just below the surface of the peak of grain (see Figure 2). This is because it's the last place aeration cooling or drying reaches, it's exposed to the sun heating the headspace, condensation from the headspace.

VIDEOS

Using Probe Traps

Always follow workplace health and safety guidelines and only climb to the top of a storage if it's safe to do so.

For more information on staying safe around grain storage facilities, see Section 3 Safety around grain storage.

Always collect samples from beneath the grain surface. At the bottom of a silo this means opening an outlet to run a small amount of grain out. A sampling probe is ideal for collecting grain from the top of a silo, but it's often impractical or unsafe to climb up a silo with a sampling probe.

Photo 14: *Probe traps left in the top of a storage can be removed and checked at each inspection. Tie the trap to something inside the storage so it doesn't get lost if it's forgotten about before out-loading. Position the trap so a small amount is left out at the top of the grain to capture insects crawling across the surface as well as those hiding beneath. (Source: Chris Warrick, Primary Business)*

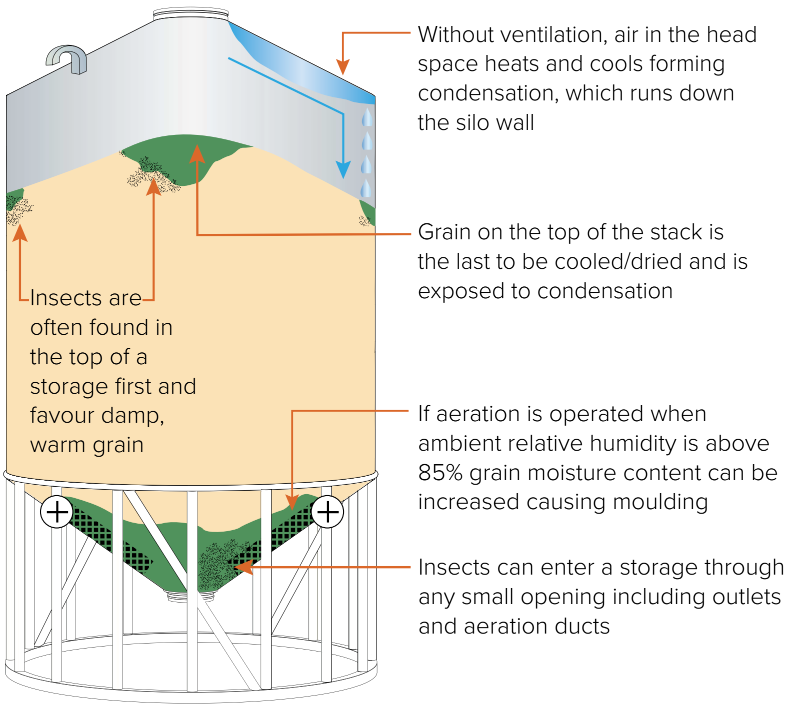

Figure 2: *Common problem areas in grain stores*

Source: Kondinin Group

VIDEOS

Sieving For Grain Pests

4.2.2 Checking for insects

Grain pests can be difficult to find because they are small, fast moving and some prefer the dark while others can be seen on the surface. There are numerous ways to detect them.

Tie a probe trap to something inside the storage so it doesn't get lost or forgotten about before out-loading. Position the trap in the grain so a small amount is protruding out the top of the grain to capture insects crawling across the surface as well as those hiding beneath.

When a sample has been taken, sieving is the most effective method of detecting grain pests. Sieve samples from the top and bottom of stores to detect low levels of insects early. Sieving samples onto a white tray will make it easier to see small insects.

Holding the tray in the sunlight warms the insects and encourages movement making it easier to identify them and monitor population numbers.

A clean glass container helps to identify grain pests. Place the live insects into a warm glass container (above 20°C so they are active, but not hot or they will die).

Weevils and saw-toothed grain beetles can walk up the walls of the glass easily, but flour beetles and lesser grain borer cannot. Look closely at the insects walking up the glass — weevils have a curved snout at the front but saw-toothed grain beetles do not.

Photo 15: *Sieve a litre sample onto a white tray. Hold the tray in sunlight to warm for 20–30 seconds to encourage insect movement for easier identification. Some insects will continually seek refuge under grain while others stay out in the light — take time to look closely with a magnifying glass. (Source: Ben White, Kondinin Group)*

VIDEOS

Monitoring Grain Temperature

VIDEOS

Monitoring

4.2.3 Temperature and moisture

Freshly-harvested grain usually has a temperature around 30°C, which is an ideal breeding temperature for storage pests (see Table 1).

Studies have shown that rust-red flour beetles stop breeding at 20°C, lesser grain borer at 18°C and below 15°C all storage pests stop breeding.

Monitoring grain temperature is not only required to manage aeration, it can indicate potential insect activity in the grain stack. Insect activity generates heat, which provides favourable conditions for mould, impacting on grain quality.

When checking grain temperature, go beneath the surface, measuring in the same spot each time. Record test results to identify any temperature spikes, which will prompt further investigation.

Monitoring grain temperature can be done by:

- Inserting a portable temperature probe into the grain and waiting for the reading to stabilise.
- Leaving a digital thermometer with a one metre cable in the grain, which can be viewed monthly. Tie it to the silo roof in case it's forgotten when outloading.
- Installing a remote monitoring cable or spear into the storage which sends temperature and moisture data to a smart phone or web portal.

Check any electronic devices used for monitoring can withstand fumigation with phosphine or remove them prior, to avoid damaging electronic components.

Grain moisture content influences insect activity and mould (see Table 1). Identifying a change in moisture can reveal an issue before it causes significant damage. For example, an increase in grain moisture at the top of a storage could be a result of a leak, condensation or problem with aeration management.

Table 1: The effect of grain temperature and moisture on stored grain insect and mould development

Grain temperature (°C)	Insect and mould development	Grain moisture content (%)
40-55	Seed damage occurs, reducing viability	
30-40	Mould and insects are prolific	>18
25-30	Mould and insects active	13-18
20-25	Mould development is limited	10-13
18-20	Young insects stop developing	9
<15	Most insects stop reproducing, mould stops developing	<8

Source: Kondinin Group

VIDEOS

Grain storage hygiene

Preventing insect pests from entering grain storage

When it comes to controlling pests in stored grain — prevention is better than cure. Grain residues in storages or older grain stocks held over from last season provide ideal breeding sites. Meticulous grain hygiene combined with structural treatments, such as diatomaceous earth (DE), can play a key role in reducing the number of stored grain pests.

5.1 Hygiene before harvest

The first grain harvested is often at the greatest risk of early insect infestation due to contamination. One on-farm test found more than 1000 lesser grain borers in the first 40 litres of wheat passing through the harvester, which was considered to be clean at the end of the previous season.

Always remove grain residues from empty storages and grain handling equipment, including harvesters, field bins, augers and silos to ensure an uncontaminated start for new-season grain.

Clean equipment by blowing or hosing out residues and dust and then consider a structural treatment.

Remove and discard any grain left in hoppers and bags from the grain storage site so it doesn't provide a habitat for pests during the off season.

Photo 1: *Clean out harvesters and grain handling equipment thoroughly with pressurised air. (Source: Chris Warrick, Primary Business)*

5.1.1 Keeping it clean

A bag of infested grain can produce more than one million insects during a year, which can walk and fly to other grain storages, where they will start new infestations.

Meticulous grain storage hygiene involves removing any grain that can harbour pests and allow them to breed. It also includes regular inspection of seed and stockfeed grain so any pest infestations can be controlled before pests spread.

5.1.2 Where to clean

Removing an environment for pests to live and breed in is the basis of grain hygiene, which includes all grain handling equipment and storages. Grain pests live in dark, sheltered areas and breed best in warm conditions.

Common places where pests are found include:

- empty silos and grain storages
- aeration ducts
- augers and conveyers
- harvesters
- field bins and chaser bins
- left-over bags or drums of grain
- trucks
- spilt grain around grain storages piled over 20mm deep
- equipment and rubbish around storages
- seed grain
- stockfeed grain and feeding equipment.

Successful grain hygiene involves cleaning all areas where grain gets trapped in storages and equipment. Grain pests can survive in a tiny amount of grain, so any parcel of fresh grain through the machine or storage becomes infested.

5.1.3 When to clean

Straight after harvest is the best time to clean grain handling equipment and storages, before they become infested with pests. Discarding the first few bags of grain at the start of the next harvest is also a good idea. Further studies in Queensland revealed insects are least mobile during the colder months of they year.

Cleaning around silos in July – August can reduce insect numbers before they become mobile and start breeding more rapidity.

Photo 2: *A concrete slab under silos makes cleaning easier. (Source: Chris Warrick, Primary Business)*

Photo 3: *An extended broom handle makes sweeping out silos easer. (Source: Chris Warrick, Primary Business)*

5.1.4 How to clean

The better the cleaning job, the less chance of pests harbouring. The best ways to get rid of all grain residues use a combination of:

- sweeping
- vacuuming
- compressed air
- blow/vacuum guns
- pressure washers
- fire-fighting hoses.

Using a broom or compressed air gets rid of most grain residues, a follow-up wash-down removes grain and dust left in crevices and hard-to-reach spots.

Choose a warm, dry day to wash storages and equipment so it dries out quickly to prevent rusting.

When inspecting empty storages, look for ways to make the structures easier to keep clean. Seal or fill any cracks and crevices to prevent grain lodging and insects harbouring.

Bags of left-over grain lying around storages and in sheds create a perfect harbour and breeding ground for storage pests. After collecting spilt grain and residues, bury, feed to livestock or spread out over the ground at a depth of less than 20mm and away from the storage so it rots or germinates. Dumping grain within one kilometre of storage facilities allows insect to easily breed up and fly back to infest grain in storage.

5.2 Structural treatments

After cleaning grain storages and handling equipment treat them with a structural treatment. While most grain buyers accept small amounts of residue on cereal grains from structural treatments, avoid using them or wash the storage and equipment out before storing or handling oilseeds and pulses. Always follow label directions for safe application and storage. Diatomaceous earth is best stored in a sealed container to prevent it absorbing moisture from the air.

It is always safer to check with the grain buyer's delivery standards for maximum residue limit (MRL) allowances before using grain protectants.

Diatomaceous earth (DE) (amorphous silica), includes commercial brands such as Dryacide, can be applied either as a dust or a slurry to treat storages and handling equipment for residual control (Table 1). DE acts by absorbing the insect's cuticle (protective exterior), causing death by desiccation (drying out). If applied correctly with complete coverage in a dry environment, DE can provide up to 12 months protection — killing most species of grain insects and with no risk of building resistance.

Photo 4: *Apply diatomaceous earth aiming for an even coat on the roof, walls and base. (Source: Chris Warrick, Primary Business)*

5.2.1 Applying diatomaceous earth dust

Diatomaceous earth requires a moving air-stream to direct it onto the surface being treated.

A venturi duster such as the Blovac BV-22 makes application of DE a quick and easy job. Another option is to use a battery or petrol powered leaf blower, trickling the DE into the air stream as it exits the blower.

The application rate is calculated at two grams per square metre of surface area treated (Table 1). Efficacy is improved with even coverage of all surfaces, so adjust the application until consistent coverage is achieved, then rinse or vacuum out any excess dust prior to filling with grain. Table 1 is a guide application rate that may require increasing to allow for aeration ducting, false floors and corrugated iron which increases surface area by approximately 10%.

Although inert, wearing a dust mask and goggles during handling and application will prevent lung and eye irritation.

Table 1: Diatomaceous earth (DE) application guide

Storage capacity (t)	DE quantity (kg)
80	0.22
100	0.27
120	0.29
150	0.33
300	0.52
1000	1.24
2000	1.94
3000	2.57

Source: Kondinin Group

5.2.2 Silo application

Open all outlets and apply via the ground access door, moving the Blovac gun or leaf blower quickly to coat the roof and walls, the base will be covered once the dust falls out of suspension.

Finish by closing all outlets top and bottom to capture the remaining suspended dust and keep moisture out of the silo. Do not leave empty, gas-tight silos sealed as pressure fluctuations from ambient conditions can damage the silo. Leave an opening, for example, the fan inlet covers, off to allow rapid pressure equalization. If silos are fitted with aeration systems, distribute the DE dust into the ducting without getting it into the motor, where it could potentially cause damage.

Full-floor aeration systems in flat bottom silos can be challenging from a hygiene perspective. Clean dust and grain residues out as best as possible before applying DE in the silo. Finish by sweeping or blowing some DE under the false floor.

5.2.3 Machinery application

DE can be used in any equipment that handles or stores grain. Application is ideally done after a thorough clean and after the annual maintenance has been completed so workers or mechanics aren't subjected to the dust as they work.

Calculation of surface areas of machinery is not normally possible.

For augers, conveyors and grain handling equipment, use a Blovac or leaf blower to apply a steady dust stream into accessible openings, coating all the internal surfaces as much as possible. Continue until a dust stream emerges from the exit/discharge points of the equipment.

For an average harvester the recommended quantity of DE is about 2.5 kilograms.

5.2.4 Applying diatomaceous earth slurry

With the right equipment, DE can also be applied in a slurry form, which is a good option for larger flat bottom silos and sheds. A little more involved than applying dust, the slurry needs to be mixed in a mixing tank then sprayed on through a flat fan nozzle capable of at least five litres per minute.

Mix the DE with water at a rate of 11 per cent (120 grams of DE per litre of water) to form a slurry and apply at five litres per 100 square metres or six grams per square metre (dry basis). The aim is to apply the slurry to give complete coverage but ensure it doesn't run off the walls of storages and equipment.

Impeller pumps are most suitable — typically a fire-fighting pump with a 3.7 kilowatt (five horsepower) motor is a good option. Do not use positive displacement pumps, such as gear or piston pumps, as they will block easily. An inline filter with 1000 micron (one millimetre) mesh and a recirculation hose for agitation will help prevent nozzle blockages and keep the slurry mixed during application.

If applying a lot of slurry regularly, use a designated, older pump or cheap pump as pumping slurry will reduce a pump's working life. Apply the slurry in the same order as the dust — start at the top of the silo or storage and work down the walls applying an even coat, avoiding runs from spraying too close or too much slurry.

A solid pipe extension on the application hose will enable a more even coating on hard-to-reach areas such as silo or shed walls.

5.2.5 External structural treatments

Controlling grain storage pests outside of storages is primarily achieved with hygiene as insects cannot survive long without shelter and food. If treatment is required after cleaning outside of storage areas, DE is unlikely to be effective unless relative humidity remains low for several days and nights.

At the time of printing, chemicals registered for structural treatment of grain storages include Fenitrothion (Fenitrothion 1000g/L), Diplomat 500 EC (Chlorpyrifos-methyl 500g/L), Fyfanon 440 EW (Malathion 440g/L) and Cislin 25 (Deltamethrin 25g/L).

While it is registered, resistance to Malathion is high so efficacy is likely to be limited. A mixture of Deltamethrin with either Chlorpyrifos-methyl or Fenitrothion would give the best chance of broad spectrum control for external areas.

Post-harvest checklist

- ✓ Sweep or blow out all empty grain storages and equipment.
- ✓ Wash down with water on a warm, dry day (if silos can be drained).
- ✓ If not storing oilseeds or pulses, apply structural treatment.
- ✓ Monitor all stored grain fortnightly during summer, monthly during winter.

5.3 Grain protectants

The use of protectants, combined with meticulous hygiene and aeration cooling, is especially useful to prevent pest incursions in unsealable storages, where effective fumigation is not possible (Protectant options are limited in Western Australia, check label registration before purchasing and applying).

Always check with potential grain buyers before applying protectants as some markets do not accept any chemical residues on grain.

Grain protectants are designed to prevent pest infestations, not to control an existing insect infestation. Apply only to clean, pest-free grain.

In order to give protectants the best chance to defend stored grain, combine their use with meticulous storage hygiene practices before and after harvest.

Cleaning up the storage site and the harvesting equipment removes harbours where pests can survive, ready to infest the new season's grain. The addition of aeration cooling also provides an unattractive environment for pests in stored grain.

VIDEOS

Grain storage protectant choice

5.3.1 Protectant choice

Always read the chemical label before choosing a protectant to ensure it is registered for use on the grain you wish to apply it to and will target the main insects commonly found in your storage. As a general guide, most protectants are only registered for use on cereal grains.

Protectant trade names vary but the primary chemistry choices are Spinosad (which will have S-Methoprene included) or Deltamethrin. Chemistry selections should be rotated each year or two to prevent resistance. Either of these options are effective against Saw-toothed grain beetle, Rust red flour beetle and Flat grain beetle but for Lesser grain borer, Spinosad has higher efficacy.

To include protection against the Rice weevil, Fenitrothion or Chlorpyrifos-methyl will need to be included or added as a mixing partner, depending on the grain type, withholding period and market acceptance.

For malt barley, rice or maize, Fenitrothion is the only choice of mixing partner but be aware of the 90 day withholding period if applied at the higher rate for nine-month protection. For application on other cereals, Chlorpyrifos-methyl has the flexibility of no withholding period but is not accepted by some export markets so is often chosen for domestic or own use feed cereals.

Some protectant manufacturers offer pre-mixed options that include; Spinosad with Fenitrothion or Chlorpyrifos-methyl; or Deltamethrin with Fenitrothion or Chlorpyrifos-methyl. Where chemistries are available pre-mixed, application is a more simple process.

Always check if the intended grain buyer accepts the chosen protectants, read and follow product label directions and apply a chemistry only once to a parcel of grain. (Note: This is a guide only and protectant choice and application is limited in Western Australia)

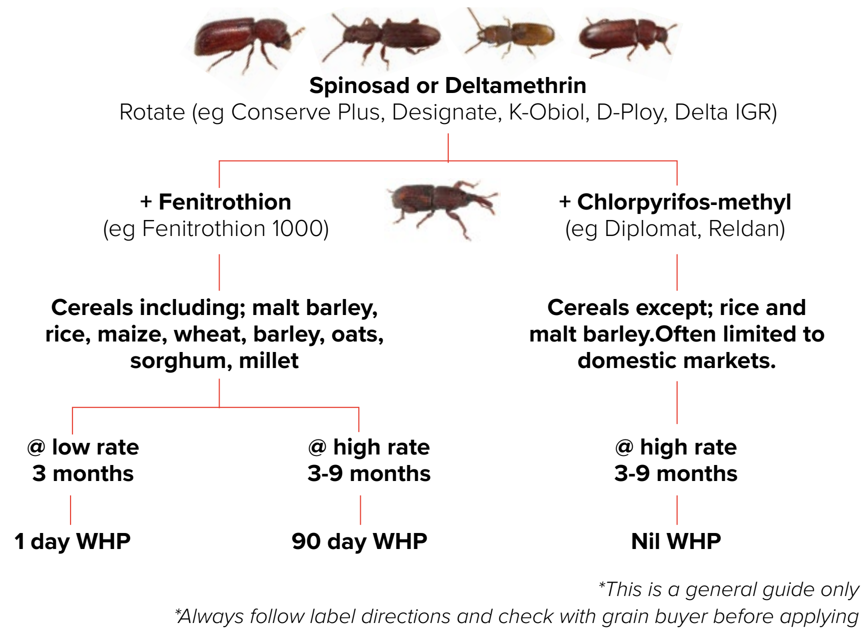

Figure 1: *Protectant choice guide (Not applicable to Western Australia))*

VIDEOS

[Stored Grain Protectant Application System Components]

5.3.2 Protectant application guide

For even protectant coating of the grain, best results are achieved with one, or even better with two, flat fan nozzles mounted to spray into the auger as the grain is loaded into storage. Applying protectants with water to grain at 1 L/t is not easy and relies on mixing to achieve coverage as the grain passes up the auger.

Applying protectants in a belt conveyor does not provide adequate mixing and even coating. Spray can also cause issues with the belt slipping on drive rollers. Some conveyor manufacturers offer a separate application kit — ensure it can apply the protectant evenly to the stream of grain and includes agitation to mix the product through the grain.

Some protectants start deteriorating 48 hours after being mixed with water so avoid leaving for long periods before applying to grain. The product label will also indicate the anticipated effective life of the protectant on the grain, generally three months but up to nine months in some applications.

The effective life of protectants is shortened if applied to grain above 12 per cent moisture content (MC) and above 27°C or is exposed to direct sunlight, such as the end of a shed or an open bunker.

Key components for protectant application systems

- Pump delivery to match auger capacity at 1 L/t plus 10% recirculation
- Bypass line for recirculation and shutoff relief
- Flow regulator or variable position tap
- Flow meter
- Pressure gauge
- Filter
- Flan fan nozzle(s) that are easily removable for checking and cleaning
- Non-return valve to stop syphoning or dribbling once lines are primed

5.3.3 Maximum residue limits (MRLs)

As grain markets have become less tolerant to protectants and maximum residue limits (MRLs) are monitored scrupulously, accurate application is essential.

Some of the protectants, even if used at the recommended label rate, are close to the MRL leaving no room for error in applying the correct rate and even spread. Commodity vendor declarations are also used in many cases to ensure a parcel of grain is only subjected to one application of the protectant to avoid exceeding the MRL. Brief training or stewardship programs are often required prior to purchasing protectants, to ensure proper use is understood and grain marketing is not compromised by misuse.

5.4 Aeration cooling

Aeration of stored grain has four main purposes — preventing mould, inhibiting insect development, maintaining grain quality and managing grain moisture. Grain aeration allows growers to maintain grain quality during harvest and storage and while aeration cooling may not eliminate the need for chemical insect control, it will dramatically slow insect development

While adult insects can still survive at low temperatures, most young storage pests stop developing at temperatures below 18–20°C (see Table 3).

At temperatures below 15°C the common rice weevil stops developing.

At low temperatures insect pest life cycles (egg, larvae, pupae and adult) are lengthened from the typical four weeks at warm temperatures (30–35°C) to 12–17 weeks at cooler temperatures (20–23°C).

Without aeration cooling, grain is an effective insulator and will maintain its warm harvest temperature for a long time.

Like housing insulation, grain holds many tiny pockets of air within a stack — 100 tonnes of barley requires a silo with a volume of about 130 cubic metres, $80m^3$ is taken up by grain and the remaining $50m^3$ (38 per cent) is air space around each grain.

Without circulation, the air surrounding the grain will reach a moisture (relative humidity) and temperature equilibrium within a few days. These conditions provide an ideal environment for insects and mould to thrive and without aeration the grain is likely to maintain that temperature and moisture for months.

Table 2: The effect of grain temperature on insects and mould

Grain temperature (°C)	Insect and mould development
40–55	Seed damage occurs, reducing viability
30–40	Mould and insects are prolific
25–30	Mould and insects are active
20–25	Mould development is limited
18–20	Young insects stop developing
<15	Most insects stop reproducing, mould stops developing

Source: Kondinin Group

VIDEOS

GCTV2: Grain Storage Cooling Aeration

GRDC: Aeration controllers with Philip Burrill

5.4.1 Air movement within the grain stack

Grain at the top of the stack is the hottest, as heat rises through the grain. The sun heats the silo roof and internal head space, resulting in the surface grain at the top of the silo heating up (see Figure 2).

When grain is stored at moisture contents above 12 per cent, the air in the head space heats and cools each day creating ideal conditions for condensation to form, wetting the grain at the top of the stack.

Grain aeration systems are generally designed to carry out either a drying or cooling function — not both.

Aeration cooling can be achieved with airflow rates of 2–4 litres per second per tonne, whereas aeration drying requires fans delivering 15–25L/s/t

Low-capacity fans cannot carry enough moisture through the grain stack so can't push the drying front through the grain fast enough to dry grain in the top section of a stack before it turns mouldy.

In addition to being inefficient, using high-capacity fans for cooling can potentially introduce moisture causing mould around the aeration duct if run when ambient conditions are above 85 per cent relative humidity. If a storage is only fitted with high-capacity aeration drying fans, options for aeration cooling include; reducing fan run time, fitting a smaller fan for cooling, restricting the drying fan inlet to reduce its capacity or installing a variable speed drive to reduce fan speed.

For more information on aeration drying, to manage high-moisture grain, see Section 7 Managing high moisture grain.

Cooling or drying — making a choice

Knowing whether grain needs to be dried or cooled can be confusing, but there are some simple rules to follow:

- Grain that is dry enough to meet specifications for sale (Typically 12.5–13 per cent for wheat or 13.5 per cent for sorghum) can be cooled, without drying, to slow insect development and maintain quality during storage.
- Grain of moderate moisture (up to 15 per cent for wheat and sorghum) will require aeration drying to reduce the moisture content to maintain quality during storage.
- If aeration drying is not available immediately, moderately moist grain can be cooled for a short period to slow mould and insect development, then dried when the right equipment and conditions are available.
- High-moisture grain (for example, 16 per cent and higher for wheat and sorghum) will require immediate moisture reduction before cooling for maintenance.
- After drying grain to the required moisture content, cool the grain to maintain quality.

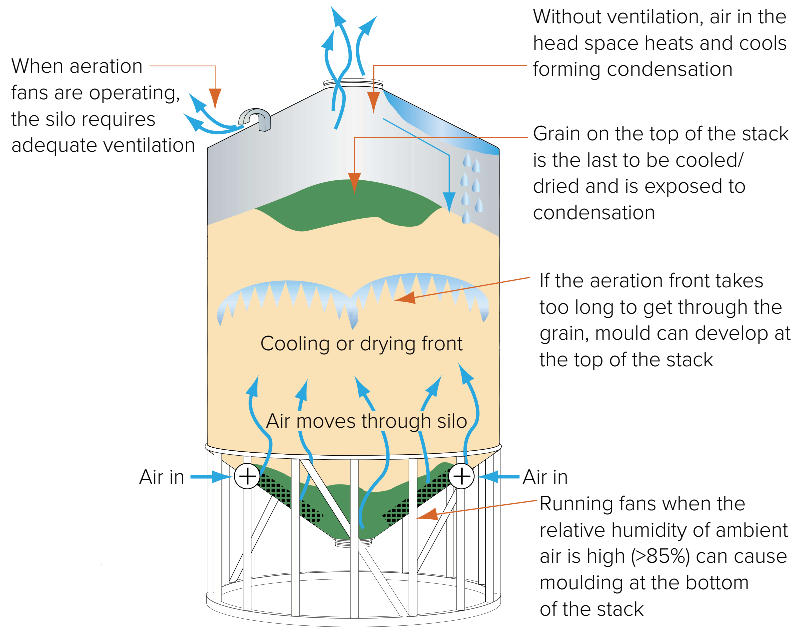

Figure 2: *Air movement within an aerated silo*

Source: Kondinin Group

5.4.2 Uniformity

Without aeration cooling, grain put into storage at warm harvest temperatures will hold these temperatures for a long time, see Figure 3. With 38 per cent of the storage area still taken up by air between individual grains, a grain stack becomes an effective insulator.

When filling a silo with harvested grain, it's common to end up with layers of various grain moisture contents and temperatures.

Aeration cooling moves the air pockets around the grain, which evens out any hot or moist areas, creating a 'uniform stack'. This prevents hot spots forming, which are ideal locations for mould and insects to develop and spread through the storage.

5.4.3 Condensation

Air in the head space of a silo heats during the day, and cools at night creating ideal conditions for condensation to form. As illustrated in Figure 2, without aeration and ventilation, condensation can cause damp patches of grain at the top of the silo. Damp grain provides a breeding ground for insects and mould. Active insects create heat, which makes it an even more attractive breeding ground, so insects quickly multiply and spread through the grain bulk.

Aeration cooling and ventilation in storage reduces condensation and the adverse effects it creates.

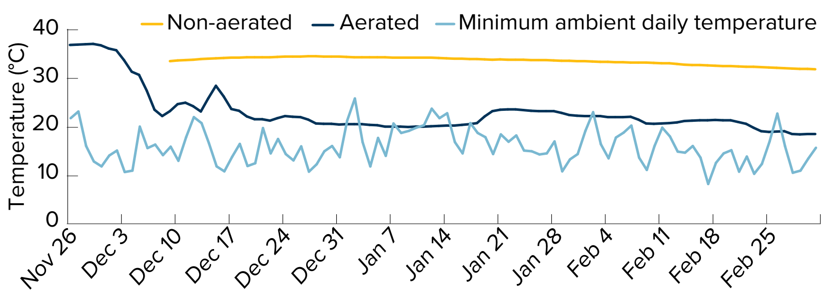

Figure 3: *Aeration cooling vs no aeration cooling*

Source: NSW DPI

5.4.4 Grain temperature targets

In the same way moisture affects the development of mould and insects; temperature also has an impact.

Storing grain at or below the delivery standard moisture content (12.5 per cent for most grains) reduces the chance of mould and insects developing, but warm or hot grain is still attractive for insects.

At cool temperatures insect pest life cycles (egg, larvae, pupae and adult) are extended from the typical four weeks at warm temperatures (30–35°C) to 12–17 weeks life cycles at cooler temperatures (20–23°C).

While adult insects can still survive at cool temperatures, young insects stop developing at temperatures below 18–20°C. At temperatures below 15°C weevils stop developing and most insects stop reproducing (Table3).

Table 3: Lower limits to reproduction

Insect	Temperature (°C)
Rice weevil	15
Bruchid — cowpea weevil	17
Lesser grain borer	18
Rust-red flour beetle	20
Saw-toothed grain beetle	20

Source: DAF, QLD

MORE INFORMATION

Aeration backpressure test results

5.4.5 Aeration system design

Fan selection

Selecting the right fan(s) for aeration requires consideration of the target flow rate, depth of grain and type of grain. As an example, the backpressure inflicted on an aeration fan operating in canola has been found to be more than double that of wheat. Large grains such as chick peas on the other hand, have been found to inflict only one quarter of the back pressure of wheat. Operating backpressure has also been found to increase exponentially with grain depth or as flow rate is increased. Follow the link or QR Code in the margin for the latest findings on aeration back pressure of various grains.

Past research has found aeration flow rates of 1-2 L/s/t will achieve cooling over time. More recent trials have found that flow rates of 2-4 L/s/t cool grain much quicker, enable short term storage of grain slightly over moisture and provide a safety margin for grains that inflict a higher backpressure on the fan.

If multiple fans are required to achieve the desired air flow rate they must be identical but be aware that a second or third fan won't double and triple flow rates. As flow rate is increased with multiple fans, so too is backpressure, reducing performance of each fan. Observations have found the second fan to increase the initial flow rate by approximately 50%, and the third fan by a further 30%. Adding a fourth fan has been found to provide negligible additional airflow or even decrease total air flow. Results of single or multiple fans will depend on each fan's backpressure operating range.

Ducting and ventilation

While aeration cooling can be achieved with relatively low airflow rates, appropriate ducting location and design to distribute air evenly through the grain stack helps prevent areas with little or no airflow.

Position ducting where it will provide even air distribution throughout the storage.

In a number of cases, such as aeration systems for large silos or grain sheds, it is important to obtain professional advice on duct and vent requirements. sheds, it is important to obtain professional advice on duct and vent requirements. As a general guide, full floor or false floor type aeration ducts provide ideal air distribution for drying. Trench style ducts are adequate for aeration cooling and can be removed for cleaning.

Any restriction to airflow due to inadequate ducting or ventilation will create extra back pressure, which will significantly restrict fan performance, resulting in reduced airflow. Systems that require flexible ducting between the fan and the silo, or fans ducted to multiple silos significantly inhibit fan performance and air distribution.

Aeration cooling fans can be retro fitted to cone bottom silos relatively simply and are a particularly valuable addition to silos that cannot be gas-tight sealed for fumigation. Look for a kit that is simple to install and easy to clean. (See photo 5)

Photo 5: *When ordering aeration kits for cone bottom silos, look for one that is simple to install and easy to clean. (Source: Chris Warrick, Primary Business)*

Hygiene in ducting

When considering ducting, what is best for aeration is often worst for hygiene. Aeration ducting collects grain dust and small particles providing an ideal environment for insect pests. Even structural treatments for insect control will not penetrate thick layers of dust in aeration ducting, so insects survive, ready to infest the next batch of grain that enters the storage.

The best solution is ducting that can be cleaned easily or removed for cleaning.

Most tubular ducting and trench-type ducts in flat-floored silos can be cleaned thoroughly with a compressed air nozzle or industrial vacuum cleaner, but a full-floor perforated air plenum in a flat-bottom silo is difficult to clean properly.

Silos have various systems for cleaning in-floor ducting and plenums, but the most thorough system is a floor with removable sections to allow access for cleaning.

For more information on hygiene around grain storages, see Section 5.1 Hygiene.

MORE INFORMATION

Note: If aeration cooling is being used to hold moderately high-moisture grain (up to 15 per cent moisture content for wheat or sorghum) temporarily until drying equipment is available, run fans continually while the ambient relative humidity is below 85 per cent. Balance this with not leaving fans off for extended periods during the first few days of storage. Airflow of 3-4l/s/t is required.

MORE INFORMATION

Note: Some automatic aeration controllers with a relative humidity override will not stop the fans if it is set on 'manual' or 'continuous' mode and may need to be set to a setting such as 'auto continuous'.

VIDEOS

Utilising aeration cooling in grain storage

Aeration cooling - too selective too soon

5.4.6 The cooling process

FAQ

When grain is at a desired moisture level, cooling can be initiated. While temperature is the focus for cooling grain, table 4 illustrates the affect that relative humidity has on the resulting grain temperature. For example, grain at 12 per cent moisture content cooled with 25°C ambient air, will reach an equilibrium of 20°C if the ambient air is 30 per cent relative humidity, or 28°C if the ambient air is 75 per cent relative humidity.

The process of cooling grain occurs in three stages — continual, rapid then maintenance.

Stage one — continual aeration

The initial aim is to get maximum airflow through the grain bulk as soon as it goes into storage, to push the first cooling front through and lower grain temperature.

Without aeration, grain typically increases slightly in temperature immediately after it goes into storage.

When first loading grain into storage, run the aeration fans continuously from the time the grain covers the aeration ducts for 5 days, or until the air coming out the top of the silo changes from warm and humid to cool and fresh. The time required for this and each cooling stage will vary with the storage size and air-flow rate.

Do not operate the aeration fans on continuous mode for more than a few hours, if the ambient relative humidity is higher than 85 per cent, as this can introduce moisture around the aeration duct and cause mould.

FAQ

Stage two — rapid cooling

After aeration fans have been running continuously to flush out the warm, humid air, reduce run time to 9–12 hours per day for the next 7 days. The difficulty is selecting the coolest air to run the fans and being on site to turn the fans on and off.

Automatic aeration controllers that use time proportioning control (TPC) call this phase 'rapid' or 'purge'. During this stage they are programmed to run fans during the coldest 12 hours of each day. The goal is to quickly reduce the grain temperature from the mid 30°Cs to the low 20°Cs.

An initial reduction in grain temperature of 10°C ensures grain is less prone to damage and insect attack, while further cooling becomes a more precise task.

Stage three — maintenance cooling

After the 'rapid' or 'purge' phase TPC automatic controllers are then switched to 'normal' or 'protect' mode. During this final phase they continually monitor ambient conditions and run fans on average during the coolest 100 hours per month.

Operating fans without a controller is a lot more difficult, but the aim is to select the coolest air, providing it is below 85 per cent relative humidity, and running fans, on average, for a total of 100 hours per month.

This rule-of-thumb run-time may vary from week to week with weather cycles and automatic controllers often won't run fans for up to 7–10 days. The controller may then take advantage of a cool change in the weather, running fans for up to 48 hours to catch up.

Table 4: The relationship between air temperature and relative humidity and grain moisture content

Inlet air		Resulting temperatures in wheat at varying moisture contents (°C)		
Temperature (°C)	Relative humidity (%)	10	12	14
15	30	15	12	10
	45	17.5	14	12
	60	20	16	13.5
	75	22	18	15.5
20	30	20	16	13.5
	45	22.5	18.5	16.5
	60	25	21	18.5
	75	27.5	23	21
25	30	24	20	17.5
	45	27	23	20.5
	60	30	25.5	23.5
	75	32.5	28	25.5
30	30	28	24	22
	45	31.5	27	25
	60	34.5	30.5	28
	75	37.5	33	30.5

Source: DAF, QLD

Photo 6: *In-floor aeration ducting in flat-bottom silos, which can be removed for cleaning, is ideal. (Source: Ben White, Kondinin Group)*

5.4.7 Automatic controllers for cooling

For the purposes of aeration cooling, automatic controllers are by far the most effective and most efficient method of control. Not only will they cool grain quickly and efficiently, they all have trigger points to turn fans off if ambient conditions exceed 85 per cent relative humidity.

Automatic aeration controllers for cooling are available in four main variations:

- Set-point controllers
- Time Proportioning Controllers (TPCs)
- Adaptive Discounting Controllers (ADCs)
- Internal sensing controllers.

Set-point controllers

The set-point controller requires the operator to select a specified temperature and relative humidity that will trigger fan operation. As time passes these set points need to be manually adjusted to allow for more precise cooling.

Set-point controllers are generally at the lower end in price and in turn provide a lower level of automation and control. Be aware that the relative humidity sensors used in lower cost controllers may not be accurate above 75 per cent relative humidity, risking inaccurate switching and moisture introduction which could cause mould.

Time proportioning controllers (TPCs)

Put simply, TPCs monitor ambient conditions and use algorithms to operate like a self-adjusting thermostat.

They continually recalculate a trigger point to select the coolest part of the day to run fans. The unique feature is that the moving trigger point means fans may not run for several days if conditions are warm. But will then run continuously for several hours, even days, to take advantage of a cool change. These controllers are generally well balanced in price, performance and usability for on-farm storages.

Adaptive discounting controllers (ADCs)

Adaptive discounting controllers rely on the operator entering all the parameters of the storage, aeration capacity, quantity of grain, grain moisture and temperature and the grain moisture and temperature targets. The ADC then monitors the ambient conditions and runs the fans at times when the ambient conditions are calculated to get the grain closer to the target temperature.

These controllers rely on the storage, aeration system and grain parameters being entered accurately at every fill, in order to be effective.

Internal sensing controllers

Internal sensing controllers use sensors inside the storage and compare them with ambient conditions. If the difference in ambient to internal conditions will get the grain closer to its target temperature, then the controller turns the fans on.

Internally sensing controllers are generally suited to high-value products stored in commercial sites as they are usually at the higher end of the pricing scale and have the highest cost of installation, but in turn are expected to have superior performance.

If considering a controller with internal sensors, ensure a fail safe or alert system notifies the operator if there's an issue with one of the sensors or communication to it.

Photo 7: *At grain temperatures below 15°C most storage pests stop reproducing. (Source: Chris Warrick, Primary Business)*

MORE INFORMATION

Insect resistance testing contact details

Managing insect pests in stored grain

The tolerance for live pests in grain sold off farm is nil. With growers increasing the amount of grain stored on farm, an integrated approach to pest control is crucial.

For grain storage, four key factors provide significant gains for both grain storage pest control and grain quality: hygiene, aeration cooling, regular monitoring and correct fumigation.

The combination of meticulous grain hygiene plus well-managed aeration cooling can prevent a lot of storage pest problems.

For more information on grain hygiene and aeration cooling, see Section 5 Preventing insect pests from entering grain storage.

The two main fumigants suited for on-farm use are phosphine and sulfuryl fluoride. Due to its cost effectiveness and ease of access, in most states with an Australian Chemical User Permit, phosphine is the most common choice. But with rising levels of resistance and a greater understanding of the importance to rotate chemistry, many growers are engaging approved commercial fumigators to use sulfuryl fluoride on a rotational basis.

Both phosphine and sulfuryl fluoride require gas-tight sealable storage for effective control on all life stages of pests. While phosphine is registered for all grains commonly grown in Australia, sulfuryl fluoride is not registered for human consumption pulses or oil seeds. If fumigating cool grain, phosphine is effective down to 150°C with a longer exposure period, sulfuryl fluoride is affect at grain temperatures as low as 200°C.

A particular strain of the Flat grain beetle (*Cryptolestes ferrugineus*), sometimes referred to as 'Rusty grain beetle' has been found to have strong resistance to phosphine. If these pests are found to survive a fumigation with phosphine, send a sample for resistance testing and refumigate with sulfuryl fluoride or other fumigant or controlled atmosphere. See the link opposite for contact details of your nearest laboratory.

VIDEOS

GCTV Stored Grain: Fumigation recirculation

GCTV Stored Grain: Phosphine dose rates

GCTV7: Overcoming phosphine resistant insects

6.1 Fumigating with phosphine

Phosphine remains the single-most relied upon fumigant to control stored grain pests in Australian grain production systems, but continued misuse is resulting in poor insect control and developing resistance in key pest species (see Figure 1).

A Grains Research and Development Corporation (GRDC) survey carried out during 2020 revealed only 54 p per cent of growers using phosphine applied it correctly — in a gas-tight, sealed silo.

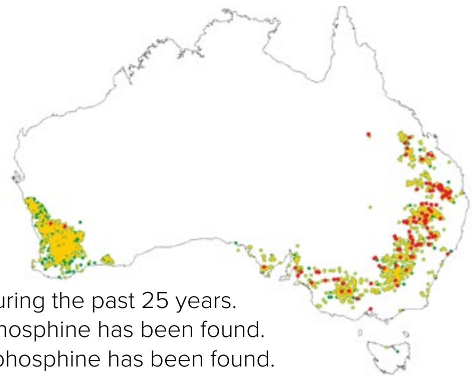

Figure 1: *Phosphine resistance – National situation*
Source: DPIRD

Taking fumigation shortcuts may kill enough adult insects in grain so it passes delivery standards, but the repercussions of such practices are detrimental to the grains industry. In order to kill grain pests at all stages of their life cycle (egg, larva, pupa, adult), phosphine gas needs to reach, and be maintained at, a concentration possible only in a gas-tight storage.

Poor fumigation techniques fail to kill pests at all life cycle stages, so while some adults may die, grain will soon be reinfested again as soon as larvae and eggs develop. What's worse, every time a poor fumigation is carried out, insects with some resistance survive, making the chemical less effective in the future.

Using the right type of storage is the first and most important step towards an effective fumigation. Only use fumigants, like phosphine, in a pressure-tested, gas-tight sealed silo. Research shows that fumigating a storage that is anything less than gas-tight sealed doesn't achieve a high enough concentration of fumigant for a long enough period to kill pests at all life cycle stages.

Photo 1: *Correct phosphine use will ensure we don't add to the population of resistant grain storage pests. (Source: DPIRD)*

Plan, monitor and control for clean grain

- Dispose of grain residues and seed gradings. Clean empty storages and grain handling equipment, including harvesters, field bins and augers.
- Apply structural treatments to empty storages and grain handling equipment.
- Sieve stored grain for the presence of insects at least monthly, and use probe traps. Also check grain temperature and moisture.
- If grain temperature has been kept below 20°C by well managed aeration cooling, insect numbers are likely to be low.
- Sample grain three weeks before sale to allow time for any fumigation treatment.
- For effective fumigations, pressure test sealable silos at least once a year to identify any leaks and maintain rubber seals.
- Phosphine fumigation process typically requires 10–17 days so allow enough time before outloading. (27 days in large storages without recirculation and longer in grain bags with only passive venting).

6.1.1 Control all life stages

To control pests at all life stages and prevent insect resistance, phosphine gas concentration needs to reach 360 parts per million (ppm) and remain above this level for 7-10 days. At this concentration, an exposure period of seven days is required when grain is above 25°C or 10 days if between 15–25°C. Insect activity and development is slower in cooler grain temperatures so require longer exposer to the gas for all life stages to receive a lethal dose.

Fumigation trials in silos with small leaks demonstrated phosphine levels are as low as 3ppm close to the leaks. The rest of the silo also suffers from reduced gas levels making it impossible to kill insects at all life stages.

Figure 2 illustrates the concentration levels achievable in a 130t gas-tight sealed silo that performs a 3.5 minute half-life, pressure test. The required 360ppm is reached at the top and middle of the silo within the first day and is reached at the bottom by mid-way through the second day. The gas concentration then remains well above 360ppm for the required seven days.

Figure 3 shows that in a 130t silo with minor leaks (not gastight) phosphine gas concentrations do not reach the required concentration level, for the necessary period, to kill pests at all life stages.

Concentration levels at the top of the silo in Figure 3 do go above the required 360ppm but only for four days, not the required seven days. At the middle of the silo gas concentration levels don't even reach 360ppm and at the bottom of the silo gas concentrations are so low (zero to 3ppm) they are barely detectable.

The poor gas concentration levels in the silo in Figure 3 are a result of gas leaking out through two minor gaps, one in the top and the other at the bottom of the silo.

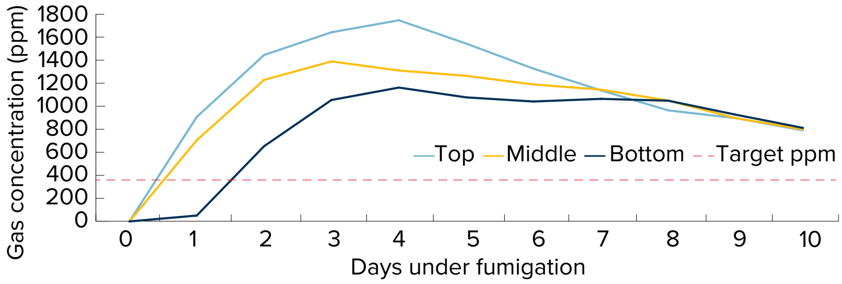

Figure 2: *Gas concentration in a gas-tight silo (3.5 minute half-life pressure test).*
Source: DAF, QLD

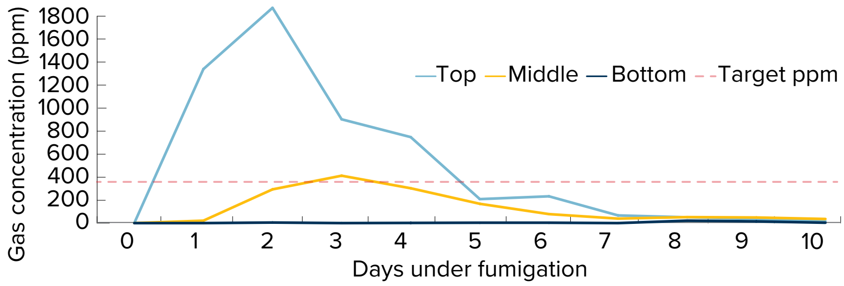

Figure 3: *Gas concentration in a non-gas-tight silo (8 second half-life pressure test).*
Source: DAF, QLD

Poor fumigations may appear successful when some dead adults are found but many of the eggs, pupae and larvae are likely to survive and will continue to develop and reinfest the grain.

These partial kills are often worse than no kill at all because the surviving insects, (adults, pupae, larvae and eggs) are likely to be those that carry phosphine resistance genes. Underdosing risks increasing the number of insect populations carrying the genes for phosphine resistance and this has serious consequences for the industry.

Storage choices

When buying a new silo, buy a quality, gas-tight sealable silo fitted with aeration and check with the manufacturer that it meets the Australian Standard for sealable silos (AS2628–2010).

Standards body SAI Global published an Australian standard for gas-tight sealable silos in response to industry concerns that phosphine fumigation performed in improperly sealed storages was not killing off the full life cycle of pests.

Resistance to phosphine has increased over the past 20 years, largely due to many grain silos failing to meet the gas-tight standard required for effective fumigation. Resistance to phosphine in target insect pests has increased in frequency and strength threatening effective control.

The standard is based on a new silo meeting a five-minute half-life pressure test. When a pressure test is undertaken, oil levels in the pressure relief valve must take a minimum of five minutes to fall from 25mm to a 12.5mm difference if the silo is sufficiently gas-tight.

The standard provides an industry benchmark when choosing to buy a sealable silo. Ask the manufacturer or reseller to quote the AS2628–2010 on the invoice as a means of legal reference to the quality of the silo being paid for and insist they demonstrate a five-mintue, half-life pressure-test on delivery or completion of the build.

VIDEOS

Get gas-tight storage

VIDEOS

[Grain Storage Series: Pressure testing silos]

VIDEOS

[Good reason to pressure test silos before fumigating]

Experience has shown that at least two, gast-tight sealable, aerated silos on farm provide the option for an effective batch fumigation and delivery program.

Many older silos are not designed to be sealed and cannot be used for fumigation, however retro-fitting aeration can reduce insect development through grain cooling.

For more information on selecting a suitable grain storage system, see [Section 1 Grain storage — planning and purchasing.]

6.1.2 Pressure testing sealable silos

Pressure testing a silo ensures it can hold gas concentrations sufficient to kill all insects at all life stages. Just because a silo is sold as a sealed silo, does not automatically mean it's suitable for fumigation. Even if a silo is sold as 'sealed' it is not sealed until it is proven gas-tight with a pressure test.

To some people a sealed silo may be one that keeps rain out or one that is sold labelled as a sealed silo. A silo is only truly sealed if it passes a five-minute half-life pressure test according to the Australian Standard AS2628–2010. Often silos are sold as sealed but are not gas-tight — rendering them unsuitable for fumigation.

The term 'sealed' has been used loosely during the past and in fact some silos may not have been gas-tight from the day they were constructed. However, even a silo that was gas-tight to the Australian Standard on construction will deteriorate over time so needs annual maintenance to remain gas-tight sealable for fumigation.

If silos are properly maintained pressure testing does not take long and should be done at three distinct times.

1. When a new silo is erected on farm carry out a pressure test at a suitable time of day to make sure it's gas-tight before paying the invoice or filling with grain.
2. When a silo is full of grain before fumigating. Particularly if cone bottom silos have a slide plate outlet that has been tested empty, retest when full to make sure the pressure of the grain doesn't compromise the seal.
3. As part of annual maintenance. It is much easier to replace seals and carry out repairs when silos are empty.

Start a pressure test with equal oil levels on the middle marker.

Pressurise silo to create a difference in oil levels of 25mm.

The time taken for the oil levels to drop from 25mm apart to 12mm apart must be no less than five minutes on new silos. For older silos, three minutes is acceptable.

Photo 2: *Pressure testing a gas-tight, sealable silo – required for effective phosphine fumigation. The Australian Standard (AS2628) states that sealable storage must perform a five-minute, half-life pressure test (photos left to right). (Source: Chris Warrick, Primary Business)*

VIDEOS

GCTV2: Pressurising a silo

VIDEOS

On-farm Grain Storage: Pressure relief valves

Carrying out a pressure test

1. Choose the right time to pressure test

Consider the ambient conditions of the day before pressure testing. The best time to pressure test silos is before sunrise or on an overcast day — when the ambient temperature is stable and the sun is not heating the silo.

Air inside a silo heats and expands as the daily temperature rises and the sun warms the silo walls, and contracts as ambient temperatures fall or wind blows having a cooling affect on the silo.

If a pressure test is done when the ambient conditions are changing, air inside the silo expands or contracts and gives a false reading which doesn't prove anything.

2. Check seals

Before performing a pressure test check seals around the lid, access hatch, and outlet and make sure the aeration fan seal is in a sound condition. Check to ensure all latches on lids are locked down firmly.

3. Install an air valve

The simplest method of pressurising silos is with a battery powered leaf blower. A 50mm ball valve fitted into the silo or an adapter to thread the ball valve onto the passive recirculation pipe make it easy to introduce air, then close off to perform the test.

4. Check oil levels

Pressure relief valves are ideally filled with light hydraulic oil such as IS046 or IS032. This provides adequate viscosity for effective pressure relief without evaporating or fouling.

Some sealable silos do not have easy to view, oil relief valves, in which case there are three options. Replace the oil relief valve, make a manometer out of a piece of hose or purchase a digital or analogue manometer.

Before pressurising the silo, check the oil levels are equal on both sides of the gauge and are at the middle indicator mark as shown in Photo 3. If markings aren't clear, use a marker pen to make it easy to see the three positions - level, 25mm apart and 12mm apart. (Remember that 25mm apart means the oil will rise 12.5mm one side and fall 12.5mm the other side. At 12mm apart, the oil will be 6mm above level on one side and 6mm below level on the other side.)

Photo 3: *Ensure the pressure relief valve has enough oil to be level with the middle indicator mark. (Source: Chris Warrick, Primary Business)*

VIDEOS

On-farm Grain Storage: Silo maintenance

Grain Storage Series: When to seal silos

5. Pressurise the silo

Once the silo is sealed, before pressurising, ensure the oil levels remain stable for a few minutes to confirm that ambient conditions aren't influencing the pressure inside the silo.

Use the leaf blower or small aeration fan if fitted, to pressurise the silo until the oil levels in the relief valve are more than 25mm apart or bubbling. This will only take a few seconds in a cone bottom silo, a minute or two in a large flat bottom silo, or a few minutes if the flat bottom silo is full.

As soon as the oil levels are more than 25mm apart, or the oil is bubbling, stop the leaf blower or aeration fan and close off the fitting or fan inlet immediately.

DO NOT use large aeration fans as they can damage the silo structure and seals.

6. Time the half life

Start the timer at the point that the oil levels are 25mm apart (aligned with top and bottom marker).

The time taken for the oil to drop from 25mm to 12mm apart (half way back to level) must be no less than five minutes on new silos.

On a digital or analog manometer, the 25mm difference in oil levels equates to 250 pascals and the half-life to 12mm is 125pascals.

This process is known as the half-life pressure test.

For older silos, three minutes has been found to enable successful fumigation, but the Australian Standard 2628–2010 for new silos is five minutes.

7. Looking for leaks

If the half-life pressure test fails, the silo has a leak that needs fixing.

To find leaks, pressurise the silo again and use soapy water in a spray bottle to check for air leaks around seals.

Common places for leaks are: bottom outlet, aeration inlet seal, damaged or bent lids or inlet stretched springs on latches, or between wall, base and roof joints.

Cone base silos that rely on the slide plate outlet to seal rather than a separate seal, may require clamping in place prior to filling the silo. The weight of grain on the slide plate has been found to render it unsealable, meaning once grain is let out, the silo cannot be resealed until it's emptied.

Older silos may require more extensive maintenance to achieve a gas-tight seal. When the leak has been fixed, pressurise the silo again and redo the half-life test — steps five and six.

When to seal silos

Gas-tight sealable silos are designed only to be sealed during the fumigation exposure period, the rest of the time they should be left unsealed to breath. Leaving silos sealed for extended periods can lead to condensation forming in the headspace, leading to mould growth.

Ambient temperature changes also change the pressure inside a sealed silo, requiring the relief valve to exchange air when a difference of 500 pascals is reached. A silo left sealed will be subjected to daily pressure differences, adding unnecessary strain on joints and seals.

VIDEOS

Masks for phosphine

6.1.3 Phosphine safety — handle with care

After a silo has been pressure tested and satisfied the half-life pressure test of five minutes for a new silo or three minutes for an older silo, it can then be used as a fumigation chamber for phosphine.

Phosphine is a highly toxic gas with potentially fatal consequences if handled incorrectly. Phosphine is classed as a schedule seven poison, which is indicated on the label — DANGEROUS POISON.

As a minimum requirement, the label directs the use of elbow-length PVC gloves and a full face breathing respirator with combined dust and gas cartridge. The combined dust and gas cartridge (canister) must be suitable for inorganic gas. Be aware that cartridges have a limited lifespan as they contain activated carbon. After use, store cartridges in a sealed container and follow manufacturer directions for replacement. Wash mask and gloves with warm water and detergent after each days use.

Working with phosphine in an open, well-ventilated area with the wind coming from the side will help carry the gas away from the body.

Avoiding explosion

Phosphine containers must only be opened outdoors. When opening containers take care and point container lids away from the face and body. Under rare conditions, a build-up of gas inside the container is possible, and can result in flash flame upon exposure to air.

When opened, use the entire contents or carefully dispose of excess chemical — do not reseal left-over tablets. After a container has been opened and exposed to ambient air carrying moisture, the phosphine tablet starts evolving into gas as it reacts with moisture in the air. If the lid is replaced, gas inside the tin continues to be released and can reach spontaneous flammability levels if it builds up to 17,900ppm.

Personal exposure limits

The National Occupational Health and Safety Commission (NOHSC) has set limits for exposure standards for phosphine, for the safety of users and people who are exposed to breathing contaminated air during or after a fumigation.

The label states TLV (TWA) 0.3ppm — but what does that really mean?

The Threshold Limit Value (TLV) for a Time-Weighted Average (TWA) — an eight-hour working day and a 40-hour working week— in which a worker may be repeatedly exposed without adverse health effects is 0.3ppm.

The MSDS also states STEL 1ppm — what does this mean?

The Short-Term Exposure Limit (STEL) or maximum concentration for a continuous exposure limit of 15 minutes (with a maximum of four such periods per day with at least 60 minutes between exposure periods) is 1ppm.

In summary, workers must not be exposed more than four times per day to levels over 1ppm for longer than 15 minutes with at least one hour between each exposure. And workers must not be exposed to more than 0.3ppm for more than eight hours per day or 40 hours per week.

The odour threshold of phosphine (for those that can smell it) is 2ppm, which is higher than both of these Threshold Limit Values. This means by the time people can smell phosphine the gas concentration level has already exceeded the safe exposure limit.

Never rely on the odour of phosphine to determine if the atmosphere is safe.

Always read the product label and Material Safety Data Sheet (MSDS) for safety information and required PPE.

VIDEOS

Phosphine meters

6.1.4 Electrical equipment

Phosphine is corrosive to copper so any equipment such as switches, meters or sensors with exposed copper should be removed from the silo or sealed before fumigating.

Personal monitors raise the alarm

Personal phosphine monitors are available and easy to use. The monitors simply clip onto the operator's collar or top pocket (close to their nose and mouth) and will sound alarms at very low gas concentrations to warn the operator.

Price may deter growers who only use phosphine occasionally, but these handy devices can potentially save a life, so are worth serious consideration. These low range meters can also be used for clearance testing at the end of the venting period, potentially avoiding delivery rejections due to unvented phosphine residue.

Photo 4: *Personal phosphine monitors sound an alarm if harmful concentration levels are detected. (Source: Ben White, Kondinin Group)*

6.1.5 Phosphine application

Phosphine is available in three different forms for on-farm use (bag chains, blankets and tablets) and there are various ways to apply each option effectively in a gas-tight, sealed silo.

Bag chains are the safest form and the best way to guarantee no residue spills on the grain or harms the operator.

The traditional and most recognised — tablets — which can be bought in tins of 100 or 500.

The other form — phosphine blankets — is designed for bulk storages larger than 600 tonnes such as flat bottom silos.

Phosphine application rates are based on the internal volume of the gas-tight, sealable storage to be fumigated.

Regardless of how much grain is in the silo the rate is the same — based on the volume of the silo. The phosphine dose could be stamped on the silo, as it will be the same rate every time it's fumigated. Some manufacturers stipulate silos must be at least two-thirds or three-quarters full of grain in order to fumigate. The rational being that silos with too little grain and a lot of airspace will have to exchange more air through the relief valve during ambient temperature changes. This would dilute the gas concentration and potentially impose structural pressure on the silo.

Using bag chains

Bag chains are available in two sizes; 340g chains which liberate 114g of phosphine so are suitable for 75m3 or 60t of wheat storage capacity, and 680g chains which liberate 228g of phosphine so are suitable for 150m3 or 120t of wheat storage capacity. Always refer to the label.

Do not cut a bag chain to save extra phosphine for use at a later date.

The phosphine will start liberating gas as soon as it is exposed to air, so will be less effective, and dangerous if it's stored for use at a later date.

Photo 5: *Phosphine in bag chains removes the risk of residue being spilt, but at least 1% of residue will not evolve until it comes into contact with moisture so a respirator and PPE are also required to remove it from the silo. (Source: Chris Warrick, Primary Business)*

Using phosphine blankets

For larger gas-tight sealable silos, a phosphine blanket may be appropriate. Like bag chains, blankets must not be cut or separated so the minimum size silo storage for fumigation using blankets is one silo with 600t of wheat storage capacity or two 300t silos.

Blankets are available in a 3.4kg pack containing two 1.7kg blankets. Each 1.7kg blanket will liberate 568g of phosphine so is suitable for 380m3 or 300t of wheat storage capacity.

Using tablets

The application rate for phosphine is 1.5 grams per cubic metre. Each tablet weighs 3g and will liberate 1g of phosphine so equates to three tablets per $2m^3$.

Considering the typical bulk density of wheat is $1.3m^3/t$ the application rate is two tablets (2g of phosphine) per tonne of storage capacity.

Phosphine tablets are available in tins of 100 or 500 tablets. The smaller tin of 100 tablets will liberate 100g of phosphine so is suitable for 67m3 or 50t of wheat storage capacity. The larger tin of 500 tablets will liberate 500g of phosphine so is suitable for 333m3 or 250t of wheat storage capacity.

Photo 6: *Phosphine tablet packs. Left: 100 tablet tin (300g) suitable for 50t of wheat storage capacity. Right: 500 tablet tin (1.5kg) suitabe for 250t of wheat storage capacity. (Source: Ben White, Kondinin Group)*

Photo 7: *Phosphine bag blanket packs. Left: Bag chain (340g) suitable for 60t of wheat storage capacity. Right: Blankets 1.7kg x 2 (total 3.4kg) suitabe for 600t (or 2 x 300t) of wheat storage capacity in silos. Or 1500t of wheat capacity in a bunker. (Source: Ben White, Kondinin Group)*

VIDEOS

Grain bags – Fumigation

Fumigating bunkers

Bunkers must be well prepared with a bottom and top tarp that is heat sealed or clamped at all joins in order to be sealable. Because bunkers cannot be pressure tested, high range phosphine meters are required to monitor gas levels during the fumigation to ensure adequate concentration over time is achieved.

Phosphine bag chain and blanket labels specify the dose rate in well-sealed bunkers greater than 1000t is 0.6g per cubic metre, and the exposure period is 20 days. Venting according to the label is two to five days with throughflow draught (wind) as a minimum.

Fumigating grain bags

Fumigation in bags has been proven in Australia as an option if the correct method of application and venting is followed. Success relies on the bag not being compromised with holes and the use of a high-range phosphine meter to monitor gas concentration during the fumigation and a low-range meter for clearance after venting.

Trials indicate phosphine placement must be no more than seven metres apart along the bag, inserted in such a way that the bag can be resealed during fumigation and removed so grain is not contaminated with the residue. One metre lengths of PVC pipe with a series of 1mm slots cut along their length, inserted horizontally has been proven to evenly distribute gas over a 10 day period.

Venting methods trialed have included propping open the finish end of the bag and inserting the suction side of a fan into the start end of the bag to draw the gas out. A passive option is to use 50mm slotted PVC pipe inserted every 7m along the bag on alternate sides, with the ends of the pipe left open after the phosphine is removed.

If 0.3 parts per million phosphine is the required clearance level, expect the fan method to take two or more days, and the passive method to take at least 35 days to vent.

Paying a commercial fumigator to use Sulfuryl Fluoride is another option for fumigating grain bags.

Application in the head space

Hang bag chains in the head space or roll out flat in the top of a gas-tight, sealed silo so air can freely pass around them as the gas dissipates.

Always spread out phosphine tablets evenly on trays, before placing them in the head space of a gas-tight, sealed silo.

The aim is to place the tablets where as much surface area as possible is exposed to air so the gas can disperse freely.

Prevent trays from sitting on an angle to avoid tablets piling up to one side and creating more than one layer in the tray.

Photo 8: *Place phosphine in large enough trays that enable tablets to spread out in a single layer to avoid smothering as they liberate. (Source: Chris Warrick, Primary Business)*

Application with passive recirculation

Some silos are fitted with purpose-built chambers for applying phosphine from the bottom. This method of application carries a safety advantage as the operator doesn't have to leave the ground to apply the phosphine.

However, ensuring top lids or vent openings on silos are in sound condition and correctly sealed before fumigation, will usually require a climb to the top.

Bottom-application chambers must have a passive or powered air recirculation system to carry the phosphine gas out of the confined space as it evolves. Without air movement, phosphine can reach explosive levels if it's left to evolve in a confined space.

Photo 9: *Some silos are built with a chamber and passive (thermo-siphon) or powered recirculation system for applying phosphine from the bottom. (Source: Ben White, Kondinin Group)*

VIDEOS

Explosion panel required in fumigation recirculation box

Application with powered recirculation

Silos larger than 150t will benefit from a sealed, powered recirculation system to distribute gas throughout the storage and achieve consistent gas concentration sooner. Trials have found that without powered recirculation, phosphine travels at approximately 6m per day through grain, in any direction,

In silos larger than 300t without powered recirculation, the phosphine label stipulates an extended exposure period of 20 days, referenced as 'surface only application'. See Figure 5. Using powered recirculation enables the fumigation period to be shortened to the standard 7-10 days depending on grain temperature.

Key components for powered recirculation systems include:

- Gas-tight sealed system – the chamber and plumbing should not compromise the sealability of the silo.
- Large enough chamber for phosphine to be placed without piling tablets or folding bag chains or blankets preventing liberation.
- Small fan to gently recirculate air from the headspace, through the chamber, into the base of the silo. A large fan is unnecessary and risks circulating residue dust from liberated tablets.
- An explosion panel in the chamber is required as a safety precaution in case the fan stops while the phosphine is liberating and gas levels in the confined space reach a concentration high enough to self-combust.

Photo 10: *Powered recirculation improves gas distribution through the silo enabling 7-10 day exposure rather than 20 day exposure when fumigating silos greater than 300t capacity. (Source: Chris Warrick, Primary Business)*

An alternative to a dedicated, powered recirculation box with a phosphine chamber is to connect a small fan between the pluming from the silo headspace to the base and place the phosphine in the headspace and/or aeration ducts at the base. This option has two main advantages; avoids the risk of explosion if the fans stops as the phosphine can safely continue liberating in the silo. Being lower cost, there is also the option to buy multiple fans so more than one silo can be fumigated at a time.

6.1.6 Fumigation period

A gas-tight, sealed silo must remain sealed for the full 7–10 days to achieve a successful fumigation using phosphine.

In a gas-tight, sealed silo smaller than 300t capacity, the required fumigation period is seven days if the grain temperature is above 25°C or 10 days if the grain temperature is between 15–25°C. If the grain temperature is below 15°C, insect pests will not be active and phosphine is not reliably effective.

In gas-tight sealed silos larger than 300t capacity that don't have powered recirculation, the exposure period is extended to 20 days regardless of grain temperature. If the silo has powered recirculation, the 7-10 day exposure depending on grain temperature applies. (see Figure 5).

Phosphine label recommendations have been developed as a result of thorough industry testing so using phosphine as the label specifies will achieve the best result.

VIDEOS

Venting phosphine after fumigating grain

6.1.7 Ventilation period

Following fumigation, ventilate silos to allow phosphine gas to escape into the atmosphere, so grain can be delivered free of harmful gas residues.

When a silo is first opened after a successful fumigation the gas concentration levels are extremely harmful.

The same PPE required for applying the phosphine is required again to open the silo and remove the phosphine residue.

Working with your side to the wind can significantly reduce the amount of phosphine gas blown past your body.

A personal phosphine meter can monitor phosphine levels to help avoid excess exposure.

After the removal of tablet residue or bag chains, a silo without aeration fans fitted must be left open to ventilate for no less than five days.

Silos with aeration fans fitted must be opened to ventilate with fans operating for no less than one day (see Table 1). Larger flat bottom silos, cool grain or extended fumigations can require more time to vent as the grain desorbs the phosphine.

A low-level phosphine meter is the safest way to ensure the grain is vented to the delivery limit set at the receival point. Grain should be spear tested at least a few hours after fans have been switched off and prior to moving in order to sample the air gaps that grain may have been desorbing gas into.

Table 1: Phosphine fumigation guide

Type of Gas-tight Sealable Storage	Cone Bottom Silo	Cone or Flat Bottom Silo (No Powered Recirculation)	Cone or Flat Bottom Silo (with Powered Recircualtion)	Well-sealed Bunker #	Well-sealed Grain Bag #
Capacity	Less than 300t	More than 300t	More than 300t	More than 1000t	200–300t
Dosage if using tablets (per tonne of wheat capacity)	2 tablets /t	2 tablets /t	2 tablets /t	na	2 tablets /t
Dosage if using bag-chains or blankets (per tonne of wheat capacity)	1 x 340g chain per 60t *or* 1 x 680g chain per 120t	1 x 340g chain per 60t *or* 1 x 680g chain per 120t *or* 1x 1.7kg blanket per 300t	1 x 340g chain per 60t *or* 1x 680g chain per 120t *or* 1 x 1.7kg blanket per 300t	1 x 340g chain per 150t *or* 1 x 680g chain per 300t *or* 1 x 1.7kg blanket per 750t	na
Phosphine exposure (days) **Grain 15-25°C** **Grain > 25°C**	10 7	20 20	10 7	20 20	10 10
Minimum ventilation (days) **No aeration fan** **Aeration fan**	5* 1+*	5* 1+*	5* 1+*	2-5 days with flowthrough draft (wind)	35** 2+**
Whitholding Period (days)	2	2	2	2	2
Total fumigaiton process (days)	10 to 17	23 to 27	10 to 17	24 to 27	14 to 47

This table is a guide only – always refer to the manufacturer label directions

High-range phosphine meters should be used in storages that cannot be pressure tested, to monitor concentration over time.

* Label stipulated requirement, but experience suggests longer periods may be required pending clearance target levels

** Guide only based on research conducted, not label specificed.

Source: Kondinin Group

6.1.8 Withholding period

The label states that grain treated with phosphine should not be used for human consumption or for stock food for a minimum of two days after the ventilation period has finished.

Photo 11: *Signing storages under fumigation helps keep track of the process and warns others to keep away. (Source: Ben White, Kondinin Group)*

6.2 Other fumigants and controlled atmospheres

Although phosphine is still the most commonly-used gas fumigant for controlling pests in stored grain, there are other options.

Each of the alternatives still requires a gas-tight, sealable silo and are currently more expensive than using phosphine, but it is good practice to rotate chemistry for a resistance break.

Carbon dioxide (CO_2) and nitrogen (N) carry the advantage of being non-chemical control alternatives.

Both CO_2 and nitrogen are sometimes referred to as controlled atmosphere (CA) treatments because they change the balance of natural atmospheric gases to produce a toxic atmosphere.

6.2.1 Carbon dioxide

CO_2 is a non-flammable, colourless, odourless gas that is approximately 1.5 times heavier than air. Food grade CO_2 comes as a liquid in pressurised cylinders and changes to a gas when released from the cylinder.

Treatment with CO_2 involves displacing the air inside a gas-tight silo with a concentration level of CO_2 high enough to be toxic to grain pests.

This requires a gas-tight seal, measured by a half-life pressure-test of no less than five minutes.

To achieve a complete kill of all the main grain pests at all life stages CO_2 must be retained at a minimum concentration of 35 per cent for 15 days.

As a guide, the amount of CO_2 required to reach 35 per cent concentration for 15 days is one 30 kilogram (size G) cylinder per 15 t of storage capacity, plus one extra cylinder, but measuring concentration is essential.

The basic process is to open the storage's top lid to let oxygen out as CO_2 is introduced. Regulate the CO_2 gas into the bottom of the silo via a short, high pressure tube.

Each cylinder could take three hours to dispense if done slow enough to prevent freezing, unless a heated regulator is used.

This method of fumigation is not recommended when temperatures are below 15°C. After the concentration at the top of the storage reaches 80 per cent, stop adding CO_2 and seal the top lid.

Even in a silo that meets the five-minute, half-life pressure test, an initial CO_2 concentration of 80 per cent or more is required to retain an atmosphere of 35 per cent for the full 15 days, because the CO_2 is absorbed by the grain, reducing the atmospheric concentration over time.

If the storage does leak, CO_2 can be added periodically over the 15 days if required. The key is to maintain the CO_2 concentration above 35 per cent for 15 consecutive days, which will require suitable electronic instruments or a gas tube detector kit for monitoring.

At temperatures below 20°C CO_2 is less effective because insects are less active so the concentration must be maintained for an extended period.

6.2.2 Nitrogen

Grain stored under nitrogen provides insect control and quality preservation without chemicals. It is safe to use, environmentally acceptable and the main operating cost is electricity.

Nitrogen also produces no residues so grains can be traded at any time, unlike chemical fumigants that have withholding periods.

Insect control with nitrogen involves a process using Pressure Swinging Adsorption (PSA) technology, modifying the atmosphere within the grain storage to remove everything except nitrogen, starving the pests of oxygen.

The application technique is to purge the silo by blowing nitrogen-rich air into the base of the silo, forcing the existing, oxygen-rich atmosphere out the top. PSA takes several hours of operation to generate 99.5 per cent pure nitrogen and before the exhaust air has a reduced concentration of less than two per cent oxygen.

At two per cent oxygen adult insects cannot survive, providing this concentration is maintained for 21 days with a grain temperature above 25°C. Anything less will not control all life stages — eggs, larvae and pupae. For grain below 25°C this period is extended to 28 days. The silo must be checked the day after fumigation and may need further purging to remove oxygen that has diffused from the grain.

Nitrogen storage will also maintain the quality of canola and pulses by inhibiting the respiration process that causes oxidation, which leads to seed deterioration, increased free fatty acids and loss of colour.

For further information on controlled atmosphere fumigation with CO_2 or nitrogen, contact the commercial suppliers of appropriate gas and equipment; BOC Gases Australia Ltd, on 13 12 62 or visit www.boc.com.au

6.2.3 Sulfuryl fluoride

Only licensed fumigators can use sulfuryl fluoride (ProFume or Zythor) however it is helpful to understand the basics to determine its suitability for the situation.

Where grain is stored for human consumption, sulfuryl fluoride is only registered for use in cereals. Where grain is stored for seed or uses other than human consumption sulfuryl fluoride can be used on grains other than cereals. It is always safer to check with the grain buyer before using any chemical treatments or fumigants.

Sulfuryl fluoride is said to be effective against most of the common pests found in Australian on-farm storages including rust-red flour beetle, lesser grain borer, saw-toothed grainbeetle, flat grain beetle, rice weevil and Indian meal moth.

Avoid last minute, rushed 'short' fumigations. Longer fumigation times in a gas-tight sealed storage provide effective pest control to all life cycle stages including the egg stage.

Before the licenced fumigator applies sulfuryl fluoride, they should use the sulfuryl fluoride Fumiguide computer program to calculate the required dosage needed for each specific situation.

At grain at temperatures below 25°C, fumigation times of 7–10 days are recommended for effective control of insect pests at all life stages.

Sulfuryl fluoride is considered a 'heavy' gas with a vapour density of 3.7 times that of our atmosphere. Ideally gas is applied into the top headspace of a silo and research indicates that powered recirculation during the fumigation period significantly improves even spread of gas concentration throughout the silo.

The maximum concentration rate is 128g/m^3 metre. Following fumigation with sulfuryl fluoride, the storage must be ventilated and confirmed that the concentration level is less than 3ppm before re-entering. Grain must be withheld for at least 24 hours before consumption.

For more information on sulfuryl fluoride contact TriCal Australia on 08 8347 3838 www.trical.com.au or Zythor contact Ensystex 13 35 36 www.ensystex.com.au

6.2.4 VaporMate®

VaporMate consists of 16.7 per cent ethyl formate by weight with the balance being CO_2. It is registered for use in cereal grains and oilseeds to control lesser grain borer, four beetle, psocids, storage months, saw-toothed grain beetle and flat grain beetle at all life stages as well as the rice weevil in egg, larvae and adult life stages.

VaporMate is supplied by BOC Gases Australia Ltd as a liquefied gas under pressure and is applied in a gas-tight, sealed storage at a rate of 420g/m^3 held for 24 hours or 660g/m^3 held for three hours.

Following fumigation, ventilation requires ethyl formate to be less than 100ppm and CO_2 to be less than 5000ppm, at which point there is no withholding period there after. An additional point to be aware of is that ethyl formate is readily absorbed by grain. This can make it difficult to reach the required concentration in the centre of a large storage and ventilation will also take longer in a large storage.

For more information on VaporMate contact BOC Gases Australia Ltd, on 13 12 62 or visit www.boc.com.au

6.3 Storage and treatment notes

6.4 Cereal grains delivered to customers

Buyers and bulk handlers are changing their acceptance of grain treated with insecticides.

Before using a grain insecticide, always check with potential buyers and bulk handlers (depot) for market acceptability.

Identify storage pests before selecting a treatment. Always follow label instructions carefully.

6.4.1 Seed held on farm (cereals — wheat, barley, oats)

Seed that is dry, cool and sound (not weather damaged) will remain viable for longer.

In well-managed storage, germination percentages can be expected to reduce by only five per cent after six months.

To achieve this, keep grain moisture content below 12 per cent.

Grain temperature also has a major impact on germination.

Aim for grain temperatures of 20°C and below in seed storage by using aeration cooling (with auto control).

Wheat at 12 per cent moisture content stored at 30–35°C (unaerated grain temperature) will reduce germination percentages and seedling vigour when stored over a long period.

Position small seed silos in the shade or paint them reflective white to assist keeping grain cool.

Treating seed with a grain protectant, in combination with aeration cooling, will maximise insect control.

Photo 12: *To minimise mechanical seed damage, auger grain as few times as possible — harvester to truck, truck to farm storage, farm storage to truck — then deliver it. (Source: Chris Warrick, Primary Business)*

6.4.2 Pulses and oilseeds

Insect control options are limited for stored pulses and oilseeds.

Grain protectants are not registered for use on these grains. Phosphine fumigation and controlled atmosphere (inert gasses such as carbon dioxide or nitrogen) may be an option.

The effectiveness of phosphine fumigation on oilseeds is often reduced due to phosphine sorption during treatment.

Use sound grain hygiene in combination with aeration cooling to reduce insect activity. Small-seed grains, such as canola, may need larger capacity aeration fans on stores.

Always store these grains at their recommended grain moisture content level.

Photo 13: *Aeration cooling is essential for storing oilseed and may require extra capacity to achieve 2–3L/s/t in small oilseeds such as canola. (Source: Chris Warrick, Primary Business)*

MORE INFORMATION

GRDC Grain Storage Checklist

GRDC Grain Storage Fact Sheet: Storing Oilseeds

GRDC Grain Storage Fact Sheet: Storing Pulses

MORE INFORMATION

CBH Guide: High moisture harvest and grain storage

VIDEOS

GCTV5: Aeration drying — getting it right

Managing high-moisture grain

Grain at typical harvest temperatures of 25–30°C and moisture content greater than 13–14 per cent provides ideal conditions for mould and insect growth. There are a number of ways to deal with high-moisture grain — the key is to act quickly and effectively.

7.1 Aeration drying

Aeration drying requires a specifically-designed system and is a much slower process than aeration cooling.

In rare situations aeration cooling fans can reduce grain moisture slightly, but they cannot reliably reduce grain moisture to a safe level. In fact this 'drying' effect is likely to be simply a redistribution of moisture within the grain stack. Much higher airflow rates are required for aeration drying in order to push a drying front through the grain bulk — aeration drying can be achieved with fans delivering 15–25L/s/t. (Figure 1)

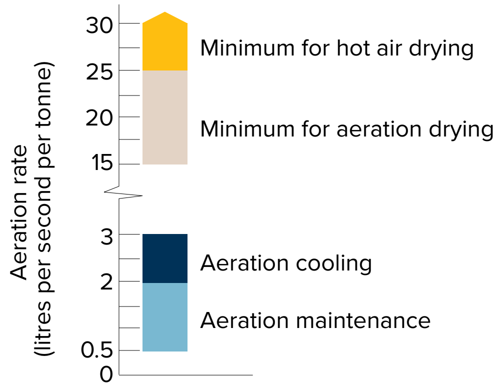

Figure 1: *Aeration rates for grain drying and cooling.*

Source: Kondinin Group

7.1.1 Managing moisture quickly

A trial done by DAF QLD revealed that over-moist grain generates heat when put into a confined storage, such as a silo.

Wheat at 16.5 per cent moisture content at a temperature of 28°C was put into a silo with no aeration. Within hours, the grain temperature reached 39°C and within two days it reached 46°C providing ideal conditions for mould growth and grain damage.

Over-moist grain, in most cases grain above the 13–14 per cent moisture content range, needs to be dealt with promptly to avoid mould and insect issues.

Figure 2 illustrates likely outcomes under various storage conditions.

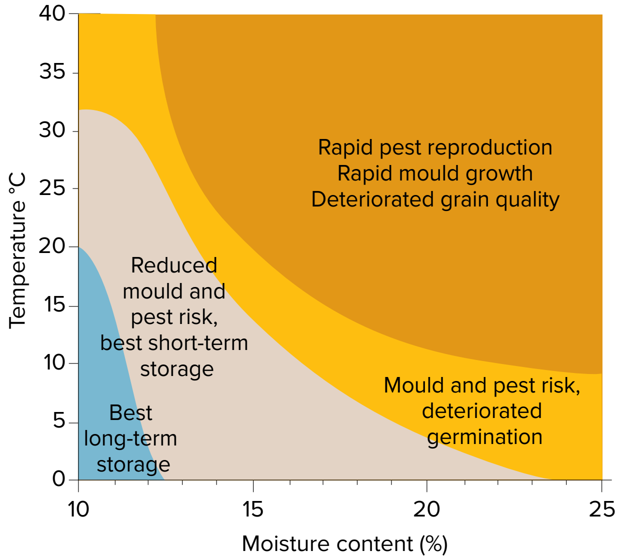

Figure 2: *Effects of temperature and moisture on stored grain*
Source: CSIRO Ecosystems Sciences

Moisture effects on seed germination

In addition to the visible degrading from mould and insect attack, storing over-moist grain risks germination loss.

CSIRO trials revealed that wheat stored at a typical harvest temperature of 30°C, without aeration cooling, has falling germination rates over time.

As moisture content exceeds 12 per cent, seed germination rate starts to fall more quickly (see Figure 3).

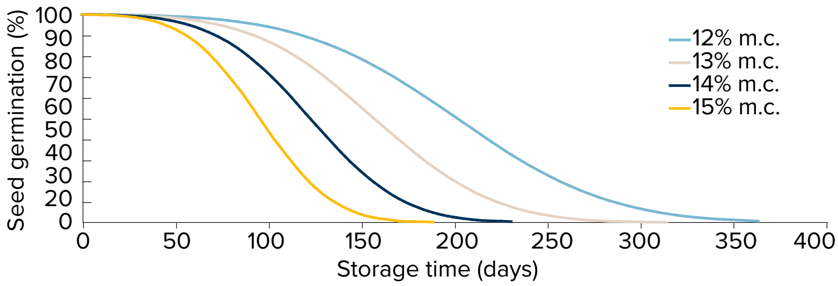

Figure 3: *Influence of moisture content (m.c.) on germination of wheat stored at 30°C.* Source: CSIRO

7.1.2 Options for high-moisture grain

Grain that is above the standard safe storage moisture content of 12.5 per cent can be dealt with in a number of ways.

- ✓ *Blending* — over-moist grain is mixed with low-moisture grain then aerated.
- ✓ *Aeration cooling* — grain of moderate moisture, up to 15 per cent moisture content, can be held for a short term under aeration cooling until drying equipment is available.
- ✓ *Aeration drying* — large volumes of air force a drying front through the grain in storage to slowly remove moisture. Supplementary heating can be added.
- ✓ *Continuous flow drying* — grain is transferred through a dryer, which uses a high volume of heated air to pass through the continual flow of grain.
- ✓ *Batch drying* — usually a transportable trailer drying 10–20t of grain at a time with a high volume of heated air to pass through the grain and out through perforated walls.

Photo 1: *If over-moist grain can't be dried immediately hold it under aeration cooling until drying equipment is available. (Source: Phillip Burrill, DAF QLD)*

Blending

Blending is the principle of mixing slightly over-moist grain with lower-moisture grain to achieve an average moisture content below the ideal 12.5 per cent moisture content.

Successful for grain moisture content levels up to 13.5 per cent, blending can be an inexpensive way of dealing with wet grain, providing the infrastructure is available.

If aeration is not available, blending must be evenly distributed, although aeration cooling does allow blending in layers (see Figure 4).

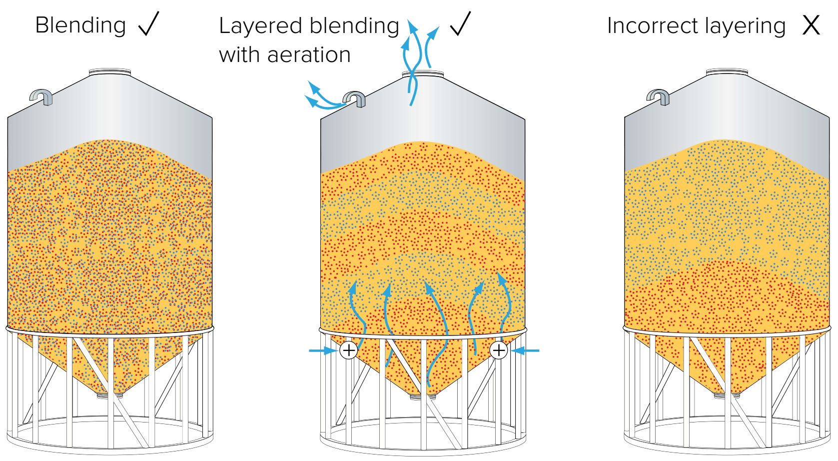

Figure 4: *Correct blending.*
Source: Kondinin Group

Assisted by aeration cooling, with time, moisture from the wet grain will migrate into the drier grain around it and the grain stack will end up being reasonably uniform in moisture content.

A blending example

Grain harvested during the middle of the afternoon might have a moisture content of 11 per cent and can be put aside for blending. The harvester can then work a little longer each day and harvest grain at 13.5 per cent moisture content.

The 11 per cent and 13.5 per cent moisture content grain can be blended at a ratio of 60:40 to produce an average moisture content of 12 per cent.

To allow a margin for error in blending it would be safer in this scenario to blend 70 per cent of the drier grain to 30 per cent of the wet grain.

7.1.3 Holding over-moist grain with aeration cooling

Over-moist grain often needs to be stored temporarily until drying equipment is available or time permits.

Shown in Figure 2, grain high in moisture and temperature post harvest, is at greatest risk of insect and mould attack. In this case, reducing the temperature alone can significantly reduce the mould and possible grain quality damage until it can be dried.

Aeration cooling fans can be used effectively to do this job with airflow rates as low as 3–4L/s/t.

Growers can store grain at 14–15 per cent moisture content safely for a month with aeration cooling fans running continuously.

It is important to keep fans running continuously for the entire period, only stopping them if the ambient relative humidity is above 85 per cent for more than about 12 hours, to avoid wetting the grain further.

Forcing air through over-moist grain creates an evaporative cooling effect, so the grain temperature is reduced quickly and there is no need to try to select cool, ambient conditions.

It is essential to check over-moist grain regularly. If the aeration fans fail for any reason, or the airflow is not distributing evenly through the stack, hot-spots will quickly form and invite mould and insect attack.

7.1.4 Aeration drying

Aeration drying relies on a high volume of air passing through the grain to slowly remove moisture. It is usually carried out in a silo with either high-capacity aeration fans, only partly filled with grain or in a purpose-built drying silo.

Aeration drying is a slow process and depends on warm, dry weather conditions. It is important to seek reliable advice on equipment requirements and correct management of fan run times, otherwise there is a high risk of reducing grain quality.

There are four key components to enable successful aeration drying: airflow rates of 15–25L/s/t, well-designed ducting for even airflow through the grain, exhaust vents in the silo roof and warm, dry weather conditions.

VIDEOS

Holding over moisture grain with aeration cooling

VIDEOS

GCTV5: Aeration drying — measuring airflow

MORE INFORMATION

Aeration backpressure test results

Photo 2: *A purpose-built silo for aeration drying has a large fan capable of more than 15L/s/t with ducting right around the silo cone. (Source: Alex Conway)*

High airflow for drying

Unlike aeration cooling, aeration drying requires airflow rates of 15–25L/s/t to move drying fronts quickly through the whole grain profile and depth and carry moisture out of the grain bulk.

As air passes through the grain, it collects moisture and forms a drying front. This moist air has to be forced all the way out the top of the grain stack before more dry air can follow and move the next drying front upwards. If airflow is too low, the drying front will take too long to reach the top of the grain stack.

If weather conditions are unfavourable for drying, or the fans are stopped for extended periods, the drying front will stall and will not reach the top of the stack. If this happens, mould will quickly form where the drying front stopped.

One method often used to increase the effective airflow is to only partly fill the grain storage. As well as reducing the back pressure the aeration fan has to force air through, it increases the effective flow rate. As an example, a 100t silo may be set up with aeration fans that can deliver 4L/s/t when full. But if only 20t of grain is put into the silo, the effective airflow rate is then 20L/s/t and suitable for basic aeration drying.

Providing the storage has sufficient aeration ducting, a drying front can pass through a shallow stack of grain much faster than a deep stack of grain. As air will take the path of least resistance, make sure the grain is spread out to an even depth.

Resistance to airflow

While the physics of air movement is complex, there are a few key components to static pressure that need to be understood so maximum airflow can be achieved.

Static pressure is anything that restricts the airflow after the air is forced out of the fan outlet.

Where there is an increase in airflow rate, static pressure will increase exponentially. Doubling the airflow rate generally results in triple the resistance of static pressure.

This means doubling the size of a fan using the same aeration ducting will not double the airflow rate through the grain.

The type and amount of ducting will contribute to static pressure — a single narrow outlet will create more static pressure than a large perforated duct with multiple outlets into the grain.

The type of grain determines how easily air can pass through it, for example canola produces about double the static pressure of wheat because the air gaps between the grains are much smaller, making it harder for air to pass between them. The deeper the grain in the storage, the higher the static pressure will be as the air has to pass through more grain before it can freely flow out the top of the stack.

Ducting for drying

Air from a fan will always take the path of least resistance through the grain, which is usually the shortest distance from the air outlet to the top of the grain stack.

For moisture transfer to take place from the grain to the air, airflow must be evenly distributed through the grain.

Any pockets in the stack that don't get a flow of air will not dry. These pockets are often referred to as hot spots because they remain moist, form mould and self heat.

The way to avoid hot spots is with adequate ducting to deliver an evenly distributed flow of air through the entire grain stack.

A full-floor aeration plenum or multiple aeration trenches covered with perforated flooring in flat-bottom silos is ideal for even distribution, providing the airflow is high enough for the quantity of grain to be dried.

The flat-bottom silo may only be able to be part filled, which in many cases is better than trying to dry grain in a cone-bottom silo with insufficient ducting.

Avoid ducting that involves splitting air from one fan for use on multiple silos at the same time. Even if the rated fan output calculates to be enough for both silos, the amount of air that actually flows through each silo will be determined by the static pressure. Unless both silos are identical in size, have identical ducting and are loaded to the same level with the same sample of grain, the silo with the higher static pressure will receive significantly less airflow, which leads to problems.

Ducting — the trap

In most cases, more ducting inside the silo equates to more even air distribution through the grain, but it also means the silo or storage is harder to clean.

When installing ducting or buying storage with ducting or a full-floor aeration plenum, consider how easy it is to remove for cleaning.

Aeration ducting usually traps dust and grain as the storage is emptied and provides a perfect harbour for grain insect pests to breed. If ducting is not cleaned thoroughly, the pests will be left to infest the next batch of grain put into storage.

Exhaust vents

An important component of aeration drying that is often overlooked is exhaust ventilation to release air from the silo. For example, delivering 20L/s/t through 60t of grain means the fan is forcing 1200L/s into the silo, which also means 1200L/s needs to escape from the silo unrestricted.

The other component to consider in ventilation is the amount of moisture that has to escape with the exhausted air. Shown in Table 1, for every one per cent moisture content removed per tonne of grain about 10L of water has to also be removed.

Table 1: Litres of water removed during grain drying

	Percentage of moisture content reduction				
Tonnes of grain	1%	2%	3%	4%	5%
1	10	20	30	40	50
50	500	1,000	1,500	2,000	2,500
100	1,000	2,000	3,000	4,000	5,000

Source: Kondinin Group

Using the same example as above, to remove one per cent moisture content from the 100t of grain, 1000L of water has to be removed from the silo. As well as restricting the airflow and without adequate ventilation, the moist air leaving the silo may form condensation on the underside of the roof and wet the grain on the top of the stack.

Vents must be weatherproof even if they are left open during rain. The fans will not be operating during rain periods but the silo still needs to ventilate to avoid condensation forming in the headspace.

If the silo is used for fumigation the vents must also be sealable so the storage is gas tight to meet a three-minute half-life pressure test as a minimum, (a five-minute half-life pressure test is required for new silos to meet the Australian Standard AS2628).

Photo 3: *Because aeration drying requires high airflow, extra ventilation is needed to allow air and moisture to escape the silo unrestricted. (Source: Chris Newman, DPIRD)*

Weather conditions for drying

Understanding that the process of drying grain requires moisture to transfer from the grain to the surrounding air helps determine what air to select. The first and most important factor is to select air with a low relative humidity.

While warm air speeds up the moisture transfer process, the critical component is still the relative humidity of the air used for drying.

Each type of grain has an equilibrium moisture content, where the moisture content of the grain is equal to the relative humidity of the air around it. At the equilibrium point, no moisture transfer occurs.

For moisture transfer to take place and drying to happen, air with a lower relative humidity than the grain's equilibrium moisture content must be used. For example, the equilibrium table on the following pages shows that wheat at 25°C and 14 per cent moisture content has an equilibrium point of the air around it at 70 per cent relative humidity. In order to dry this wheat from its current state, the aeration drying fans would need to be turned on when the ambient air was below 70 per cent relative humidity. (See link opposite for more detailed equilibrium tables for various grain types).

MORE INFORMATION

Equilibrium tables — grain moisture content to air relative humidity

7.1.5 Fan operation for drying

In addition to much higher airflow rates, fans need to be controlled differently — for drying rather than for cooling grain. When over-moist grain is first put into storage it is critical to get a large volume of air through it for most of the 24 hours in a day. This quickly flushes out any surface moisture and prevents the grain self heating.

Phase one of drying

Aeration drying fans can be turned on as soon as the aeration ducting is covered with grain and left running continuously until the first drying front has moved through the full grain profile. This usually takes about 5–7 days but depends on the main variables of the airflow rate, the ducting, the grain moisture content, the ambient conditions and the amount of grain in the storage.

The only time drying fans are to be turned off during this initial, continuous phase is if ambient air exceeds 85 per cent relative humidity for more than a few hours.

A passing storm that raises the ambient relative humidity for a few hours will not have a significant effect. But if fans are left running above 85 per cent relative humidity for more than a few hours the grain will become moist because the relative humidity of the ambient air is higher than the grain's equilibrium moisture content.

An aeration controller with drying mode capabilities can assist during this stage by setting the relative humidity trigger point at 80–85 per cent to turn fans off.

It is also worth monitoring the accuracy of the controller, as some models use relative humidity sensors that are not accurate at those levels. The controller may need to be set at 80 per cent relative humidity to ensure it stops before ambient conditions go above 85 per cent and start re-wetting grain.

The risk of wet weather

Due to aeration drying relying entirely on ambient conditions, the greatest risk is that ambient relative humidity stays above 85 per cent for an extended period and the grain can't be dried.

In the case where over-moist grain is still sitting in storage and ambient conditions don't allow for drying, the fans need to be turned on for a couple of hours to push a fresh lot of air through the grain. Running the fans for just a couple of hours won't increase moisture content significantly and without aeration for several days, over-moist grain will self heat and start to mould.

It is critical in this scenario to monitor the grain temperature and moisture daily to keep a check on what's happening in the storage.

Increasing grain temperature is a signal of self heating and mould or insect activity development and requires immediate attention.

If ambient conditions don't allow for drying, or hotspots are found within the storage, the safe option is to turn the grain. Turning in most cases will involve removing it from the storage and putting it back in. This process mixes grain and disperses any hotspots.

Phase two of drying

After aeration fans have flushed an initial front through the grain to even it out and the air coming out the top of the storage smells clean and fresh, it's time to start getting more selective with fan run times.

By monitoring the temperature and moisture content of the grain in storage, and reading the equilibrium tables for the grain type, a suitable relative humidity trigger point can be set.

As the grain is dried the equilibrium point will also fall, so the relative humidity trigger point will need to be reduced to further dry the grain.

There are no set rules with the aerating drying operation because there are so many variables within the process.

The key is knowing the grain moisture content and selecting air with a lower equilibrium relative humidity, which will result in drying.

Drying the whole storage

When monitoring grain under aeration drying, check grain moisture and temperature at the top and the bottom of the storage. In most cases the grain closest to the aeration ducting will be a few per cent drier than the grain at the top.

Slowly reducing the relative humidity trigger point during phase two of the drying process will help keep this difference to a minimum by ensuring the fans get adequate run time to push each drying front right through the grain stack. As the air flows past grain at the bottom of the stack it collects moisture and carries it out through the top of the stack, resulting in the grain at the top is the last to be dried. Getting too selective too soon with the air used for drying will mean the fans are running for less hours each day, and only push each drying front part way through the grain stack.

Table 2: Effect on increased inlet air temperature

	Starting conditions	Increasing inlet air temperature with supplementary heating			
		+4°C	+6°C	+8°C	+10°C
Air temperature (dry bulb)	25°C	29°C	31°C	33°C	35°C
Relative humidity (RH)	70%	56%	49%	44%	39%
Approximate equilibrium wheat moisture with starting RH of 70%	14.0%	11.8%	11.0%	10.2%	9.6%
Outcome starting with a higher relative humidity					
Relative humidity	90%	71%	64%	57%	51%
Approximate equilibrium wheat moisture with starting RH of 90%	>16%	14.1%	12.7%	11.7%	10.8%

Source: GRDC

Equilibrium tables for sorghum and wheat

Sorghum Equilibrium moisture content / Grain Moisture (%)

Relative Humidity (%)	Temperature (°C) 0	5	10	15	20	25	30	35	40	45
90				18	18					
88		18	18				17	17		
86	18			17	17	17		16	16	
84			17			16	16			
82		17		16	16			15	15	
80	17		16				15			14
78		16			15	15			14	
76	16			15				14		
74			15				14			13
72		15				14			13	
70					14			13		
68	15			14			13			12
66			14			13			12	
64		14			13			12		11
62	14			13					11	
60			13				12	11		
58		13				12				
56					12		11			10
54	13			12		11			10	
52			12		11			10		
50		12					10			
48				11		10				
46	12		11		10					
44		11		10						
42	11		10							
40		10								
38	10									

Wheat Equilibrium moisture content

Grain Moisture (%)

Relative Humidity (%)	Temperature (°C)									
	0	5	10	15	20	25	30	35	40	45
90						16			15	
88					16			15		
86							15			
84				16						
82						15				14
80			16						14	
78					15			14		
76		16								
74				15			14			13
72	16								13	
70			15			14		13		
68		15			14					12
66				14			13			
64	15					13			12	
62			14							
60					13			12		11
58		14					12			
56				13		12			11	
54	14		13							
52					12			11		
50		13					11			
48				12		11				10
46									10	
44			12		11			10		
42	13						10			
40				11		10				9
38		12							9	
36			11		10			9		
34										
32				10			9			
30		11				9				
28	12		10							
26					9					
24										
22		10		9						
20	11		9							
18										
16		9								
14	10									
12										
10	9									

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GRDC Grain storage extension project

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