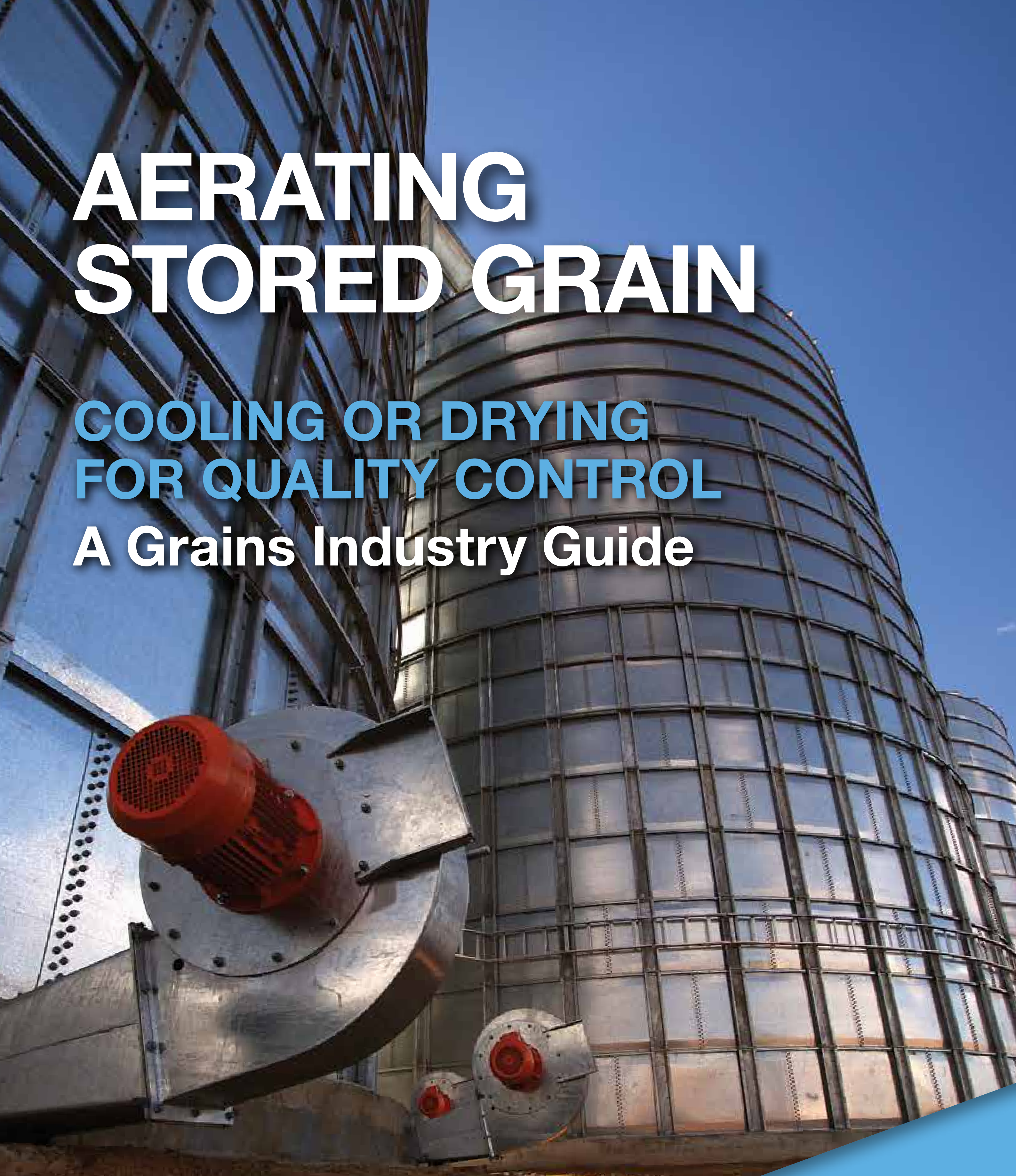
AERATING STORED GRAIN

COOLING OR DRYING FOR QUALITY CONTROL

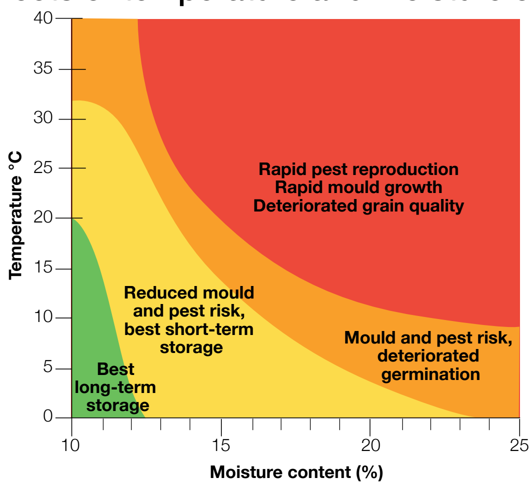
A Grains Industry Guide

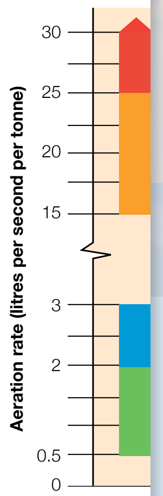


www.storedgrain.com.au

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

Effects of temperature and moisture on stored grain

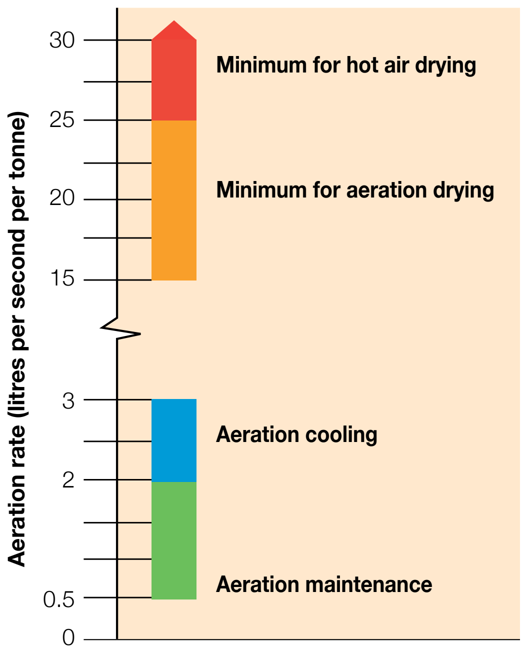




Source: Kondinin Grou

SOURCE: CSIRO ECOSYSTEMS SCIENCES

Aeration rates for grain drying and cooling



SOURCE: KONDININ GROUP

See pages 3 and 8 for more information.

CONTENTS

Author: Chris Warrick, Primary Business
Editor: Catriona Nicholls, Hot Tin Roof Communications
Designer: Liz Rowlands, Elizabeth Rowlands Graphic Design

Acknowledgements:
Ben White, Kondinin Group
Philip Burrill, DAF QLD
Peter Botta, PCB Consulting
Chris Newman, Stored Grain Services
Mark Conway, Control Unlimited
David Atkins, Agridry

PUBLISHED **July 2011 (Reprinted July 2016)**

FUNDED BY THE **GRDC Grain Storage Extension Project, www.storedgrain.com.au**

PRODUCED BY **www.primarybusiness.com.au**

GRDC PROJECT CODE **PRB00001**

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

GRAIN AERATION — THE FLEXIBLE GRAIN STORAGE TOOL

Grain aeration is a popular grain storage tool offering harvest flexibility, increased marketing opportunities and better control of grain quality, both at harvest and during storage.

As the range of chemical control options is reduced, grain aeration provides a powerful non-chemical stored grain insect management option.

The 2009 Kondinin Group *National Agricultural Survey* (NAS) revealed that 26 per cent of respondents currently use grain aeration on farm.

Through manipulating grain temperature and moisture, aeration cools the grain stack and achieves a more uniform bulk, delivering an optimal storage environment. Not only does this inhibit insect activity, but also maintains grain quality. This booklet explains the key differences and processes involved in aeration cooling and aeration drying.

About aeration

Aeration of stored grain has four main purposes — preventing mould, inhibiting insect development, maintaining seed viability and reducing grain moisture.

Without aeration 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 — for example 100 tonnes of barley requires a silo with a volume of about 130 cubic metres, $80m^3$ is taken up by the 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.

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 1).

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.

From the aeration fan outlet, air will take the easiest route to the top of the grain stack — the path of least resistance. Poor aeration ducting can result in pockets of grain not being aerated.

The peak of grain in a silo is another common place that aeration bypasses. The path of least resistance is to the side, below the peak of the stack as it is a shorter distance from the aeration ducting.

Cooling or drying

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 2–3 litres per second per tonne delivered from fans driven by a 0.37 kilowatt (0.5 horsepower) electric motor.

Aeration drying can be achieved with fans delivering 15–25L/s/t, typically powered by 7kW (10hp) electric motors (see Figure 2).

Low-capacity fans cannot push this drying front through the grain fast enough to dry grain in the top section of a stack before it turns mouldy.

The risk of using high capacity fans for cooling is they increase grain moisture very quickly 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.

Management for cooling or drying

Managing the aeration system is different for cooling or drying, with fan run times required at different times of day and at different intervals.

An automatic aeration controller increases the efficiency of an aeration system by negating the need for manual fan control, but it's vital to set the controller to operate the aeration fans for their designed purpose — either cooling or drying.

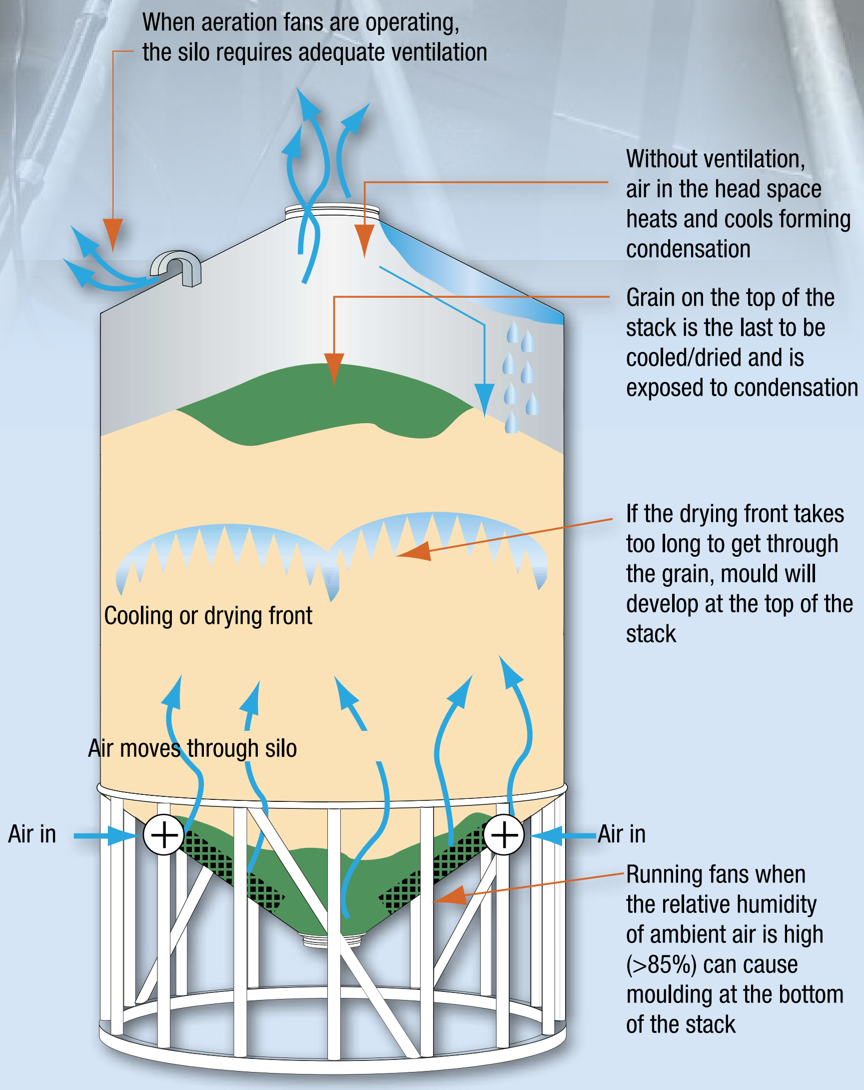
COOLING OR DRYING — MAKING A CHOICE

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 (12.5 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 is available.
- After drying to the required moisture content, cool the grain to maintain quality.
- High-moisture grain (for example, 16 per cent and higher for wheat and sorghum) will require immediate moisture reduction before cooling for maintenance.

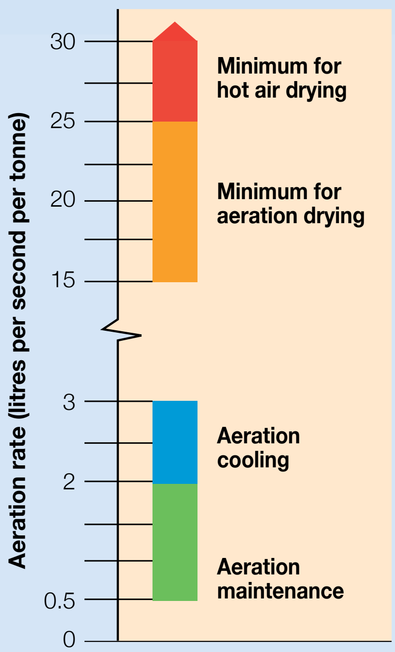
PHOTOS: CHRIS WARRICK, KONDININ GROUP

FIGURE 1 Air movement within an aerated silo



SOURCE: KONDININ GROUP

FIGURE 2 Aeration rates for grain drying and cooling



SOURCE: KONDININ GROUP

AERATION COOLING

The aim of aeration cooling is to maintain grain quality during storage. By lowering grain temperature and creating uniformity through the grain stack mould is less likely to develop, it is less attractive for insects, conditions slow (and can even stop) insect development and preserve seed viability.

Uniformity

Without aeration cooling, grain put into storage at warm harvest temperatures will hold these temperatures for a long time, in most cases taking months to cool down on its own. With 38 per cent of the storage area still taken up by air between individual grains, a grain stack becomes an effective insulator. If portions of the grain are put into storage with a higher moisture content or temperature, these areas will take a long time to even out through the grain stack. 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.

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 1, 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.

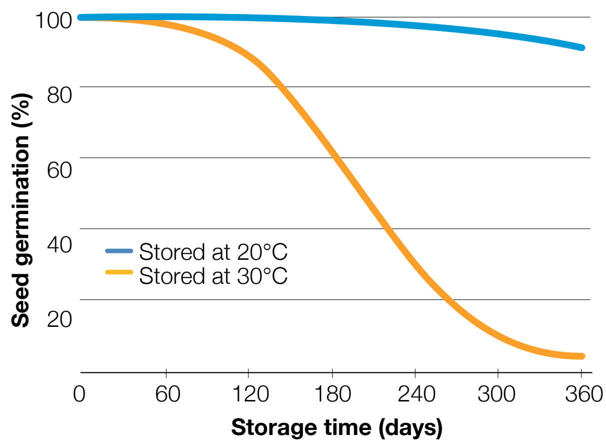
Temperature effects on seed viability

One way of measuring change in grain quality over time is seed germination.

A reduction in germination rate is the result of a breakdown of grain cellular structure and function, with related changes in chemical composition and modification to enzyme and other bio-chemical systems.

Stored grain deteriorates with time under any conditions, but poor storage conditions (high grain temperature and moisture) accelerate the deterioration process markedly.

FIGURE 3 Influence of temperature on wheat germination stored at 12 per cent moisture content



SOURCE: CSIRO

Keep it clean: *Tubular ducting in cone-bottom silos is much easier to clean if it can be easily removed.*

CSIRO research illustrated in Figure 3 shows how moisture content and temperature affect the rate at which seed germination declines, based on premium quality seed with an initial 100 per cent viability. The research revealed that the viability of wheat stored at 12 per cent moisture content and at a temperature of 20°C decreased by only 1 per cent after 150 days in storage. The same wheat stored at 12 per cent moisture content and at a temperature of 30°C, decreased in viability by 21 per cent after 150 days in storage.

Grain temperature targets

In the same way that 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 (refer to Table 1 and Table 2).

Ducting and ventilation for cooling

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.

PHOTO: CHRIS WARRICK, KONDININ GROUP

TABLE 1 Insect and mould development

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

TABLE 2 Lower limits to reproduction

INSECT	TEMPERATURE °C
Rice weevil	15
Lesser grain borer	18
Rust-red flour beetle	20
Saw-toothed grain beetle	20
Bruchid – cowpea weevil	20

SOURCE: DEEDI

PHOTO: CHRIS WARRICK, KONDININ GROUP

Let it vent: *Ensure airflow is unrestricted by opening silo lids when fans are operating.*

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. 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.

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.

PHOTO: BEN WHITE, KONDININ GROUP

***Access all areas:** In-floor aeration ducting in flat-bottom silos, which can be removed for cleaning, is ideal.*

AERATION COOLING PROCESS

1. **Continual aeration** — running fans for the first 2–3 days.
2. **Rapid mode aeration** — running fans for the coolest 9–12 hours per day for 3–5 days.
3. **Maintenance aeration** — running fans for the coolest periods, averaging 100 hours per month.

The cooling process

When grain is at a desired moisture level, cooling can be initiated.

***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.**

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 2–3 days, or until the air coming out the top of the silo changes from warm and humid to cool and fresh.

However, 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 will wet the grain.

***Note:* Even an automatic aeration controller with a relative humidity override will not stop the fans if it is set on 'manual' or 'continuous' mode.**

Stage two — rapid cooling

After aeration fans have been running continuously to flush out the warm, humid air for 2–3 days, reduce run time to 9–12 hours per day for the next 3–5 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.

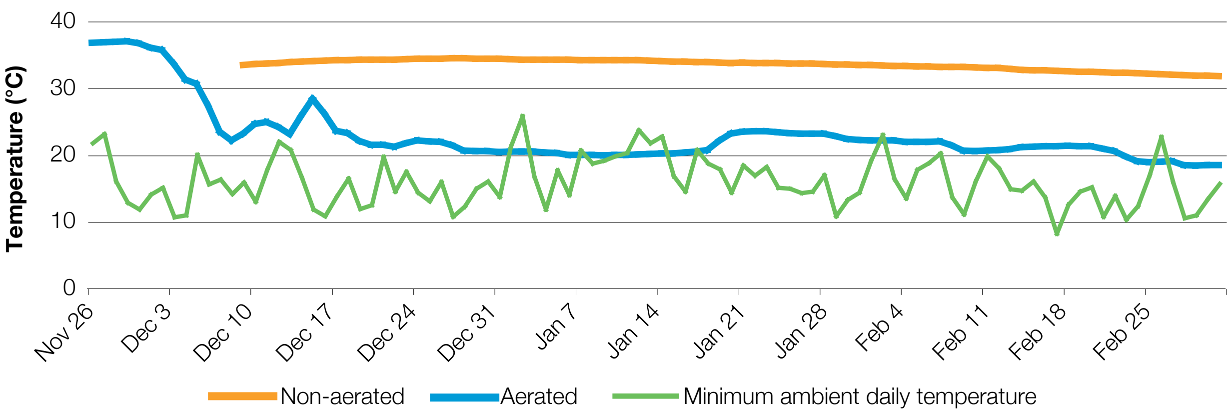
An initial reduction in grain temperature of 10°C ensures grain is less prone to damage and insect attack, while further cooling becomes a more precise task.

Stage three — maintenance cooling

After 3–5 days of aeration in 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.

FIGURE 4 Aeration cooling vs no aeration cooling



SOURCE: NSW DPI

Aeration cooling — the possibilities

Research carried out by the Department of Employment, Economic Development and Innovation, (DEEDI) Queensland shows that with the support of an aeration controller, aeration can rapidly reduce stored grain temperatures to a level that helps maintain grain quality and inhibits insect development.

During trials, grain was harvested at 30°C and 16.5 per cent moisture content. When put into storage without aeration, grain temperature rose to 40°C within a few hours.

An automatic aeration controller was used to rapidly cool grain to 20°C and then hold the grain between 17–24°C during November through to March. Figure 4 shows the difference in stored grain temperature as a result of aeration cooling operated by an automatic controller compared to grain with no aeration cooling.

Before replicating similar results, growers and bulk handlers need to:

- Know the capacity of their existing aeration system.
- Determine whether grain requires drying before cooling can be carried out.
- Have an understanding of the effects of relative humidity and temperature when aerating stored grain.
- Determine the target conditions for the stored grain.

While automatic aeration controllers take much of the guesswork out of aeration management, a basic understanding of the grain cooling processes and monitoring grain with a temperature probe will ensure a more successful outcome.

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, which can wet grain.

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.

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

PHOTO: BEN WHITE, KONDININ GROUP

Keeping aeration under control: *Automatic aeration controllers take the guess work out of aeration but they are not a set-and-forget tool.*

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 will get the grain closer to the target temperature.

Pricing of these controllers generally becomes competitive as the number of silos to be controlled increases and they perform efficiently, providing all parameters are entered accurately and correctly for each storage situation and cooling operation.

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.

This option is 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.

Aeration controllers for drying

Most aeration controllers are now available with a drying function, which is generally performed using the manual, set-point method, the adaptive discounting method, or the internal sensing method of control. However drying depends completely on the airflow through the grain and even with the addition of a drying function does not mean it will dry grain without appropriate quantity and quality of airflow.

An aeration controller will greatly assist the drying process, but they are not a set-and-forget tool, as the grain requires regular monitoring and in most cases the controller requires regular adjustments.

Operating in drying mode, aeration controllers select for air with low relative humidity. They also provide the added benefit of ensuring fans are not left running when the ambient conditions exceed 85 per cent relative humidity and grain could be re-wet.

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.

Managing moisture quickly

A trial done by DEEDI 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 5 illustrates likely outcomes under various storage conditions.

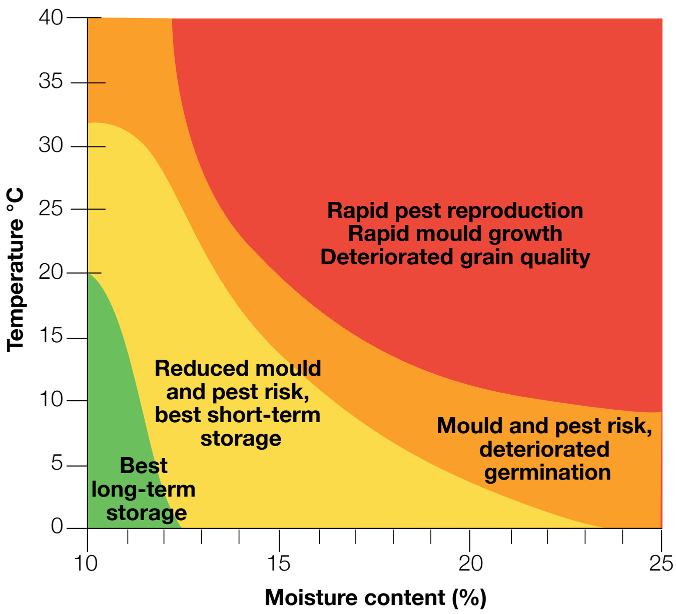
Moisture effects on seed germination

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 6).

FIGURE 5 Effects of temperature and moisture on stored grain



SOURCE: CSIRO ECOSYSTEMS SCIENCES

***Stay cool — stay safe:** If over-moist grain can't be dried immediately hold it under aeration cooling until drying equipment is available.*

Options for high-moisture grain

Grain that is over the standard safe storage moisture level of 12.5 per cent moisture content 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 and 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 10–20 tonnes of grain at a time with a high volume of heated air to pass through the grain and out through perforated walls.

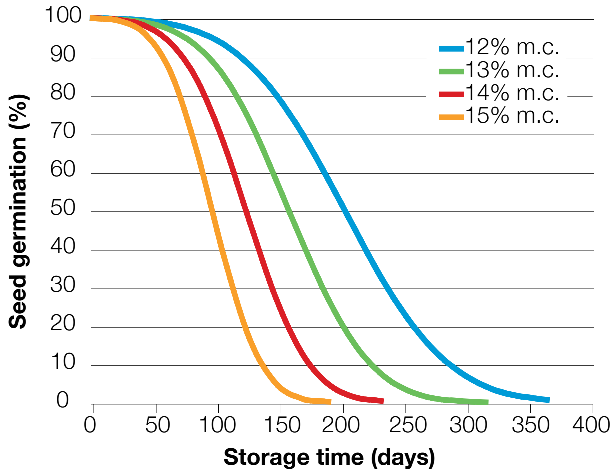
Blending

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 7).

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.

FIGURE 6 Influence of moisture content (m.c.) on germination of wheat stored at 30°C



SOURCE: CSIRO

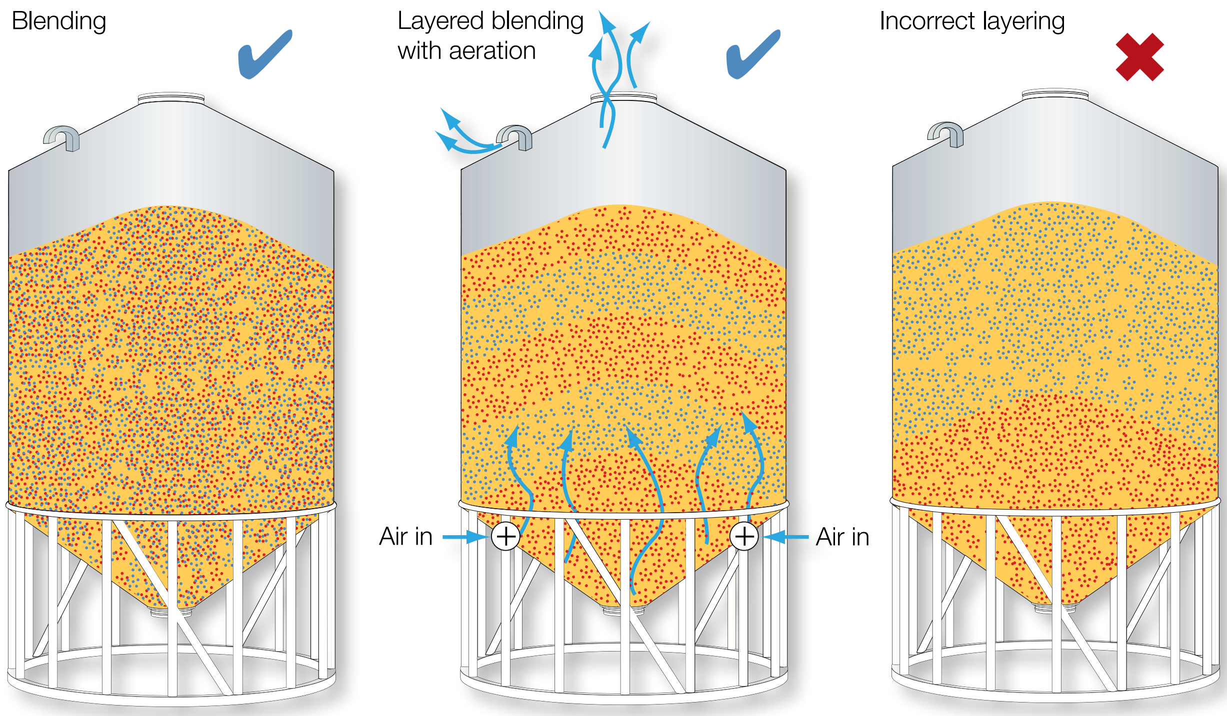
A blending example

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.

FIGURE 7 Correct blending



SOURCE: KONDININ GROUP

PHOTO: PHILLIP BURRILL, DEEDI

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 5, grain high in moisture and temperature post harvest, is at greatest risk of insect and mould attack. But 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 2–3L/s/t.

Growers can store grain at 14–15 per cent moisture content safely for a month or two 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.

Aeration drying

Aeration drying relies on a high volume of air passing through the grain to slowly remove moisture. It is usually done in a silo with either high-capacity aeration fans, only partly filled with grain or 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.

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 illustrated previously in Figure 1 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.

PHOTO: PHILIP BURRILL, DEEDI

Even airflow distribution: *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.*

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 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.

PHOTO: CHRIS WARRICK, KONDININ GROUP

Up and away: Known as a 'rocket' this type of ducting is only effective if the silo is full of grain to avoid the air taking the path of least resistance and going straight out the top.

TABLE 3 Water removed from grain during drying (L)

	PERCENTAGE OF MOISTURE CONTENT REDUCTION				
TONNES OF GRAIN	1%	2%	3%	4%	5%
1	10	20	30	40	50
10	100	200	300	400	500
25	250	500	750	1,000	1,250
50	500	1,000	1,500	2,000	2,500
75	750	1,500	2,250	3,000	3,750
100	1,000	2,000	3,000	4,000	5,000

SOURCE: KONDININ GROUP

PHOTO: BEN WHITE, KONDININ GROUP

Keep it clean: A full-floor perforated air plenum, provides even distribution of airflow but must be able to be cleaned thoroughly to prevent insects breeding and infesting the next batch of grain.

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 3, for every one per cent moisture content removed per tonne of grain about 10L of water has to also be removed.

Using the same example as above, to remove one per cent moisture content from the 60t of grain, 600L 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).

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, Table 4 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.

Comprehensive tables at the back of this booklet show more precise equilibrium moisture contents for wheat and sorghum.

These tables can be used to help set an aeration controller for drying.

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.

TABLE 4 Equilibrium moisture content for wheat

Grain moisture content (%)

Relative humidity (%)	Temperature (°C) 15	25	35
30	9.8	9.0	8.5
40	11.0	10.3	9.7
50	12.1	11.4	10.7
60	13.4	12.8	12.0
70	15.0	14.0	13.5

SOURCE: GRDC

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 wheat or sorghum at the back of this booklet, 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.

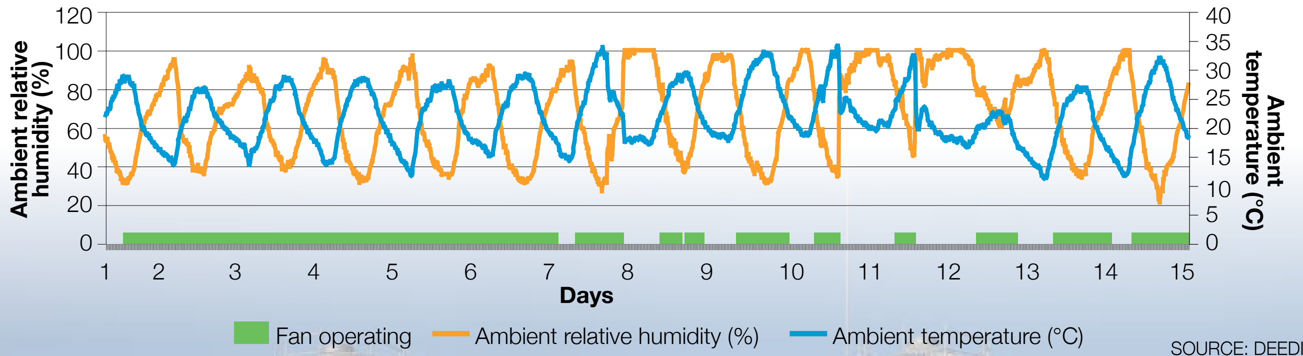
Aeration drying — the possibilities

Ambient conditions

With the right equipment and knowledge, aeration drying allows greater harvest flexibility. It's helpful to understand what to expect before attempting to dry grain with aeration.

DEEDI carried out the following trial on a farm in south-west Queensland during December 2006. While the time of year provided favourable temperatures to assist drying (see Figure 8) there was a fair amount of time when the main element for drying (relative humidity) was high, which was unhelpful.

FIGURE 8 Ambient conditions during aeration drying



SOURCE: DEEDI

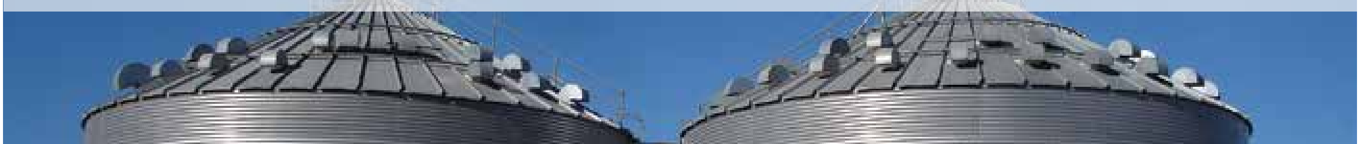


PHOTO: CHRIS NEWMAN, DAFWA

Exhausted air: *Because aeration drying requires high airflow, extra ventilation is needed to allow air and moisture to escape the silo unrestricted.*

For the trial, an aeration controller was set to leave fans running while ambient conditions were below 85 per cent relative humidity for the first seven days. An inaccuracy in the relative humidity sensor on the controller actually meant the fan didn't turn off for the first seven days.

After seven days the drying process moved into phase two by reducing the aeration controller trigger point down to 70 per cent relative humidity. The green bars at the bottom of Figure 8 show that after day seven the fan operated at times when the ambient relative humidity (yellow line) was below 70 per cent.

Results of aeration drying trial

Using a 60t silo designed for aeration drying, the DEEDI trial delivered textbook results, helped by favourable weather conditions at the time.

For the first seven days with the fans running continuously (while ambient conditions were below 85 per cent relative humidity), the grain was rapidly cooled, surface moisture was removed and self heating was prevented.

By day seven the main drying front reached the mid-point of the silo (location of sensor) and the set-point controller's trigger point for relative humidity was reduced to 70 per cent. This meant the fans only ran when ambient relative humidity was below 70 per cent relative humidity, which resulted in further grain drying.

The lesson to take away from this trial is that even with a specifically-designed aeration drying silo, with adequate airflow rates, ideal ducting and favourable weather conditions (plus the help of a set-point aeration controller) it still took 12 days to get 60t of wheat from 17.5 per cent moisture content down to 12.5 per cent (see Figure 9).

With anything less than this equipment, and these favourable conditions, the process would have taken even longer.

Aeration drying is not a fast process and requires meticulous management.

Supplementary heating

Supplementary heating can be used in conjunction with aeration drying. The aim is not necessarily to make the process quicker but to widen the window of time when fans can be run by improving the conditions of the ambient air as it enters the fans.

Increasing the air temperature does two things to aid the drying process. Firstly, warm air can transfer moisture from the grain more effectively than cold air. Secondly, increasing the temperature reduces the air's relative humidity, lowering its effective equilibrium point with the grain and enabling it to carry more moisture from the grain out of the storage.

Table 5 demonstrates the effect on inlet air conditions after it's heated. For example, inlet air at 25°C and 70 per cent relative humidity will result in a wheat moisture content of about 14 per cent. By heating that inlet air by 4°C its relative humidity is reduced to 56 per cent, meaning it can theoretically dry wheat to its equilibrium point of 11.8 per cent moisture content.

How much heat?

The two biggest risks with adding heat to aeration drying are: fire risk from an open flame (so constant monitoring and observation is required) and the over heating and over drying of the grain close to the aeration ducting.

Heat can be added to aeration drying in proportion to the airflow rate. Higher airflow rates allow more heat to be added as it will push each drying front through the storage fast enough to avoid over heating the grain close to the aeration ducting.

As a general guide, inlet air shouldn't exceed 35°C to avoid over heating grain closest to the aeration ducting.

While continuous flow and batch dryers heat grain above this temperature, it is only for a short period of time, so grain damage is minimised.

Heating for a prolonged period, such as in an aerated silo, will cause the grain skin to shrink and crack, downgrading its quality and viability (capacity to germinate).

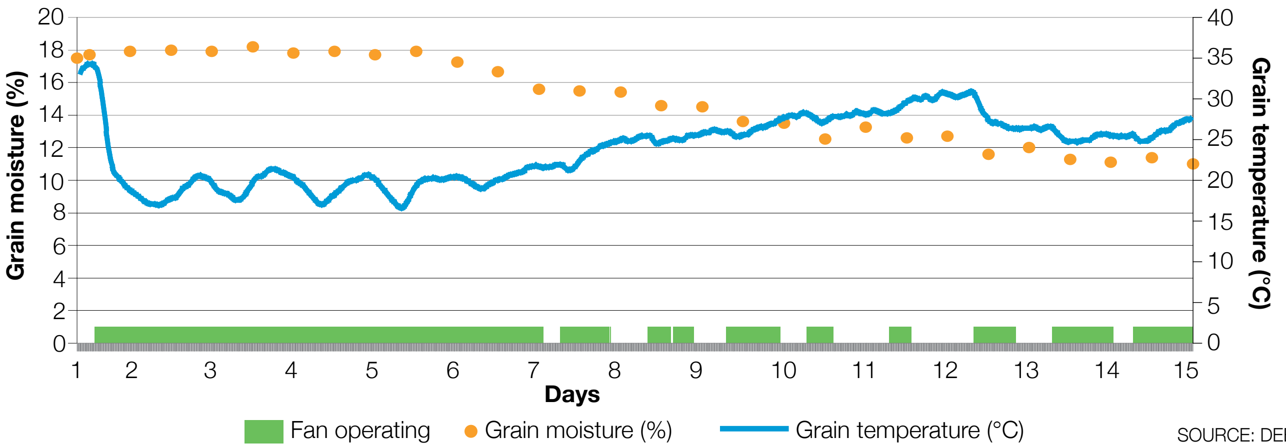
For malt barley, grain temperatures above 43°C for any period of time decrease germination.

Cooling after drying

Regardless of whether supplementary heat is added to the aeration drying process or not, cool grain immediately after it has been dried to the desired level.

Refer to the cooling section of this booklet to maintain grain quality and prevent mould damage and insect infestation.

FIGURE 9 **Aeration drying results**



SOURCE: DEEDI

TABLE 5 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

Dedicated drying machines

Dedicated drying machines are the next step up from aeration drying because they rely far less on ambient conditions.

Warm, dry weather helps, but dedicated drying machines can heat grain to higher temperatures for short periods so it dries quickly, regardless of ambient conditions.

For growers and bulk handlers who plan to have large volumes of grain at high moisture contents (above 16 per cent) dedicated drying machines are a more reliable option for drying grain quickly.

Batch drying

Designed for drying high-moisture grain in moderate quantities, batch dryers can typically remove about 3 per cent moisture content from 8–10t/hr depending on the type of grain, size of dryer and the ambient conditions.

Batch dryers can be set up as a stationary batching machine or as a portable trailer, but both use the same drying principle.

A batch of grain is put into the dryer, usually with mesh walls, and high volumes of pre-heated air are forced through the grain to dry it quickly.

After grain is dried to the desired level the heater is turned off and the fan is left running for a period of time to cool the grain before augering it back into storage.

Continuous flow drying

At the higher end of the grain drying equipment scale, continuous flow dryers are the most efficient way of drying large quantities of high-moisture grain.

Typical operating capacity removes 3 per cent moisture content from 10–37t/hr depending on the type of grain, size of dryer and ambient conditions.

Continuous flow dryers blow pre-heated air through a stream of grain before another fan blows cool air through the grain just before it leaves the dryer.

The efficiency of a continuous flow dryer is largely due to the fact that the heaters remain on for the whole time and the grain never stops moving.

The heaters continue to operate as grain is augered from the storage to the dryer and back again, with no time wasted in having to turn them off and wait for them to reheat.

The amount of drying can be measured on the go with samples taken from the dryer outlet. If grain requires more drying, the metering rollers on the outlet are slowed making the grain stay in the dryer for longer, which allows it to be dried further.

Grain is generally cooled by a separate fan as it leaves the dryer so it's safe to be augered back into storage.

PHOTO: AGRIDRY

***Batching it:** Drying batches of grain at a time, these machines use diesel-powered heaters and high-flow electric fans driven by a PTO-powered generator.*

PHOTO: BEN WHITE, KONDININ GROUP

***On the move:** Continuous flow dryers blow pre-heated air through a steady flow of grain.*

PERFORMANCE TESTING AERATION SYSTEMS

Why measure aeration air-flow

Throughout the grains industry a wide range of local and imported aeration fans are in use, fitted to a large variety of grain storage types and sizes. These storages hold a range of grain types from small-seeded canola to larger cereal or pulse grains. Grain, storage and aeration fan type, along with the numerous ducting and venting designs used with aeration systems, all impact on the final working air-flow rates.

Air-flow rates well below or above recommended rates can result in the aeration system being of no benefit, wasting both the capital investment and electricity. In some cases inappropriate air-flow rates will cause serious grain damage. Accurately measuring airflow can be achieved by following the advice outlined below.

A simple device called an ‘A-Flow’ has been developed to measure the air-flow rate of an aeration system to check its performance.

Making an A-Flow device

The A-Flow device consists of a tube with a slot, designed to be used with a vane anemometer (Kestrel®) to measure air speed. The design and dimensions of the A-Flow device, along with the procedure to measure air-flow are critical for obtaining accurate readings. Simply placing an anemometer directly in front of the fan air intake or even in front of the A-Flow device does not provide reliable readings.

This A-Flow device is suited to test aeration fans with an air intake diameter of less than 235mm. Large fans and a few very small fans can not be tested using this size A-Flow device.

Shopping list

Key components required:

- ✔ 700mm length of 250mm diameter PVC stormwater pipe (approximate cost of $40)
- ✔ Kestrel® anemometer (models 3000 or 2500 approximate cost of $330)

Other components required:

- ✔ Four handles
- ✔ Four short (250mm) octopus (occy) straps
- ✔ Cardboard and felt-tip marker
- ✔ 12mm wooden dowel (550mm long)
- ✔ Cloth tape
- ✔ Self-adhesive rubber seal (900mm long — for example, Raven RP48 or Moroday door and window)
- ✔ 12mm Nylex clear tubing (900mm long)

On-farm test: *The A-Flow device is designed to be made on farm to measure the air-flow rate of grain aeration fans.*

STEPS TO MAKING AN A-FLOW DEVICE

STEP 1

Ensure both ends of the 700mm long PVC pipe are cut square. Mark one end of the tube as the 'fan' end. Mark the midpoint 350mm from the fan end and fit four handles, spaced evenly around the outside in the middle of tube (see Figure 10). These handles will enable four short octopus straps to hold the A-Flow tube in place over the fan intake during the air-flow testing.

PHOTOS: DAFF QLD

FIGURE 10

Handles fixed onto the PVC A-Flow tube enable octopus straps to hold the tube against the fan during testing.

STEP 2

To make the anemometer entry slot, make a cardboard template with a hole that allows the anemometer to move through freely. Mark a point on the PVC tube, 265mm from the fan end, and trace the cardboard template onto the tube with the mark in the centre of the rectangular hole. Drill multiple holes inside the rectangle to remove waste and then file to shape.

STEP 3

Cut a 550mm long piece from the 12mm wooden dowel. Use a sanding disc to flatten an 80mm long section on one end of the dowel. Rest the back of the anemometer on this flattened section and use the cloth tape to fix the anemometer to the dowel (see Figure 11).

Drill a 13mm hole in the PVC tube next to the rectangular hole. Shape this to allow the anemometer, taped on the dowel, to move freely in and out of the tube.

FIGURE 11

A piece of wood dowel with a flattened end is secured to the back of the anemometer with cloth tape.
A rectangle hole in the PVC A-Flow tube allows the mounted anemometer to slide in and out of the tube freely.

STEP 4

To ensure the A-Flow tube forms an effective seal up against the aeration fan, fit a length of self adhesive 'rubber seal' to the fan end of the tube. (Raven RP48 or Moroday — Door & Window weather strip, EPDM rubber, 6mm).

STEP 4

Finally, to assist with smooth air entry into the A-Flow tube, take a length of the 12mm Nylex clear tubing and carefully cut a slit along one side of the tube face so it can be fitted over the non-fan end. Use cloth tape to hold in place (see Figure 12).

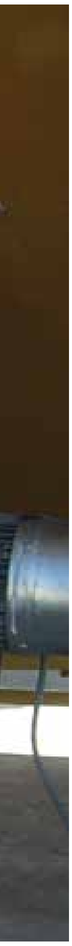
FIGURE 12

A piece of slit Nylex tube creates a rounded edge on the non-fan end of the PVC A-Flow tube to reduce turbulence as the air is sucked into the tube.

PHOTO: DAFF QLD

***Simple system:** Measuring the air-flow requires setting the anemometer to read m/s and to read 'average' then slowly sliding it in then out of the PVC A-Flow tube over a 20-second period.*

PHOTO: DAFF QLD



Using the A-Flow to take air flow measurements

The aim is to accurately measure the air speed (metres per second) going through a tube of a known diameter (239mm). A simple calculation can then determine the volume of air (cubic metres or litres per second) the aeration fan is pushing into the grain storage.

For realistic measurements, carry out the test when the storage is full of grain. This creates the normal operating back-pressure restricting air-flow. Ensure the aeration system is running and the hatches or vents are open as under normal system operation.

- Mount the A-Flow tube to the face of the operating (on) aeration fan intake using the four octopus straps. Ensure the A-Flow tube is centered over the intake and an effective seal is achieved against the fan housing.
- Set the anemometer to read metre per second (m/s) air-flow. Select the averaging function 'AVG' on the anemometer. The anemometer will now display the average air speed from when the instrument is turned on.
- Hold the anemometer, which is taped to the wooden dowel, and check it is set to m/s and displays AVG. Now turn the anemometer off.
- Insert the anemometer about 50mm into the slot so the vane is spinning. You should still be able to see the blank screen of the anemometer outside the A-Flow tube. Allow the vane to get up to speed (5–10 sec) then turn the anemometer on and steadily push the anemometer through the tube over a 10-second period until it touches the far side. Steadily pull the anemometer back towards you over another 10-second period. Read the air speed 'm/s average' reading from the anemometer screen when the screen first appears out of the slot. This is the average air speed over the 20 seconds (see Figure 13).
- Repeat this process three times. These three readings of average air speed (m/s) should be of a similar value if you are careful (for example, 5.9, 6.1, 6.0m/s). A practice run is usually helpful.

Aeration system performance

When an aeration fan is delivering well below or above the recommended flow rates, consider the following and make appropriate changes:

- Fan model or design is not suited to its current use (for example, storage size, grain type).
- Aeration system ducting, venting or other features are restricting fan performance.
- Maintenance or repairs are required on the fan or aeration system (for example, dust build-up on fan impeller).

FIGURE 13 20-second test

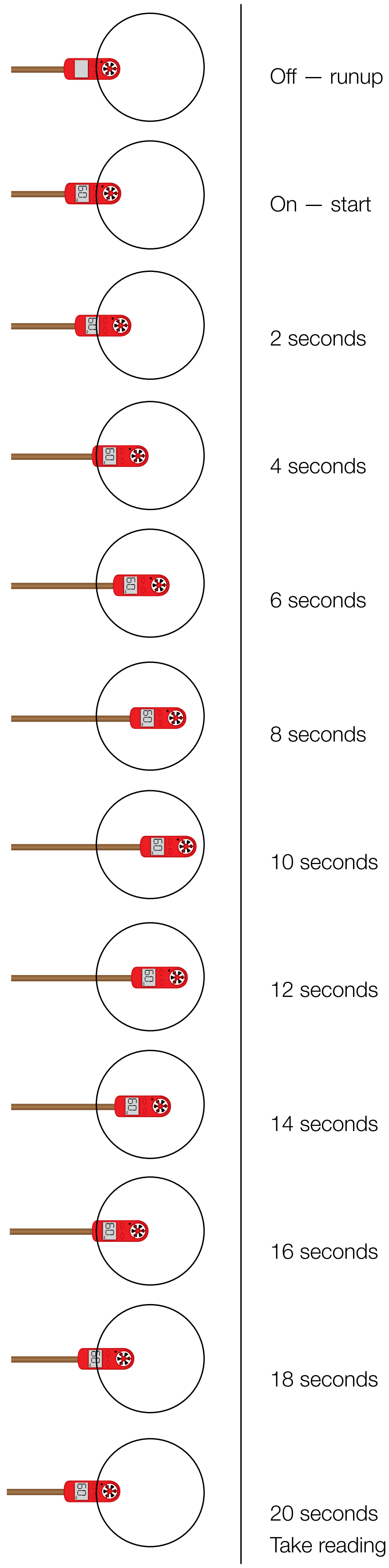


PHOTO: CHRIS WARRICK, PROADVICE

CALCULATING THE AIR-FLOW RATE

STEP 1

Find the internal area of the PVC A-Flow tube using Лr². (Л = 3.142, r = radius)

Example:

Internal radius of tube = 119.5mm, which is 0.1195m

So internal area =
0.1195 x 0.1195 x 3.142 = 0.04486m²
(If you've used the specified PVC tube with internal diameter of 239mm the area is 0.04486m²)

Write 0.04486m² clearly on the outside of the PVC A–Flow tube.

STEP 2

Multiply the average air-flow measured (for example, 6.0m/s) by the area of the tube to give cubic metres of air-flow per second (m³/s).

Example:

6.0m/s x 0.04486m² = 0.2692m³/s

Convert to litres of air per second by multiplying by 1000.

Example:

0.2692 x 1000 = 269.2L/s

STEP 3

Now calculate L/s/t of grain by dividing the amount of grain in the silo by the air-flow rate.

Example:

If the storage contained 150t of wheat, the calculation would be 269.2L/s divided by 150 t = 1.8L/s/t.

Multiple fans on a storage: If you usually operate two or more fans on a storage, take readings (m/s) on each fan while they are all operating.
Calculate air-flow rates for each fan (L/s) and add these together to arrive at a total air-flow going into the storage.

Example:

180L/s + 150L/s = 330L/s

Divide this figure by the tonnes of grain in the storage to determine L/s/t.

Remember: *if the amount of grain in the storage is reduced, or the grain type is changed (for example, from wheat to canola) this will significantly impact on air-flow rates. Testing is usually best carried out when the storage is filled to its usual level (full) with the usual grains stored.*

EQUILIBRIUM TABLES — GRAIN MOISTURE CONTENT TO AIR RELATIVE HUMIDITY

TABLE 6 Sorghum equilibrium

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									

GRAIN MOISTURE (%)

SOURCE: CUSTOMVAC

FURTHER READING

Aeration cooling for pest control (GRDC Fact sheet)

Keeping aeration under control (Kondinin Group research report)

How aeration works (GRDC Update)

Aeration in on-farm storage – what's possible (GRDC Update)

www.storedgrain.com.au

GRAIN STORAGE SPECIALISTS

National hotline
1800 weevil (1800 933 845)

QLD and northern NSW, Philip Burrill
philip.burrill@daf.qld.gov.au

Southern

NSW, VIC, SA and TAS Peter Botta
pbotta@bigpond.com

WA, Ben White
ben@storedgrain.com.au

GRAIN BIOSECURITY CONTACTS

Plant Health Australia
02 6215 7700
biosecurity@phau.com.au
www.planthealthaustralia.com.au

USEFUL RESOURCES

GRDC Grain storage extension project
www.storedgrain.com.au

Grain Trade Australia
02 9235 2155
www.graintrade.org.au

TABLE 7 ASW wheat equilibrium

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									

SOURCE: CUSTOMVAC

www.storedgrain.com.au

GRDC GRAINS RESEARCH & DEVELOPMENT CORPORATION

PO Box 5367, Kingston ACT 2604 | **T** +61 2 6166 4500 | **F** +61 2 6166 4599 | **E** grdc@grdc.com.au | **W** www.grdc.com.au