Grain aeration design and performance guide

A summary of development activities conducted 2021-2024,

as part of the GRDC Grain Storage Extension Project PRB2011-001SAX.

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Acknowledgments: Charlie Bergmeier, Brock Dembowski, Mark Earles and the numerous growers, manufacturers and businesses who supplied sites, equipment and grain for testing.

Preface

This summary of development activity work conducted by the GRDC grain storage extension team investigates current knowledge and understandings relating to the aeration of grain in storage in Australia.

While aeration uptake varies nationally, the scope for application is universal pending an understanding of ambient conditions, aeration performance characteristics and the dynamics of aeration flow through grain in storage.

While simulation and modelling could theoretically assist in the design of grain aeration systems, the breadth of variables is extensive. As a result, simulation and modelling of aeration flow alone are unlikely to accurately predict aeration flow characteristics.

This body of work distils current knowledge and focusses on empirical measurement of representative airflow rates through a range of grains typically grown in Australia.

The shared findings are intended to be used by industry specialist who have prior knowledge of grain aeration. The aim is to assist in the design and implementation of aeration systems including post installation performance analysis. (See Figure 1)

Key takeaways:

- Growers:
    - Ask manufacturers and suppliers of new equipment if the aeration performance is measured or calculated/theoretical. Only buy from suppliers who have field-tested the performance of their aeration equipment.
    - If existing aeration system is not achieving expected results, test airflow.

- Manufacturers and suppliers of aeration equipment:
    - Use all available resources and modelling as a guide only. There are many influencing variables and in-situ airflow measurement is the only way to confirm performance meets expectations.

- Researchers:
    - The key unknowns remaining are the influence of other variables on aeration backpressure. For example, duct type, duct size, duct open area, plenum design.

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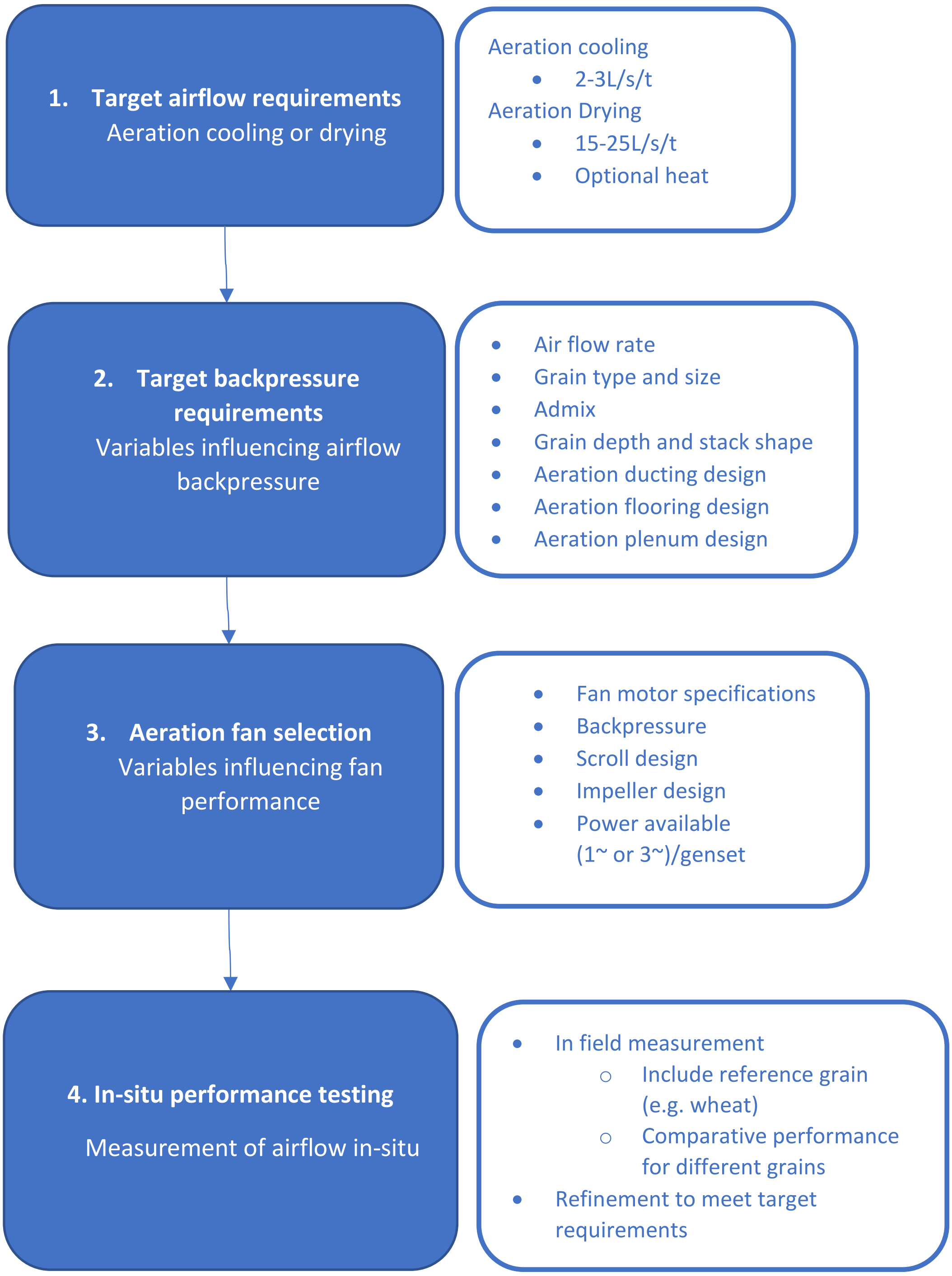
Grain aeration – matching performance requirements with equipment and infrastructure selection.

Figure 1: Grain aeration system considerations, design, selection and testing



1. Target airflow requirements
Aeration cooling or drying

Aeration cooling
- 2-3L/s/t

Aeration Drying
- 15-25L/s/t
- Optional heat

2. Target backpressure requirements
Variables influencing airflow backpressure

- Air flow rate
- Grain type and size
- Admix
- Grain depth and stack shape
- Aeration ducting design
- Aeration flooring design
- Aeration plenum design

3. Aeration fan selection
Variables influencing fan performance

- Fan motor specifications
- Backpressure
- Scroll design
- Impeller design
- Power available (1~ or 3~)/genset

4. In-situ performance testing

Measurement of airflow in-situ

- In field measurement
    - Include reference grain (e.g. wheat)
    - Comparative performance for different grains
- Refinement to meet target requirements

1: Target airflow requirements

Determine the aeration flow requirement per tonne of stored grain.

For aeration cooling, between 2 and 4 litres of air per second is required for every tonne of grain in the stack (also denoted in this guide as l/s/t). For example, a 100 tonne silo full of grain will require a minimum of 200-400 litres per second.

Aeration drying requires significantly higher airflow rates of 15 to 25 l/s/t.

Ensure ample quality air is available for the intended purpose, particularly if storing grain in the tropics where higher levels of ambient temperatures and relative humidity are likely.

For further reading see:

- Quantifying opportunity for aerated grain storage in northern/tropical regions of Australia

2: Target backpressure requirements

Establish the backpressure range due to the grain being aerated.

Backpressure can vary with grain size and shape where smaller, more spherical grain generally (but not always) increases the backpressure at a given flowrate. Cracked grain and admix can also impart significant influence on backpressure so allowances should also be made for this with a factor of safety.

An extensive literature review found previous tables and charts referencing back pressure for grains largely referenced research conducted in the United States around 1953. Some of this research may not take into account all variables influencing backpressure, in particular, grain settling or packing.

The GRDC grain storage extension team developed a method and apparatus for evaluating the backpressure induced by a range of different grains. Data for both loosely packed and settled grain was measured.

Field measurements across a range of grains and grain storage types verified the backpressure due to the grain but also determined additional backpressure was levied by the aeration delivery system. Ducting, plenums, transitions and floor grates all influence the level of backpressure experienced by the fan and can vary according to design.

Refer to the below, plenum backpressure charts, to establish the likely range of backpressures for the grains that will be aerated in the storage at full depth and establish an airflow budget required to operate at that backpressure. Remember that these charts have logarithmic axes when referencing them.

Aeration flows in the stack will preference the path of least resistance, that is, where grain is shallowest in the silo stack and where the grain is most loosely packed. Having fan capacity capable of flowing through settled grain at the maximum depth should guide the backpressure requirement.

Identify the grain likely to be stored that imposes the highest backpressure at the desired airflow rate as this will define the system’s peak requirement.

Remember to allow an additional factor of safety for the backpressure from the aeration delivery system. Field measurements found full-floor aeration imposed the lowest additional backpressure.

For further reading see:

- Gathering knowledge: Literature review – Grain aeration backpressure
- Aeration backpressure testing device
- Aeration backpressure: testing airflow resistance in Australian grain
- Airflow distribution in grain silos
- Field testing aeration backpressure

3: Aeration fan selection

Evaluate the range and performance of available fans.

Aeration fan selection takes into consideration the available power sources (single or three phase) and air flow requirement for the desired outcome, be it cooling or drying.

Manufacturers should provide a performance curve for each aeration fan as a reference for determining likely air flow within the expected backpressure range.

Applying the estimated backpressure in step 2, select an aeration fan that will deliver the required airflow at this nominated backpressure.

Where multiple fans are to be used simultaneously in a single silo, identical fans must be used and remember that the airflow delivery of a single fan is not simply multiplied. Depending on the backpressure and flow performance of the fan, a backpressure equilibrium state between the fans will see a reduction in individual fan output.

For further reading see:

- Performance testing aeration fans

4: In-Situ performance testing

Measure flow outputs through system and grain stack to ensure targets are met.

Aeration measurement in-situ ensures fans are sized appropriately.

Testing in the field requires the use of a measurement apparatus, for example a hot wire anemometer and smooth wall pipe around 8-10 diameters in length to achieve laminar air flow in the intake side of the aeration fan without impeding performance.

In-situ performance testing should be ideally conducted under the grain imposing the maximum backpressure to ensure target air flows are met under the most challenging backpressure conditions.

If aeration rates for cooling exceed a nominal 5l/s/t, consider a choke or intake baffle plate, or where fans are driven by an electronically commutated motor, reduce the speed of the fan accordingly, or turning off some fans in a multi-fan system.

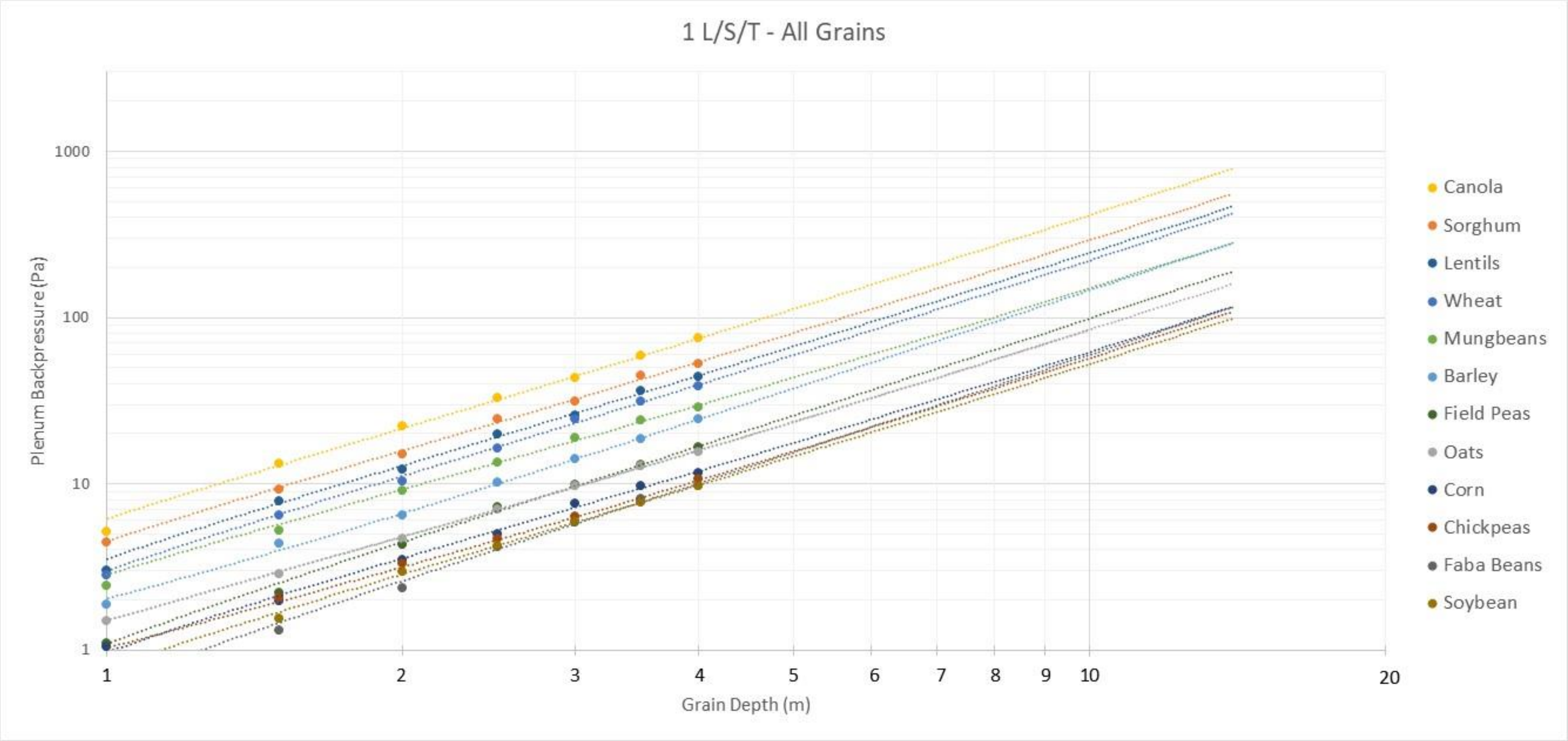
To maximise efficacy, the use of an aeration fan controller is strongly advised to optimise run times and limit operation when relative humidity is above 85 per cent.

For further reading see:

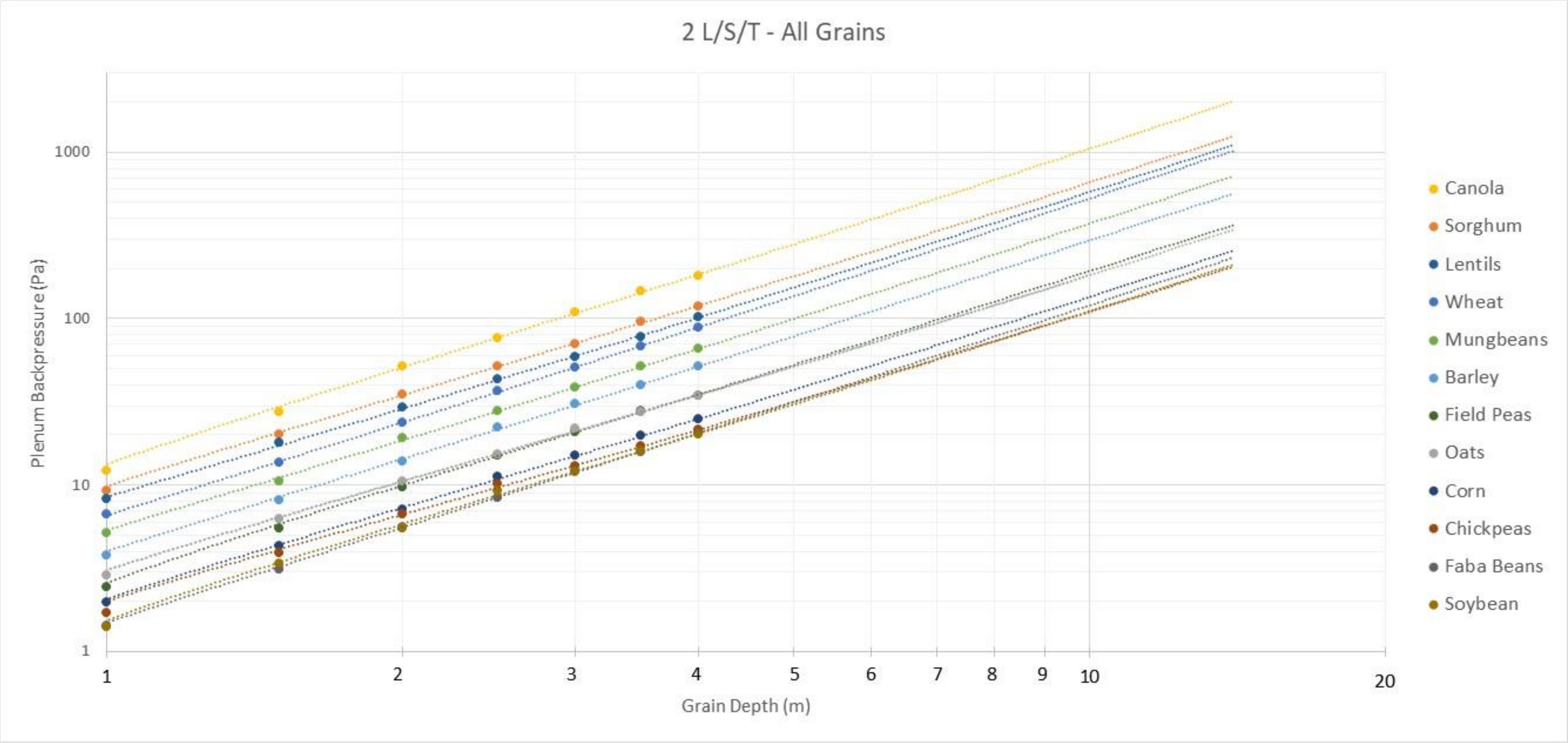
- Field testing aeration backpressure
- Grain settling impact on aeration

Expected backpressure charts

The following series of charts derived utilising a lab-based test-rig can be used as a guide to indicate grain-induced only backpressure at a range of air flow rates.



Note: Backpressure indicated is for a consolidated (not loose fill) sample. Additional backpressure induced through, for example, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.



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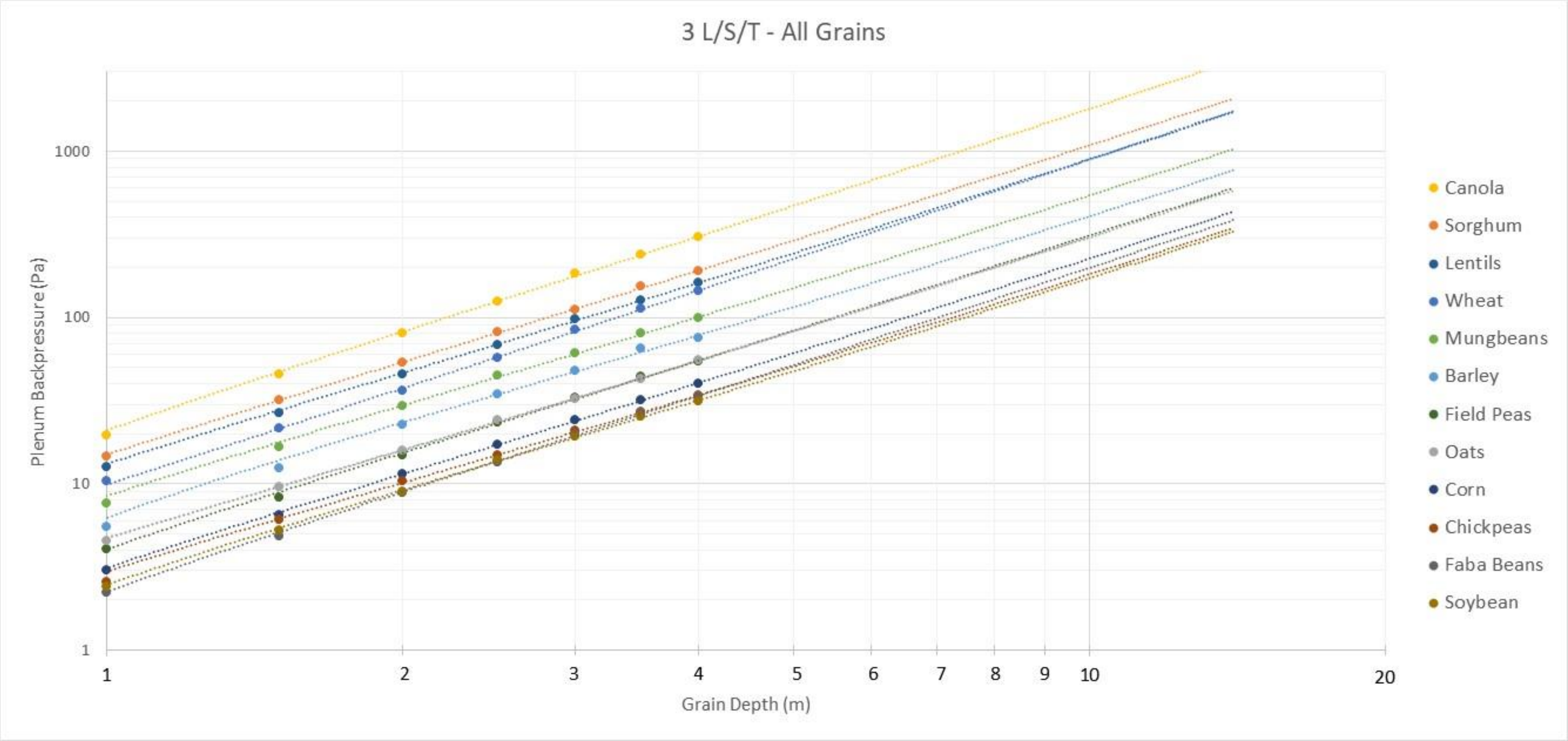

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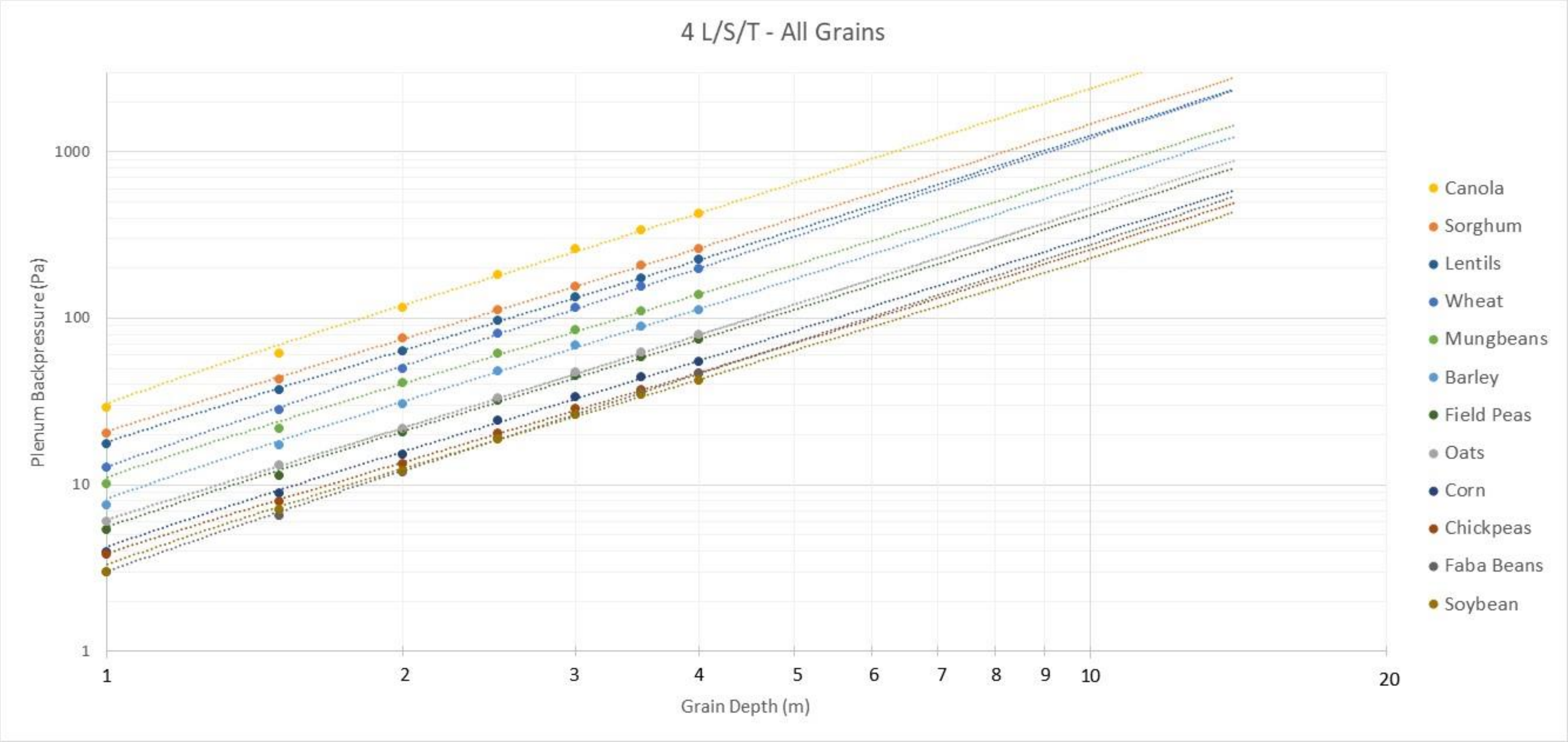

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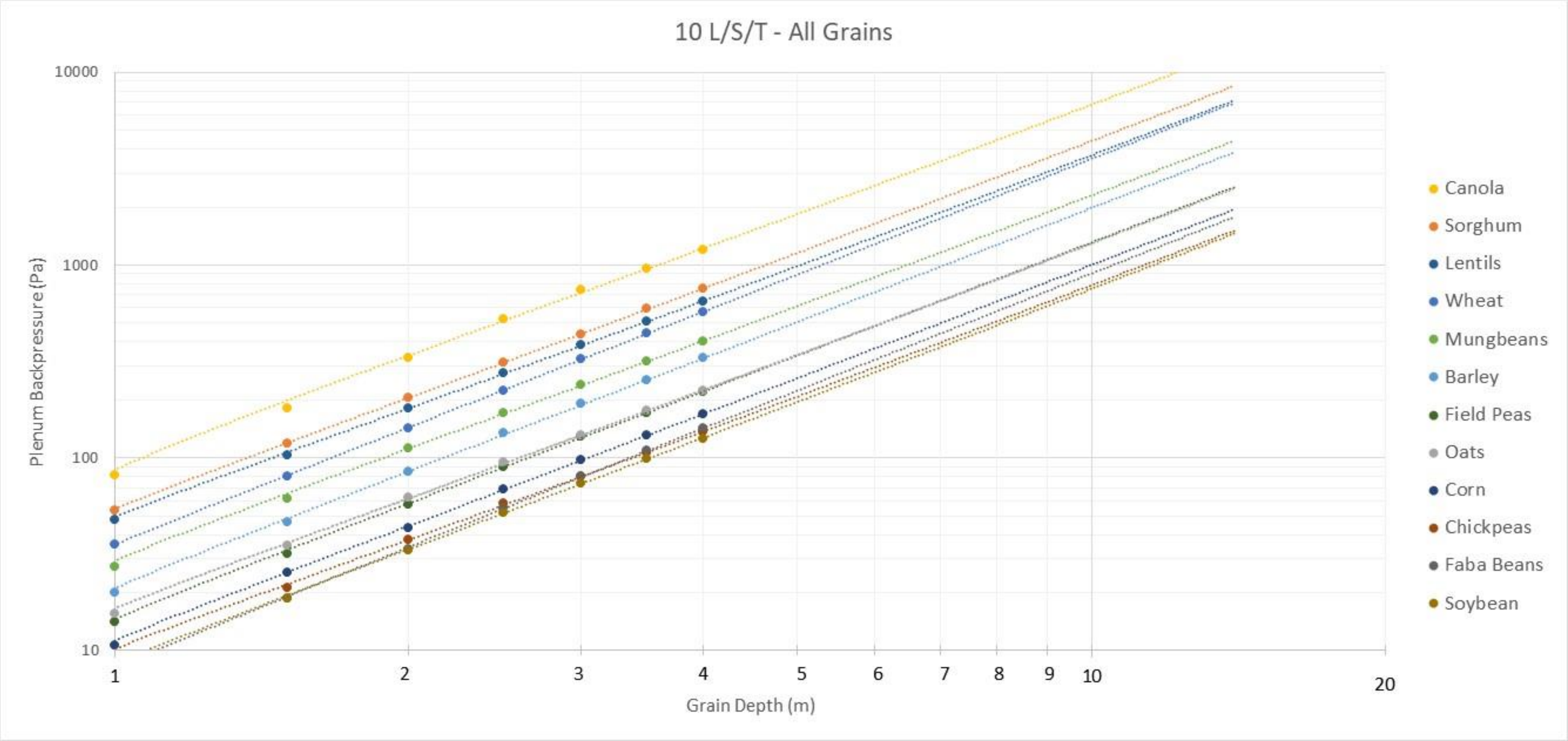

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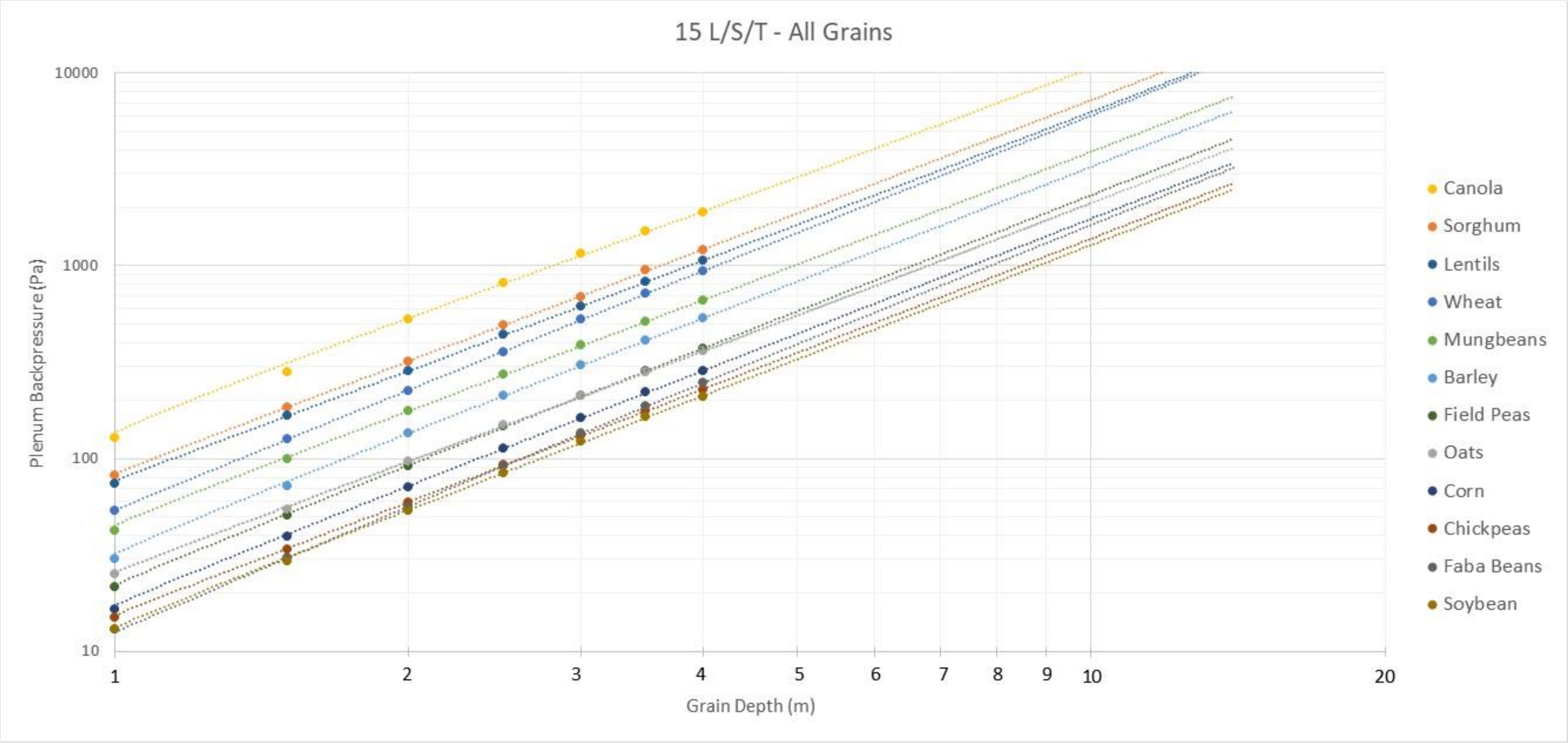

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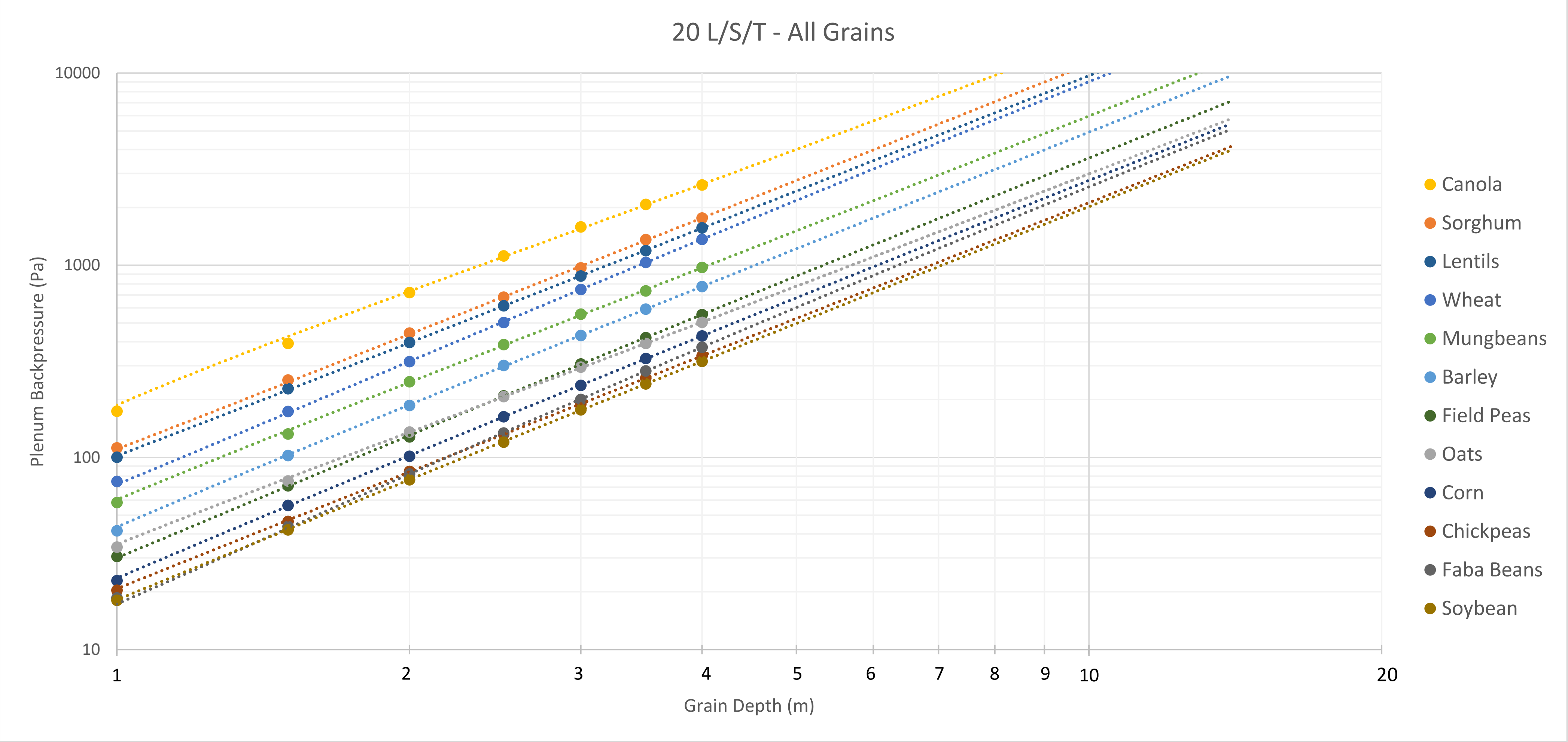


Note: Backpressure indicated is for a consolidated (not loose fill) sample. Additional backpressure induced through, for example, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Appendices: References and further reading

Development activity reports containing details and results that have informed this guide.

1. Gathering Knowledge: Literature review- Grain aeration backpressure (DA2021-2)

Objective – (Question or information gap to answer)

Explore and collate any relevant information on aeration backpressure to determine what gaps exist, what lessons have been learnt from prior testing and what methodology was used.

Background

Grain aeration is an essential management tool used by Australian grain growers in preserving the quality of grain in storage.

Equipment used to administer aeration for cooling or drying includes aeration fans, typically axial or backward curved centrifugal designs, plumbed with plenums or ducting to distribute air as uniformly as possible.

Given the importance of achieving optimal cooling aeration rates of 2-4l/s/t or aeration drying airflow rates of 15-25l/s/t, it is surprising that the vast majority of manufacturers supplying grain aeration fans do not have performance curves for their fans.

Aeration requirements and matching

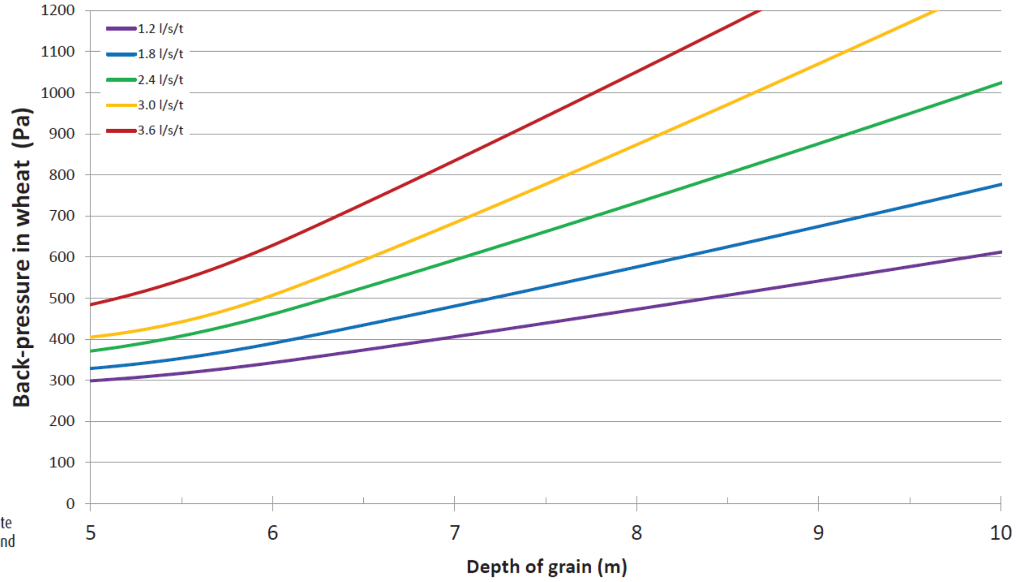
The availability of performance curves for grain aeration fans would assist in selection and matching of fans for a given operating specification.

However, fan performance specifications are only applicable where the operating backpressure for a fan is known.

Published metrics

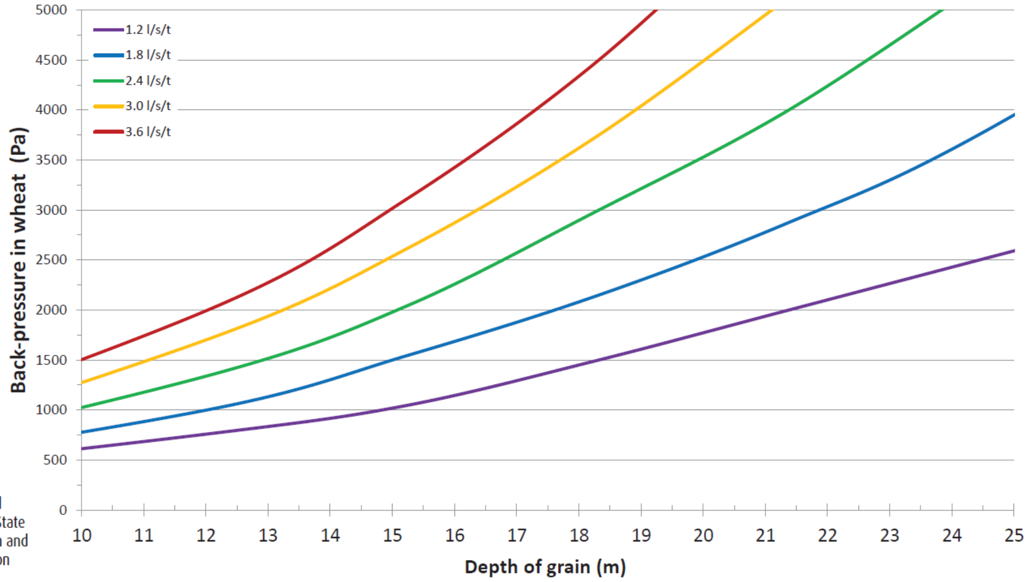
Current references include the metric adaptation of other work as published by the Kondinin Group in 2020.[i]

Figure 6. Expected back-pressure for aeration cooling in wheat for a range of airflow rates: 5-10m
(Excludes back-pressure due to ducting, ventilation constrictions and transitions)



Source: Adapted from K-State research and extension

Figure 7. Expected back-pressure for aeration cooling in wheat for a range of airflow rates: 10-25m
(Excludes back-pressure due to ducting, ventilation constrictions and transitions)



Source: Adapted from K-State research and extension

It should be noted that the backpressure charts from Kondinin Group reference published work for wheat only. Figures presented have adapted data from imperial to metric measure using information sourced in a K-State research and extension Stored Product Protection publication.[ii]

Data history and origins

The publication from K-State discuss the measurement of backpressure, or static pressure as it is referred to in the context of evaluating aeration system efficiency. Navarro is the lead author of the grain aeration section of the K-State publication having previously penned papers between 1982 and 2002 with a focus on the mechanics and physics of grain aeration.

In the K-State publication, Navarro references two papers of particular interest.

The first, Navarro published with Calderon (1982) for the Food and Agriculture Organisation of the United Nations (FAO) titled *Aeration of Grain in Subtropical Climates.*[iii] Unfortunately the paper is not available publicly but was fortuitously sourced from an attendee in hardcopy.

In their FAO submission, Navarro and Calderon (1982) described and consolidated research around the physical and mechanical influences on grain airflow. In particular, the FAO submission focusses on airflow resistance through grain bodies across a range of commodities including wheat, sorghum, barley, shelled corn, soybeans and peanuts.

Navarro and Calderon (1982) identify backpressure for wheat, corn, sorghum and soybeans under a range of depths and airflow rates in figures 25 – 28 respectively from the FAO submission.

Unlike many other aeration backpressure references, Navarro and Calderon embrace the metric system for these log-log scale figures.

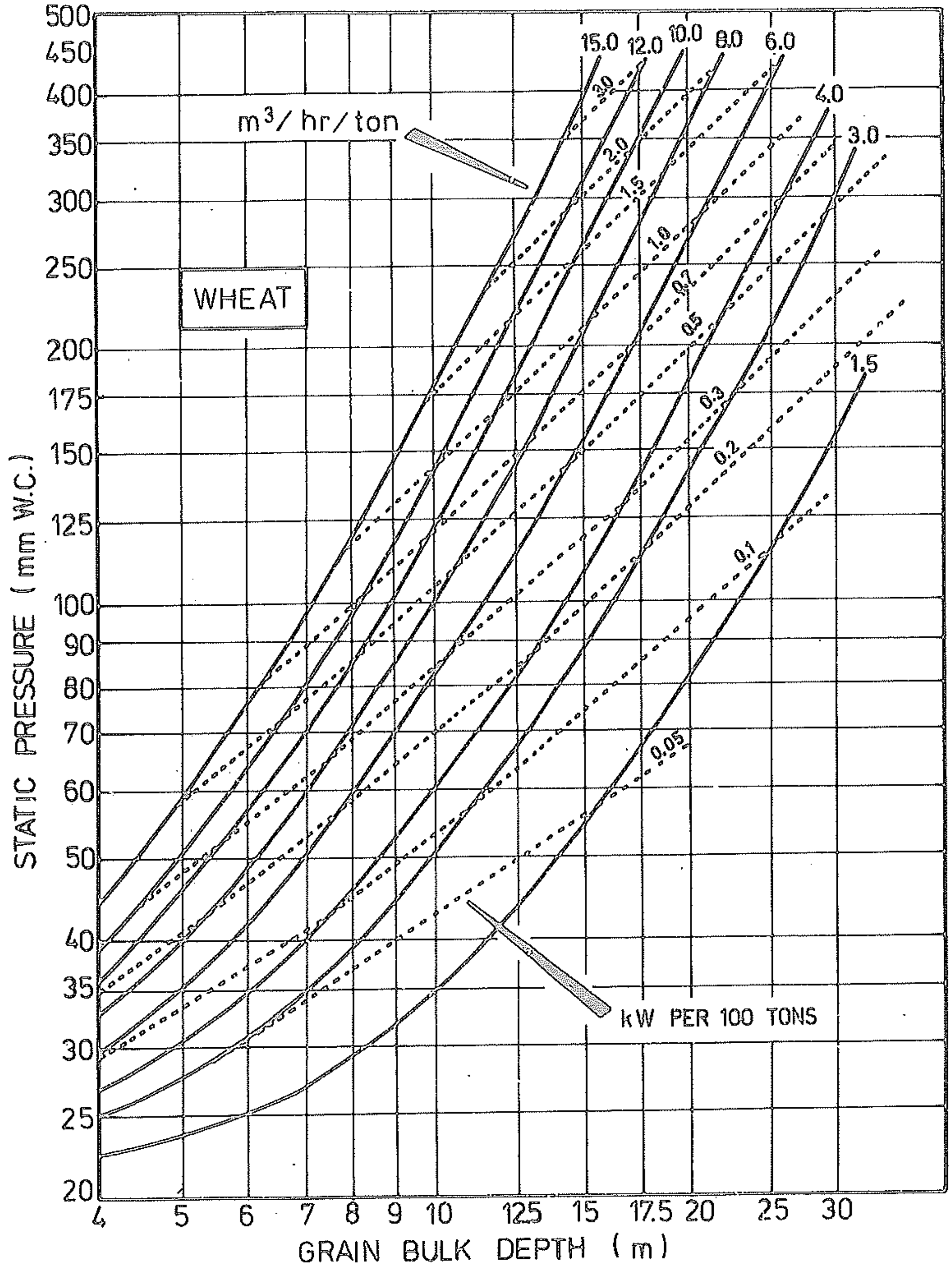


Fig. 25 Static pressure developed at different airflow rates and fan power requirements for aerating wheat (bulk density 0.830 ton/m^3).

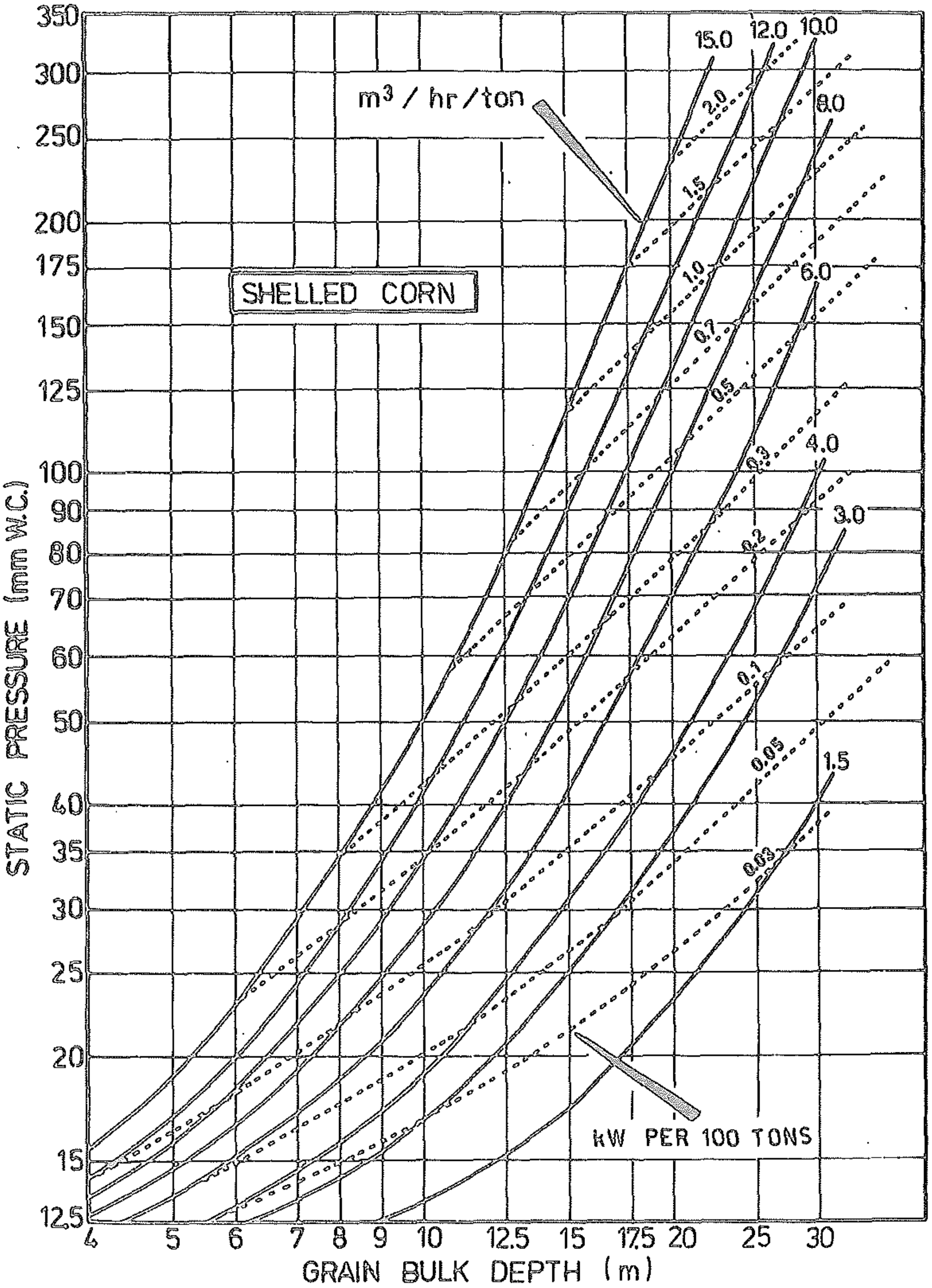


Fig. 26 Static pressure developed at different airflow rates and fan power requirements for aerating shelled corn (bulk density 0.764 ton/m^3).

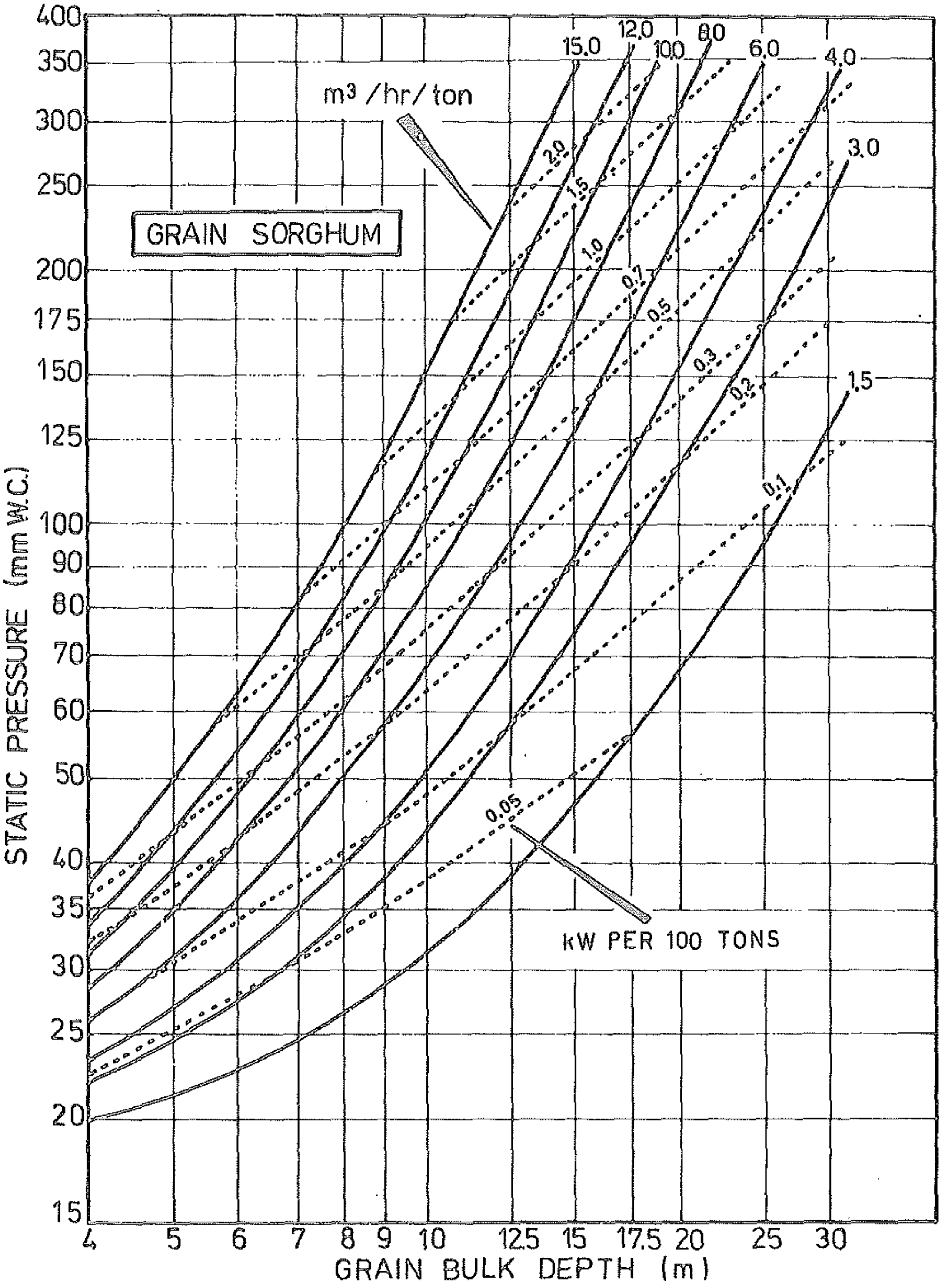


Fig. 27 Static pressure developed at different airflow rates and fan power requirements for aerating grain sorghum (bulk density 0.800 ton/m^3).

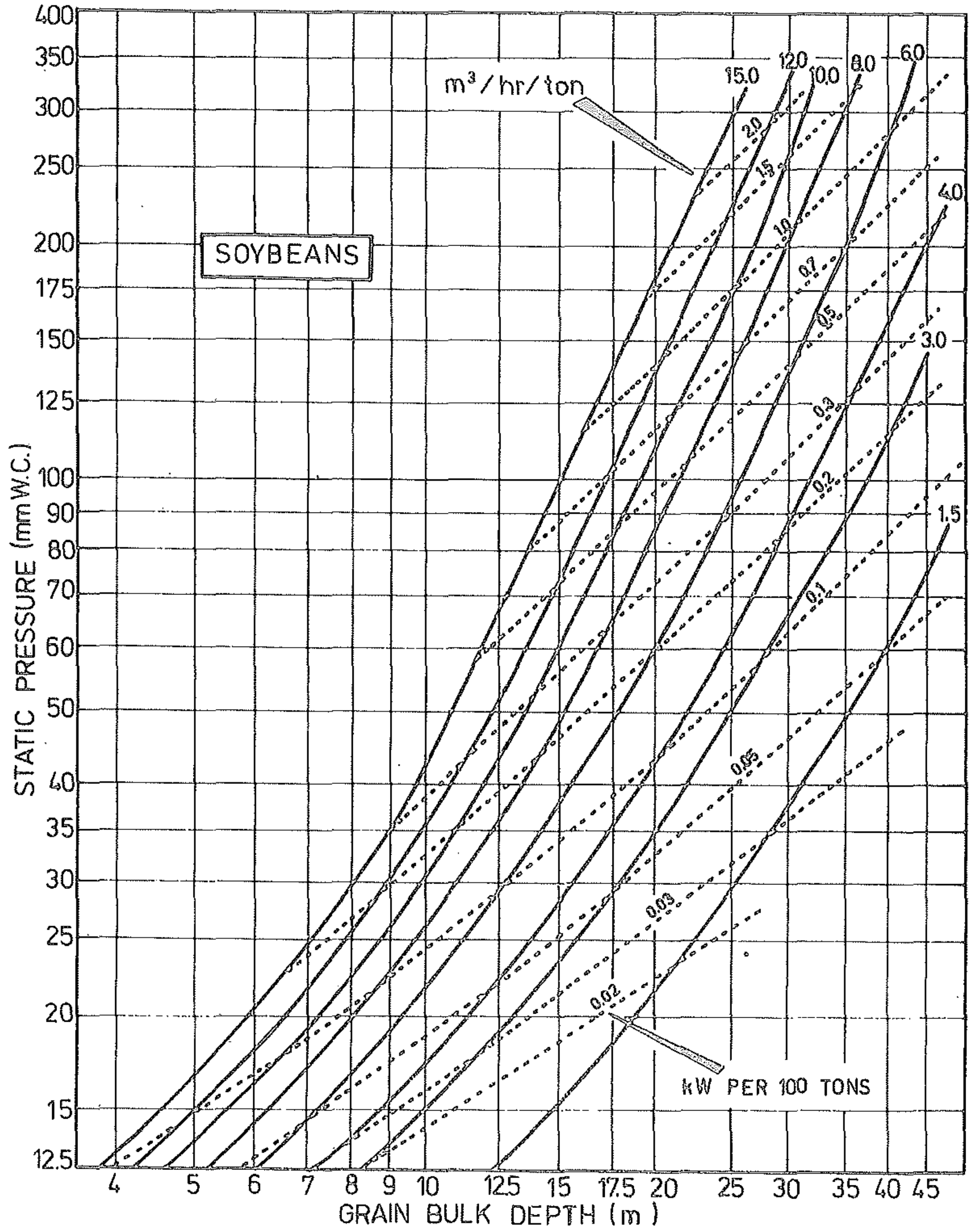
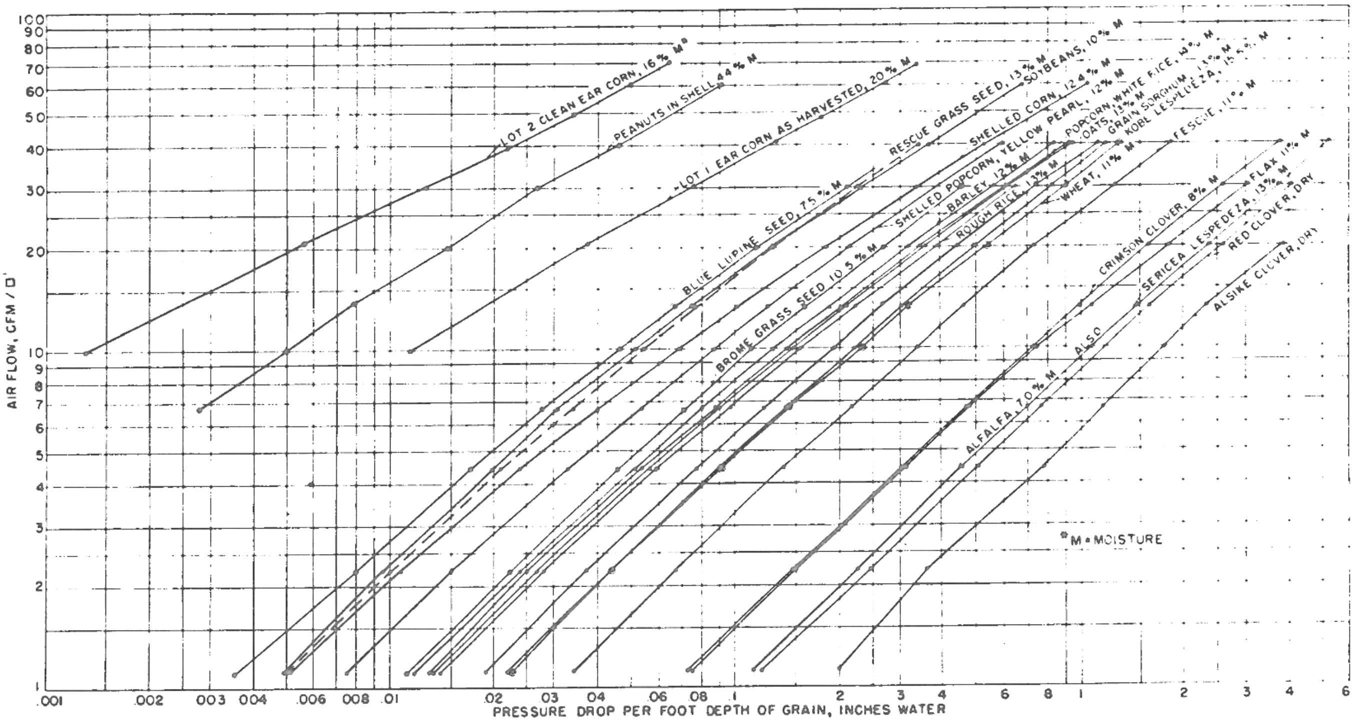


Fig. 28 Static pressure developed at different airflow rates and fan power requirements for aerating soybeans (bulk density 0.800 ton/m^3).

Mid-century origins

The second paper cited worthy of note in the K-State (2012) publication is one that Navarro describes as one of the pioneers of aeration for stored grain management; Shedd (1953).[iv] This paper is significant because the work published by Navarro in the K-State (2012) publication and Navarro and Calderon (1982) references the empirical work done by Shedd decades prior.

Shedd (1953) published a log-log plot of air pressure drop with varying airflow rates across a range of grains and seeds. Conversion from cubic foot per minute (cfm) per square foot (denoted by the □ symbol) of floor area translates to an airflow velocity in feet/minute.



Original methods

In earlier research, Shedd (1951)[v] described the apparatus for measuring backpressure used to generate the graphs in his 1953 paper.

Employing a displacement method for administering and measuring airflow, a plumbed bell lowered into a water tank via an electric drive motor with roller chain drive and actuator arm.

The displacement method described by Shedd provided sufficiently low and consistently uniform airflow rates comparable to that typically encountered in a grain silo under aeration.

Variable rates of airflow were achieved by using a range of drive sprocket sizes to drive the actuator arm at differing speeds.

The displaced air from the bell was plumbed to a plenum chamber feeding air into a column of grain measuring 203mm in diameter and just over 3m in length.

Pressure measurements were made at the plenum using water manometers of varying sensitivity but included micromanometers to measure pressures up to 190Pa, inclined manometers (up to 1118Pa) and U-tube manometers (up to 2032Pa).

Static pressure measurements were made in nine incremental positions at 12” (304.8mm) intervals up the column to provide figures for pressure drop at depth.

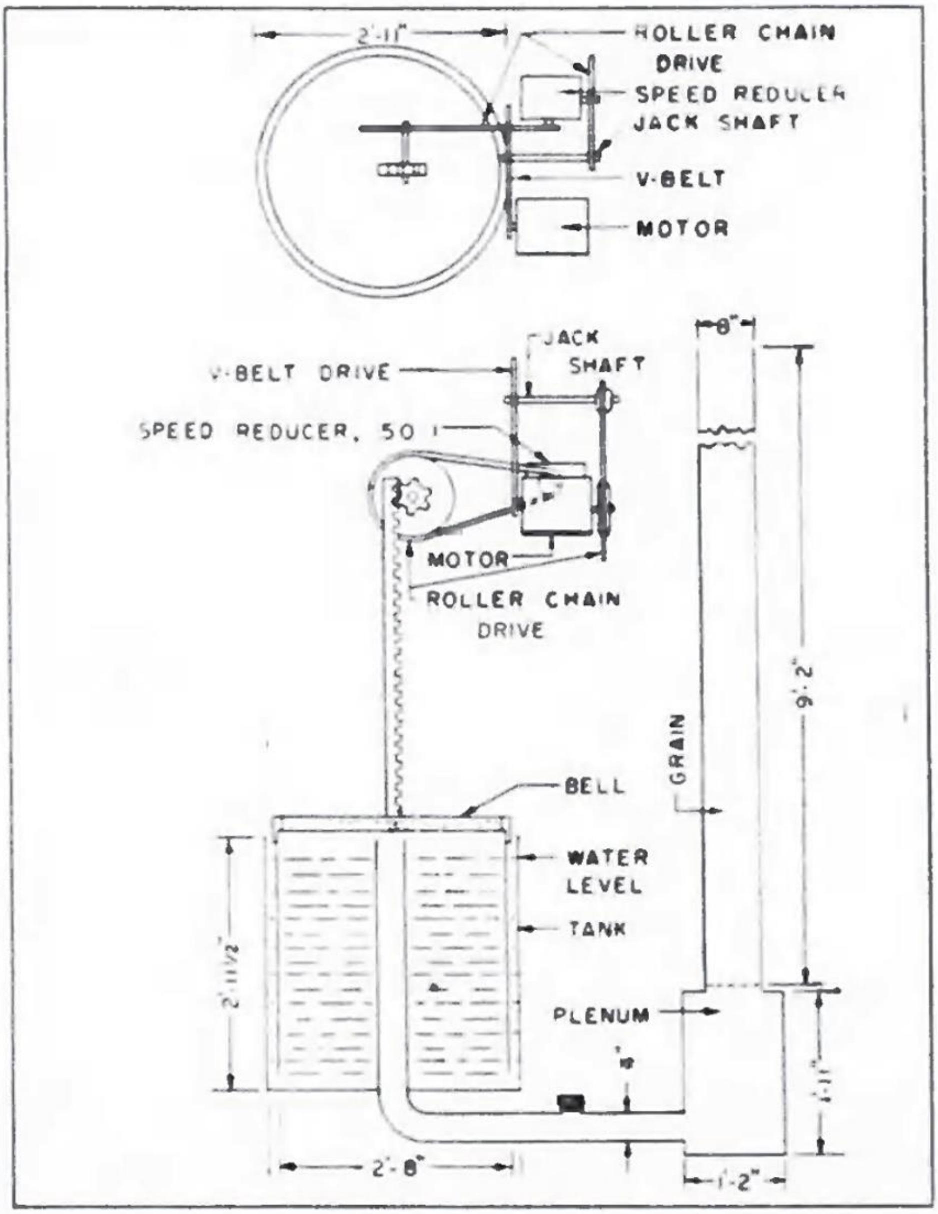


Fig. 1 Outline drawing of apparatus used in tests of resistance of grains to air flow

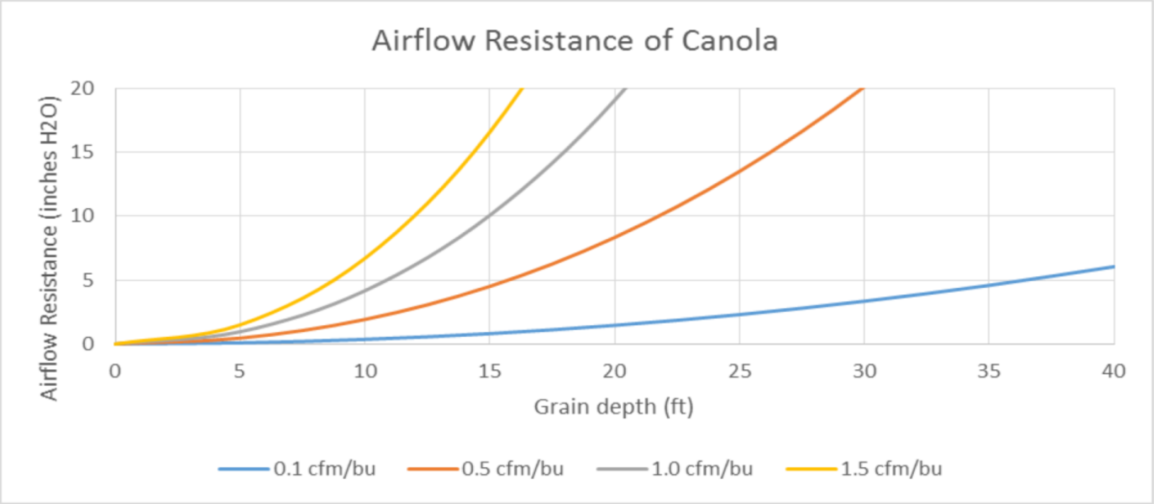
Citation frequency

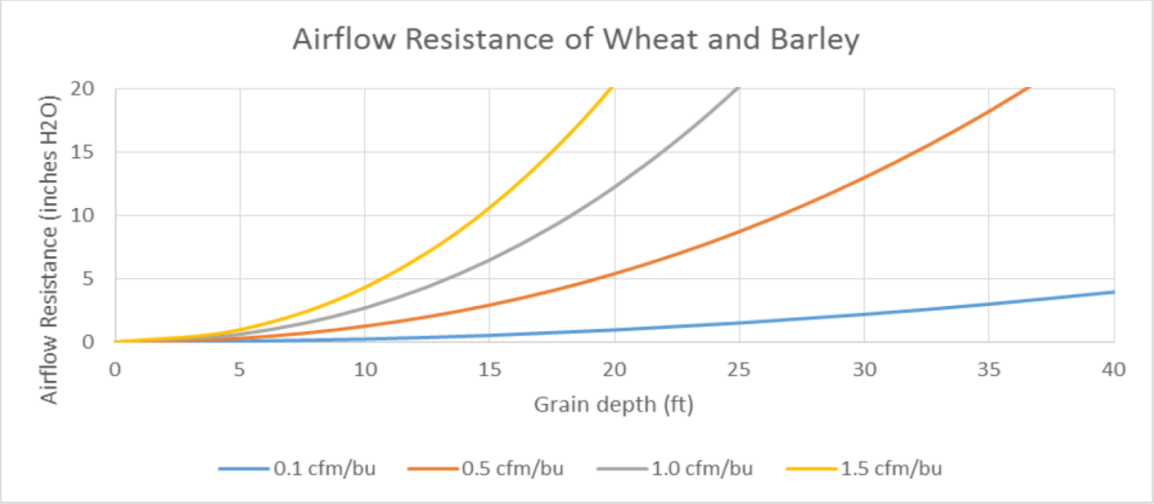
The work conducted and published by Shedd in 1953 has been revalidated and the work is widely cited including the American Society of Agricultural and Biological Engineers (ASABE) Standard ASAE D272.3 MAR1996 (R2016)[vi].

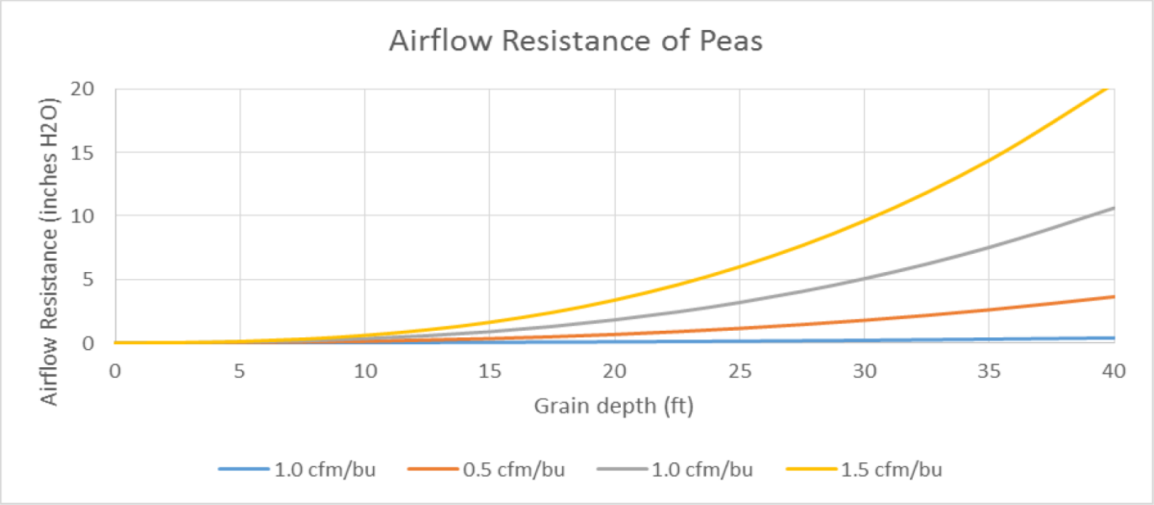
More recent references include the 2018 Canadian-based Prairie Agricultural Machinery Institute (PAMI)[vii] paper citing the work undertaken by Shedd as the primary source of backpressure information.

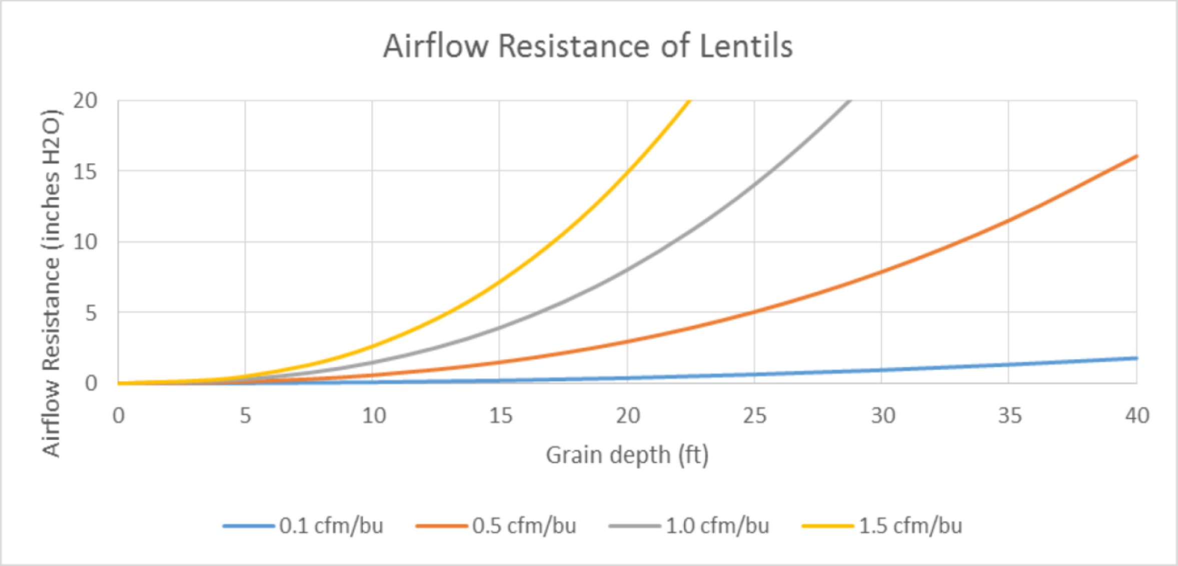
The PAMI paper extends the usability of the data, graphically presenting backpressure for:

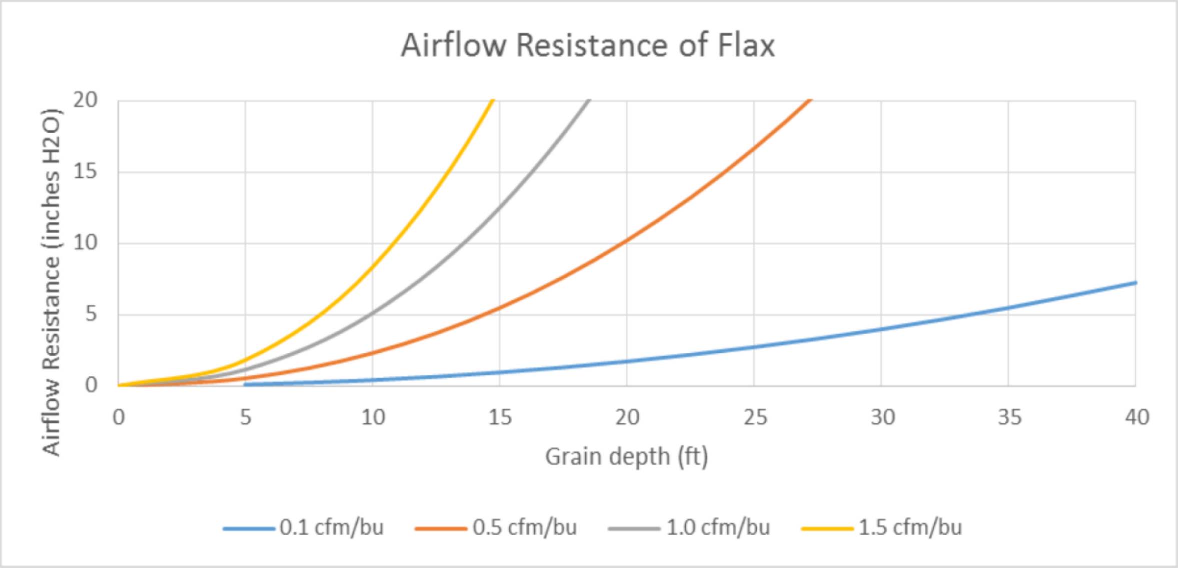
Cooling airflow bands of 0.1cfm/bu to 0.25cfm/bu (1.8-4.5 l/s/t using a nominal bulk density of 0.75t/m^3) and drying airflow bands of 0.5cfm/bu to 1cfm/bu (8.9-17.8 l/s/t).

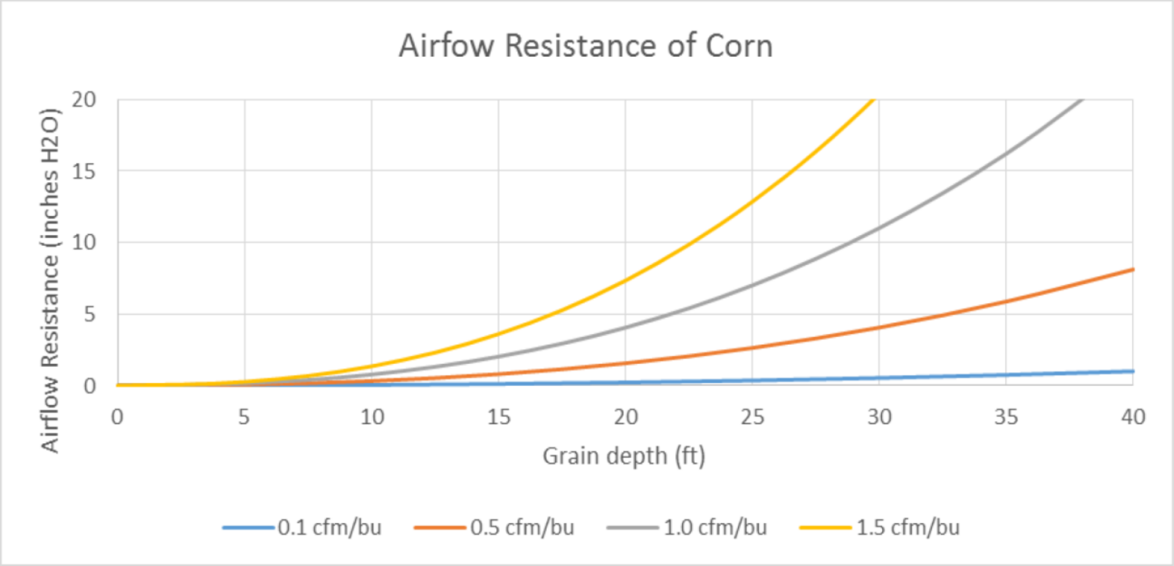

Airflow Resistance of Canola
Airflow Resistance (inches H2O)
0
5
10
15
20
0
5
10
15
20
25
30
35
40
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airflow Resistance of Wheat and Barley
Airflow Resistance (inches H2O)
0
5
10
15
20
0
5
10
15
20
25
30
35
40
Grain depth (ft)
0.1 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu


Airflow Resistance of Peas
Airflow Resistance (inches H2O)
0
5
10
15
20
0
5
10
15
20
25
30
35
40
Grain depth (ft)
1.0 cfm/bu
0.5 cfm/bu
1.0 cfm/bu
1.5 cfm/bu







Adaptation

The ASABE standard also cites a publication by Hukill and Ives (1955)[viii] which leveraged the work of Shedd to derive an equation for pressure drop over narrow ranges of air flow velocity using constants a and b as derived from the work done by Shedd.

$$\Delta P = \frac{LaQ^2}{log_e(1+bQ)}$$

Where;

ΔP = Pressure drop in Pa

L = depth of grain

Q = airflow in $m^3/s.m^2$ (m/s)

a and b are constants (see table 1)

Table 1: Values for constants in airflow resistance equation

Grain	Constant a	Constant b	Range of Q	Source
Wheat (low airflow)	8410	2.72	0.00025–0.0203	Sheldon et al.[ix]
Wheat (high airflow)	27000	8.77	0.0056–0.203	Shedd
Barley	21400	13.2	0.0056–0.63	Shedd
Canola (Tobin)	52200	7.27	0.0243–0.2633	Jayas and Sokhansanj (1989)[x]
Canola (Westar)	45500	9.72	0.0243–0.2633	Jayas and Sokhansanj (1989)
Oats	24100	13.9	0.0056–0.203	Shedd
Sorghum	21200	8.06	0.0056–0.203	Shedd

More recent research

Research has been conducted more recently by Gunasekaran and Jackson (1988)[xi] relating to high moisture (16.5-23%) sorghum with less admix than the Shedd data from 1953.

Gunasekaran had also previously worked with Jindal and Shove (1982)[xii] to derive airflow resistance of paddy rice in shallow depths.

Shahbazi (2011)[xiii] published a paper outlining the resistance of bulk chickpea seeds to airflow.

Grain aeration resistance modelling

Molenda (2005)[xiv] suggests that with knowledge of the bulk density, Erguns equation (1952)[xv] could be used for grain aeration design.

Molenda points to research by Li and Sokhansanj (1994)[xvi] and Bakker-Arkema et al. (1969)[xvii] who concluded that Ergun's equation could be the basis for a model of airflow resistance through agricultural products.

$$\frac{\Delta P}{\Delta L} = 2 f_E \frac{1-\varepsilon}{\varepsilon^3} \frac{\rho V^2}{d_p}$$

$$= 2\left(\frac{k_1}{(\mathrm{Re})_{d_p}} + k_2\right) \frac{1-\varepsilon}{\varepsilon^3} \frac{\rho V^2}{d_p}$$

Molenda determined that Erguns equation could be applied with only minimal errors compared to empirical datasets pending bulk density measurements (and grain loading dynamics). However the equation is not easily applied to a typical grain storage installation and requires product dependent constants (k_1 and k_2) as a function of grain type.

Changes in grain physical properties

Since the mid 1950’s, grain breeders have developed higher yielding varieties over time[xviii], and with that, grain kernel size has increased. It could be argued that with larger grain kernels, airflow resistance may have changed in the period between 1953 and today.

Australian research

Despite aeration being demonstrated as an effective tool for maintaining grain quality in storage, no published work has been conducted specifically using Australian grain.

It could be argued that Australian Grain varieties may differ in kernel size and moisture content in storage and therefore may present differing results to those for North American bred and grown grains as tested by Shedd almost 70 years ago.

Anecdotally, rules of thumb are usually applied when determining grain aeration fans which may or may not be accurate.

Implications for future Australian research

Based on the need for a simplified reference for fan manufacturers, growers, researchers and system designers, empirical research and data gathering for Australian grain aeration systems will pose some unique requirements.

While a test rig could replicate designs used by Shedd, Shahbazi or Gunasekaran, flow control and volumes to match Australian grain aeration rates must be achieved and measured.

While Shedd (1953) applied a displacement method of administering flow, Shahbazi (1988) used a fan with an intake choke to control and limit flow rates through the grain column.

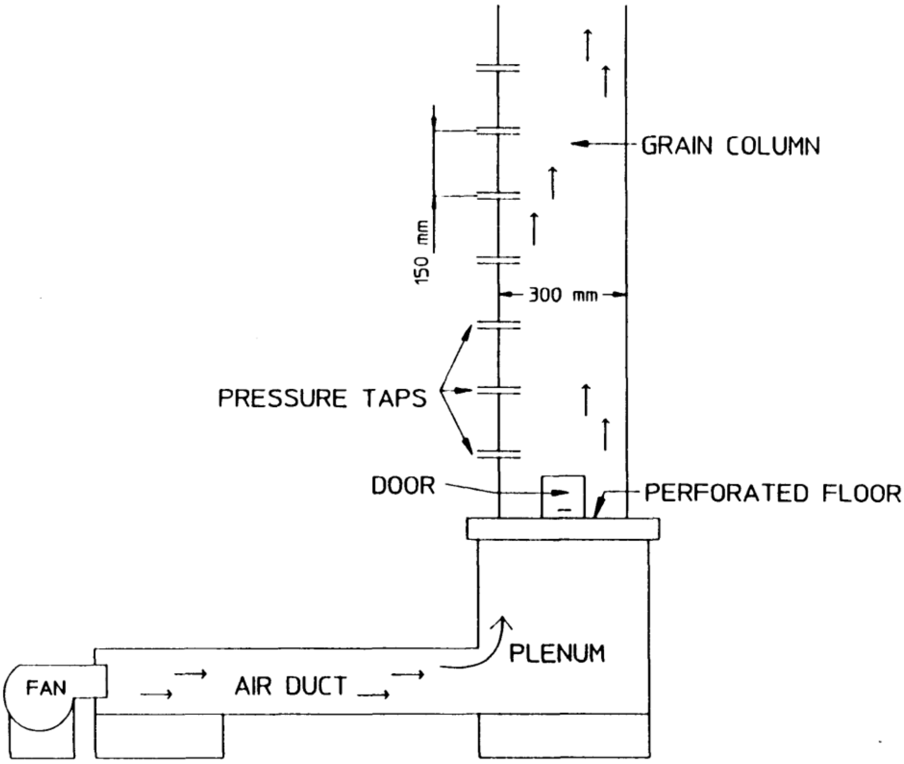
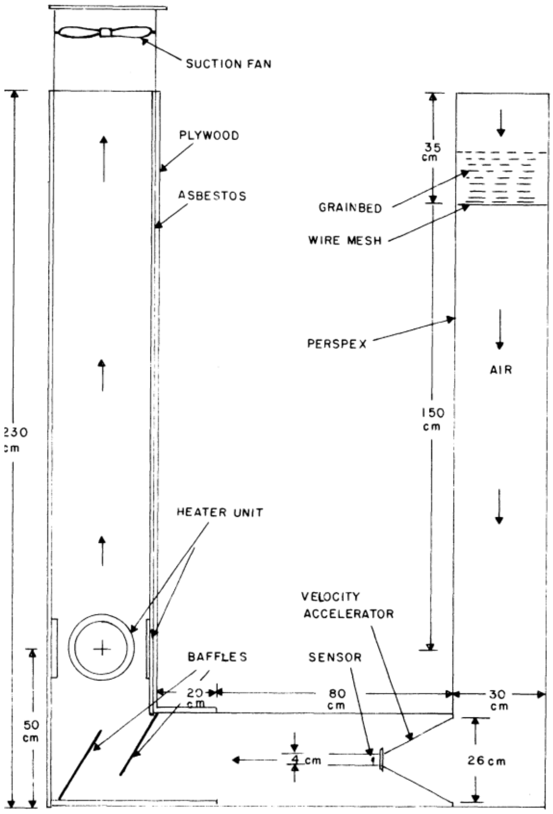


Fig. 1—Apparatus used for resistance to airflow measurements.

Looking for very low flow rates, through rice, Gunasekaran devised a thermal gradient method of low rates of airflow.

A heating element in the base of a column to heat air causing it to rise and draw air through a grain bed of varying depth via a thermal anemometer provided airflow rates as low as 0.001m^3/s.m^2 (1mm/s)

Flow rates this low will not be required, rather, flow rates between those achieved with this method and the Shedd method would be typical of Australian grain aeration flow rates.



ig. 5—Apparatus used for resistance of paddy to airflow easurement.

Because previous research has focussed on North American grain aeration systems, data is typically focussed on higher airflow rates typical of those locations.

Australian airflow rates of 2-4l/s/t are, by comparison, relatively low and sit at the bottom-end of most other empirical studies.

Provision of a variably adjusted, low uniform airflows may require the use of brushless direct current (DC) electronically commutated (EC) fans.

This may pose some challenges for measuring airflow requiring the necking of the airflow to amplify flow velocity for available instrumentation.

Pressure measurement using off-the-shelf digital differential pressure meters should be of adequate precision for backpressure (plenum) measurements as well as column pressure readings.

Flow rate conversions

1 cfm/bu = 0. 80356 m^3/m^3 min = 48.214m^3/m^3 hr

1 cfm/ft^3 = 1.0 m^3/m^3 min

1 ft^3/min = 1cfm = 1.699 m^3/hr

1 m^3/m^3 min = 1. 24446 cfm/bu

1 m^3/m^3 hr = 0. 020741 cfm/bu

2. Aeration backpressure testing device (DA2021-3)

Objectives – (Question or information gap to answer)

Can a test rig be built to measure aeration backpressure of various grains at various depths?

Background

To address the apparent absence of farmer-friendly airflow resistance information for Australian grain aeration cooling and drying, this development activity focusses on deriving a set of backpressure reference charts for a range of Australian Grains.

Because ducting, pan plenums and distribution methods vary, the work will focus exclusively on grain-induced backpressure.

While progress has been made and continuation of the testing is pending the arrival of specialist equipment from North America, the development of an appropriate test rig has presented some challenges.

Approach

Utilising the learnings of the literature review grain aeration backpressure, it was determined that replication of a standing grain column similar to that used by Shedd (1953)[xix], or Shahbazi (2011)[xx] could provide a lab-based option for data generation.

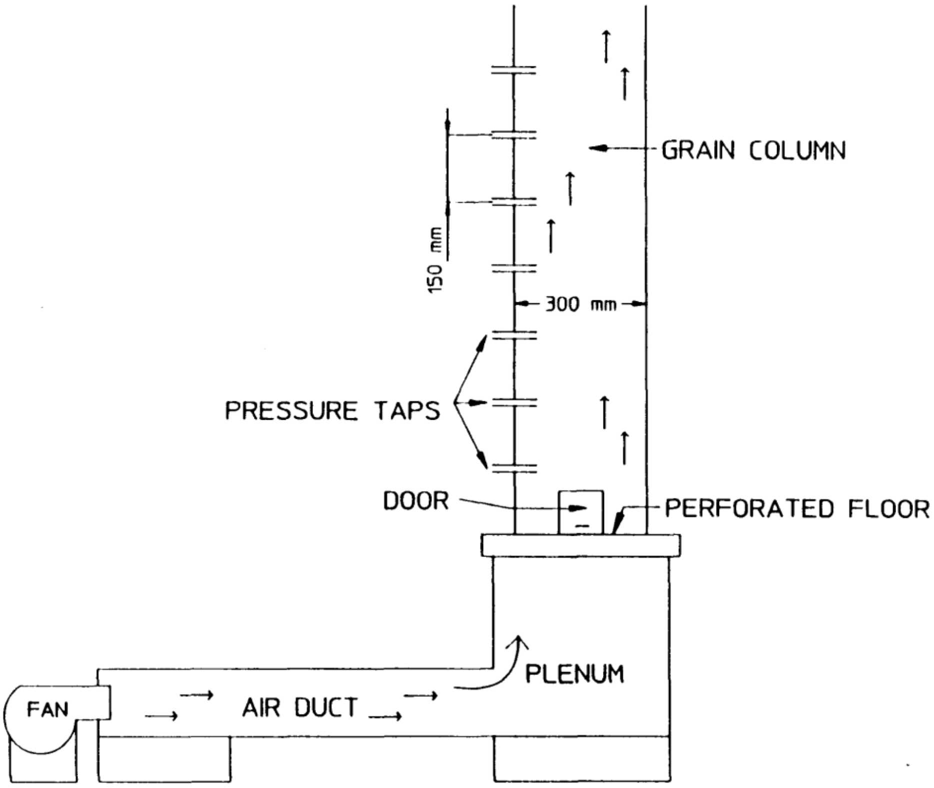


Fig. 1—Apparatus used for resistance to airflow measurements.

Lab testing

Initial testing validated the lab test method, ensuring any velocity-induced pressure differentials would not influence the static pressure measurements. While flow rates are low, some column-wall friction may influence flow velocity and therefore backpressure. So it was determined that column measures of static pressure from the pressure taps should be inserted at least 25mm in from the column wall to minimise any influence.

Field testing

A field validation involved taking static pressure measurements in a small sorghum silo. Pressure readings were taken at the intake plenum at a range of grain depths as the silo was filled. Three spot static pressure measures were taken up the silo wall once the silo was filled. This field test demonstrated backpressure readings could be taken at varying grain depths for a single flow rate with the depth below the surface of the grain equivalent to that of the backpressure at the fan plenum under an equivalent depth of grain.

Field testing also demonstrated some important considerations for the design of the test rig. These included careful selection of the perforated plenum transition material ensuring backpressure induced by the perforated floor will not influence results. An analysis of open area and flow rate ranges identified an appropriate mesh gauge with sufficient strength to carry the weight of grain while allowing free passage of airflow with no induced backpressure.

Flow tables

In order to generate airflows typical of cooling and drying grain in Australia, a series of tables identifying flow rates, airflow velocity and expected backpressure ranges were generated. See Appendix 1.

Flow rates depend on the selected grain column diameter with larger diameter pipes arguably providing opportunity for improved precision of measurement. But larger diameter pipes required larger volumes of grain, so test rig scale and precision of data must be balanced with practicality and safety considerations.

Primary challenges

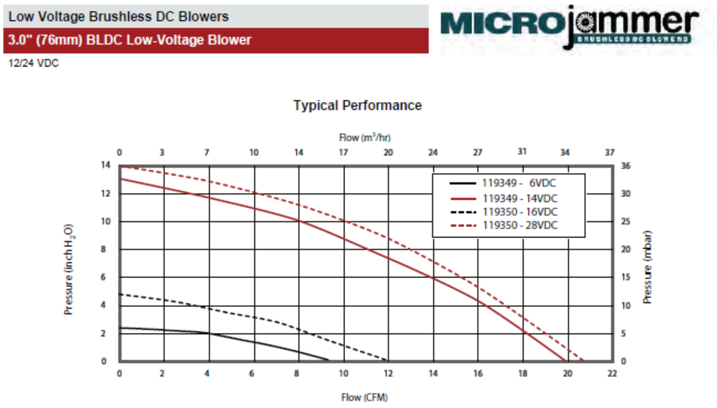
Development of a test rig similar to that used by Shedd and Shahbazi requires a variable speed airflow source, intake plenum, grain column, pressure taps with an ability to measure a wide range of differential pressures and a method of accurately measuring airflow.

Delivery of a uniform flow into the grain column across a range of flows from the equivalent of 1l/s/t to 20l/s/t requires a fan capable of a wide range of flows depending on the column diameter and length selected.

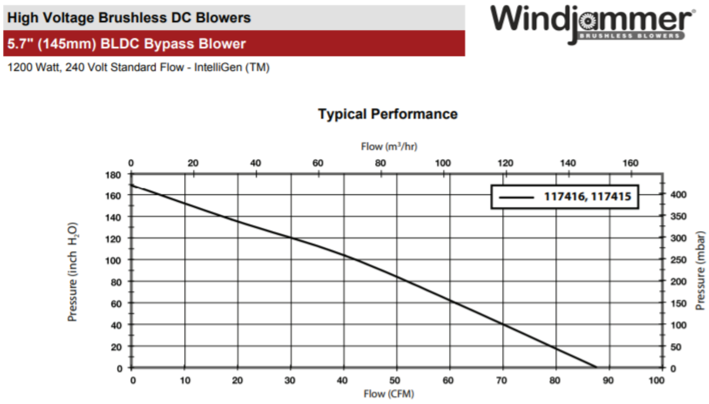
The use of electronically commutated (EC) fans provides the opportunity to vary flow rate provided adequate pressure delivery profiles can be achieved at the given flow rates.

An extensive search including positive displacement air pumps identified two fans capable of delivering the expected flow rates for 152mm and 300mm PVC stormwater grain columns with grain depths of up to 6m.

For low range flows, an Ametek 76mm, 12VDC low-voltage blower was selected, sourced and purchased.



For higher flow rates, a 1200w Ametek 117415 brushless DC windjammer with 0-10v speed control was selected and paired with a 0-10v signal generator for control.



Measurement: Pressure

Digital differential pressure sensors with resolution of 1Pa have been selected and purchased.

A tapped plenum will be built once the test rig design has been completed to minimise measurement times.

Measurement: Airflow

Digital hot wire anemometers were selected for measuring airflow, but due to the very low rates of flow, ducting had to be modified and choked to reduce cross-sectional area and amplify flow velocity.

The test rig was constructed initially with 150mm diameter grain column, but backpressure results did not match the published research of Shedd.

Several verifications were performed to check the repeatability of each test, it was found that an error margin of approx. 0.04m/s averaged between tests (often less).

All backpressure readings were stable. Pressure was verified with a second manometer at several points and proven to be very accurate.

Further investigation of the issue, identified the hot wire anemometer probe may have effectively further reduced the cross-sectional area of the ducting, causing erroneous flow velocity readings.

Options to address the issue have been explored with a number of solutions identified.

The first is to increase the scale of the rig to minimise the influence of the hot-wire anemometer probe. This however means that nearly 600kg of grain for each test will be required, making this solution less practical but will be explored to test the validity of the assumed hot-wire problem.

Alternatively, after an extensive search for higher precision airflow instrumentation, a medical-grade flowmeter has been found that will read airflow rates from 0-300l/minute.

The flow meter uses a hotwire anemometer method but with a specialist housing and digital display.

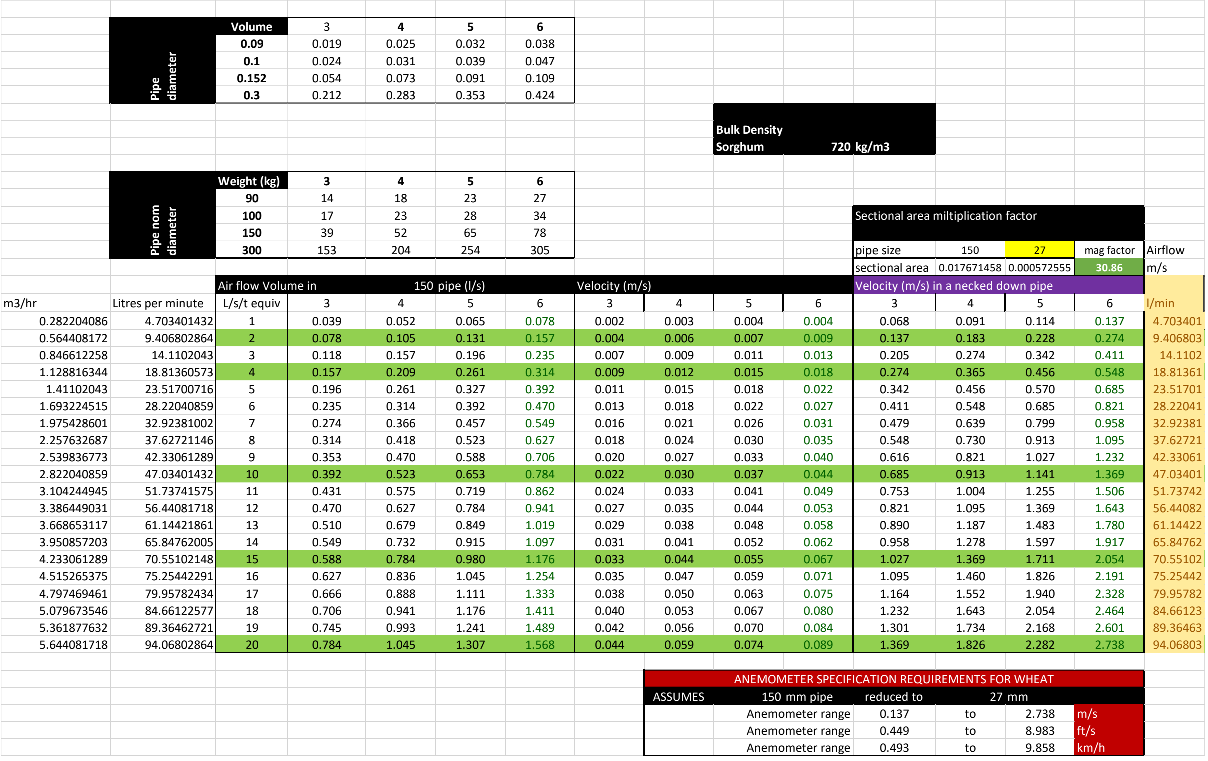
Further testing with this new instrumentation will continue in late January 2022.

References

[i] 1953 Shedd, C.K. Resistance of grain and seeds to airflow. Transactions of the ASAE. 34: 616-619.

[ii] 2011 Shahbazi, F. Resistance of bulk chickpea seeds to airflow. J. Agr. Sci. Tech. (2011) Vol. 13: 665-676

Appendix 1 – Airflow test-rig design tables, initial testing results and expected backpressure utilising Navarro data



Pipe diameter	Volume	3	4	5	6
	0.09	0.019	0.025	0.032	0.038
	0.1	0.024	0.031	0.039	0.047
	0.152	0.054	0.073	0.091	0.109
	0.3	0.212	0.283	0.353	0.424

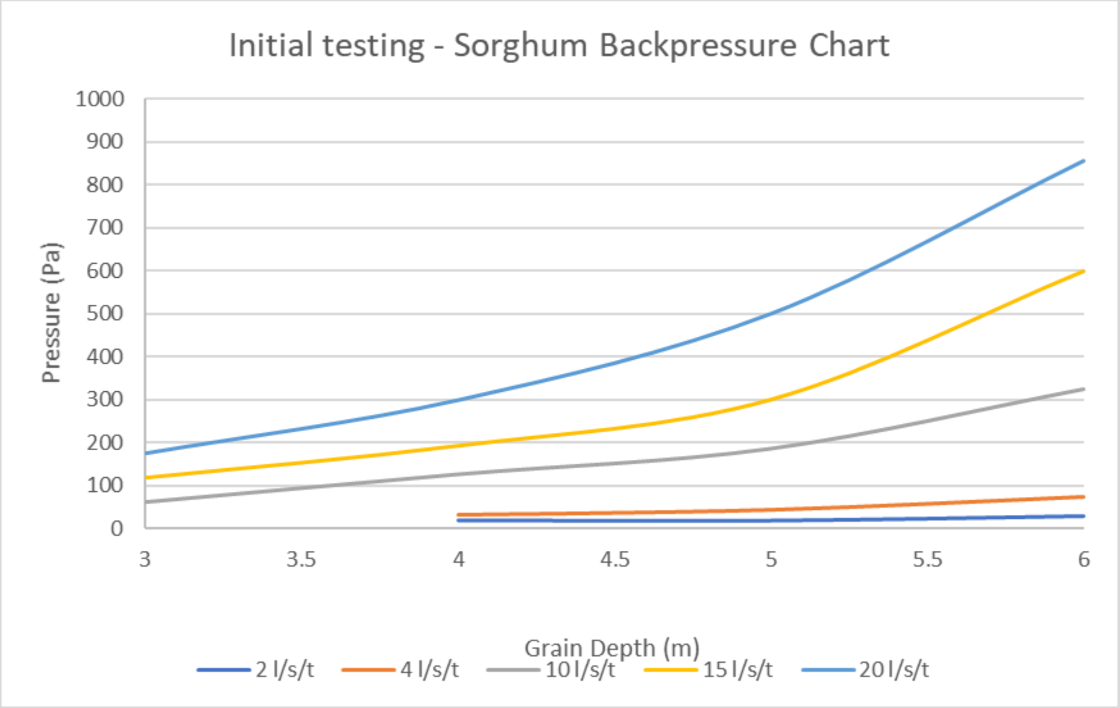
Bulk Density
Sorghum 720 kg/m3

Pipe nom diameter	Weight (kg)	3	4	5	6
	90	14	18	23	27
	100	17	23	28	34
	150	39	52	65	78
	300	153	204	254	305

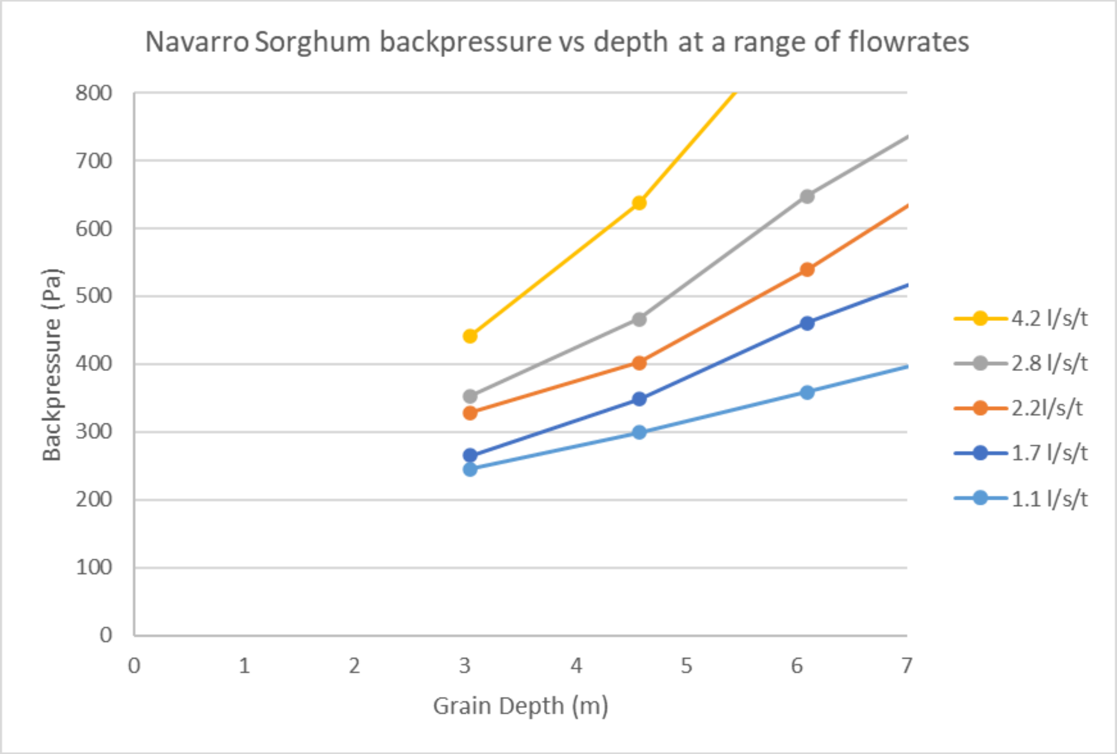
Sectional area miltiplication factor				
pipe size	150	27	mag factor	Airflow
sectional area	0.017671458	0.000572555	30.86	m/s

		Air flow Volume in	150 pipe (l/s)				Velocity (m/s)				Velocity (m/s) in a necked down pipe				
m3/hr	Litres per minute	L/s/t equiv	3	4	5	6	3	4	5	6	3	4	5	6	l/min
0.282204086	4.703401432	1	0.039	0.052	0.065	0.078	0.002	0.003	0.004	0.004	0.068	0.091	0.114	0.137	4.703401
0.564408172	9.406802864	2	0.078	0.105	0.131	0.157	0.004	0.006	0.007	0.009	0.137	0.183	0.228	0.274	9.406803
0.846612258	14.1102043	3	0.118	0.157	0.196	0.235	0.007	0.009	0.011	0.013	0.205	0.274	0.342	0.411	14.1102
1.128816344	18.81360573	4	0.157	0.209	0.261	0.314	0.009	0.012	0.015	0.018	0.274	0.365	0.456	0.548	18.81361
1.41102043	23.51700716	5	0.196	0.261	0.327	0.392	0.011	0.015	0.018	0.022	0.342	0.456	0.570	0.685	23.51701
1.693224515	28.22040859	6	0.235	0.314	0.392	0.470	0.013	0.018	0.022	0.027	0.411	0.548	0.685	0.821	28.22041
1.975428601	32.92381002	7	0.274	0.366	0.457	0.549	0.016	0.021	0.026	0.031	0.479	0.639	0.799	0.958	32.92381
2.257632687	37.62721146	8	0.314	0.418	0.523	0.627	0.018	0.024	0.030	0.035	0.548	0.730	0.913	1.095	37.62721
2.539836773	42.33061289	9	0.353	0.470	0.588	0.706	0.020	0.027	0.033	0.040	0.616	0.821	1.027	1.232	42.33061
2.822040859	47.03401432	10	0.392	0.523	0.653	0.784	0.022	0.030	0.037	0.044	0.685	0.913	1.141	1.369	47.03401
3.104244945	51.73741575	11	0.431	0.575	0.719	0.862	0.024	0.033	0.041	0.049	0.753	1.004	1.255	1.506	51.73742
3.386449031	56.44081718	12	0.470	0.627	0.784	0.941	0.027	0.035	0.044	0.053	0.821	1.095	1.369	1.643	56.44082
3.668653117	61.14421861	13	0.510	0.679	0.849	1.019	0.029	0.038	0.048	0.058	0.890	1.187	1.483	1.780	61.14422
3.950857203	65.84762005	14	0.549	0.732	0.915	1.097	0.031	0.041	0.052	0.062	0.958	1.278	1.597	1.917	65.84762
4.233061289	70.55102148	15	0.588	0.784	0.980	1.176	0.033	0.044	0.055	0.067	1.027	1.369	1.711	2.054	70.55102
4.515265375	75.25442291	16	0.627	0.836	1.045	1.254	0.035	0.047	0.059	0.071	1.095	1.460	1.826	2.191	75.25442
4.797469461	79.95782434	17	0.666	0.888	1.111	1.333	0.038	0.050	0.063	0.075	1.164	1.552	1.940	2.328	79.95782
5.079673546	84.66122577	18	0.706	0.941	1.176	1.411	0.040	0.053	0.067	0.080	1.232	1.643	2.054	2.464	84.66123
5.361877632	89.36462721	19	0.745	0.993	1.241	1.489	0.042	0.056	0.070	0.084	1.301	1.734	2.168	2.601	89.36463
5.644081718	94.06802864	20	0.784	1.045	1.307	1.568	0.044	0.059	0.074	0.089	1.369	1.826	2.282	2.738	94.06803

ANEMOMETER SPECIFICATION REQUIREMENTS FOR WHEAT					
ASSUMES	150 mm pipe	reduced to		27 mm	
	Anemometer range	0.137	to	2.738	m/s
	Anemometer range	0.449	to	8.983	ft/s
	Anemometer range	0.493	to	9.858	km/h



Airflow	Grain Depth (m)			
(l/s/t)	3	4	5	6
2		18.7	18.2	29.3
4		32.2	43.8	73.6
10	61.7	126.5	186.3	325.1
15	118.7	193.2	301	600.4
20	175.1	299.4	500.8	857.2



3. Aeration backpressure: testing airflow resistance in Australian grain (DA2021-4)

Objectives – (Question or information gap to answer)

What back pressure do aeration fans work against in the commonly grown grains in Australia? Ultimately this activity aims to determine aeration fan performance requirements for the most common grains stored in Australia. It is expected the next step will be to field test results to ensure applicability in the storage environment.

Background

Ben White, Chris Warrick and Alex Conway invested a number of weeks in Q1 of 2022 refining the lab-based testing apparatus developed in the previous development activity and finessing a finalised rig design.

This development activity utilised a test rig to measure backpressure at a wide range of airflows across three grain types; wheat, sorghum and canola. Further testing repeated the testing for wheat and added barley, mung beans, corn, faba beans, soy beans, chickpeas, lentils, field peas and oats.

The refinement of the testing apparatus ensured air flow rates as low as 0.006 litres per second could be precisely measured with full aeration flow extending to the equivalent of 20 litres per second per tonne accurately emulated in a four-metre differential pressure port column tested using each of the three grains.

Test apparatus

Initial testing investigated a number of variants and result influences including:

- Grain column diameter
- Grain column length
- Grain column angle
- Adequate fan flow rate range
- Adequate pressure measurement precision and range.

Column Diameter

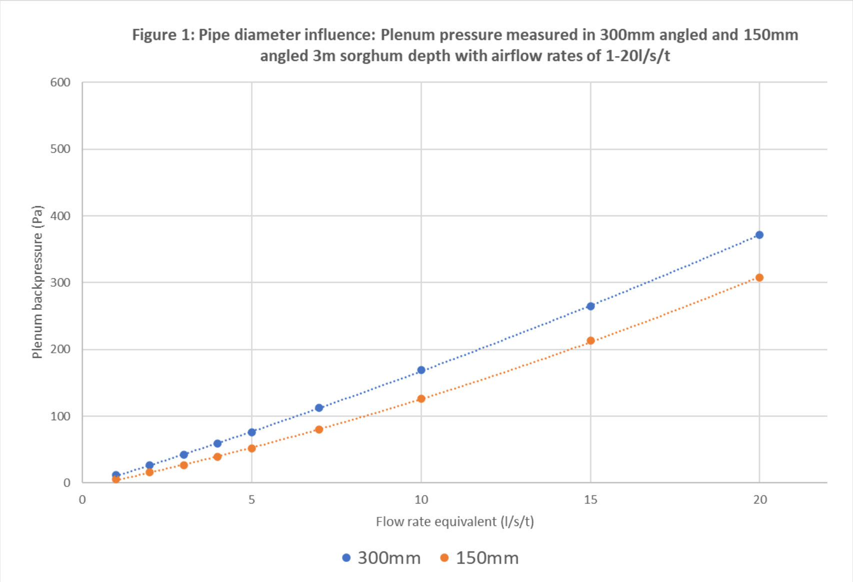
A series of tests were conducted using sorghum to evaluate plenum pressures in a series of tests in both 150mm and 300mm diameter pipes.

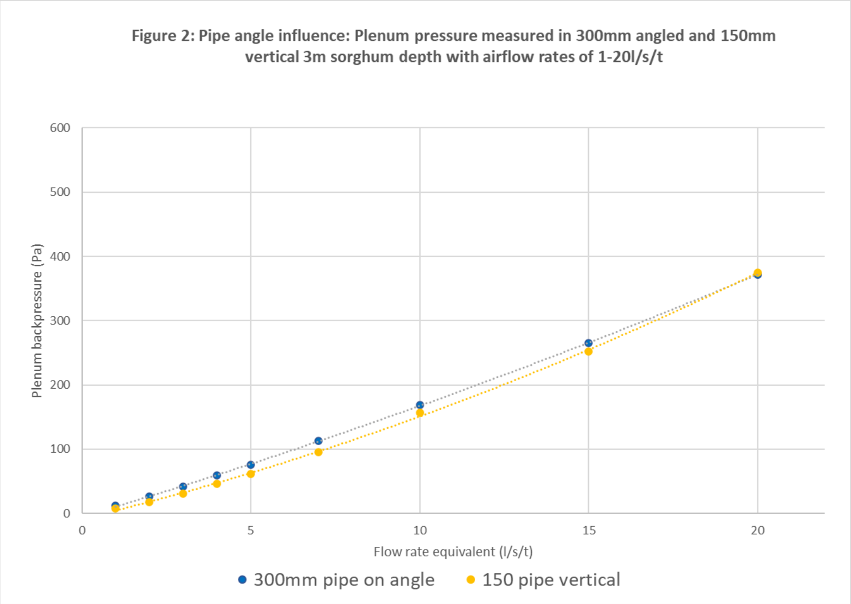
Both pipes were angled at a position less than the angle of repose of the grain and filled to a depth of 3m. Pressure was measured in the plenum at an equivalent flow rate of between 1l/s/t and 20l/s/t.

While some variation in plenum pressure was noted (See figure 1), it is thought that the most likely influence between the 300mm and 150mm pipe was filling method and total weight of grain compressing the sample in the 300mm pipe which may have led to a small increase in bulk density and backpressure.

This is supported by the realignment of the 150mm column to a vertical orientation and refilling from above, resulting in a more closely aligned bulk density of grain in the 150mm column to that of the 300mm column.

In this orientation, plenum pressures measured were almost identical to that of the 300mm column. (See figure 2)





With previous studies indicating a comparable test column diameter to the 150mm column used with little impact of edge effect or resistance, it was determined that a 150mm column was suitable for the purposes of the test. It also negated a requirement for up to 750kg of grain for a single test.

Development activity methodology

As discussed in a research paper by Molenda et. al. and Stephens and Foster (1978)[xxi], filling method has been shown to influence flow resistance.

Research papers identified in aeration backpressure Literature review development activity, indicate test results from a much shorter columns of grain (<2m).

Despite this, a 4m column was selected for a number of reasons; firstly it allows a more precise measure of airflow with a larger mass of grain. With a larger mass of grain, sensitivity to measurement precision of airflow and airflow control is reduced.

Secondly, a 4m column also more closely emulates the drop height for grain fill in a typical Australian grain silo and the resulting bulk density likely in silo storage.

Finalised apparatus design

Utilising a 151.5mm (nominal internal dimension 150mm) PVC pipe and standard galvanised metal grain plenum screen (open area 11%), air was pumped via an Ametek 76mm, 12VDC low-voltage blower powered through a variable voltage laboratory power supply with high precision voltage and current adjustment.

Air flow rate was measured using a medical-grade TSI 40401 airflow meter capable of measuring 0-300l/minute accurate to ±2% of reading.

Pressure in the plenum and at the tap positions was measured using a TSI Alnor AXD620 differential micromanometer.

The backpressure test apparatus includes the adaptation of pressure taps at 500mm intervals up the 4m height of the grain column.

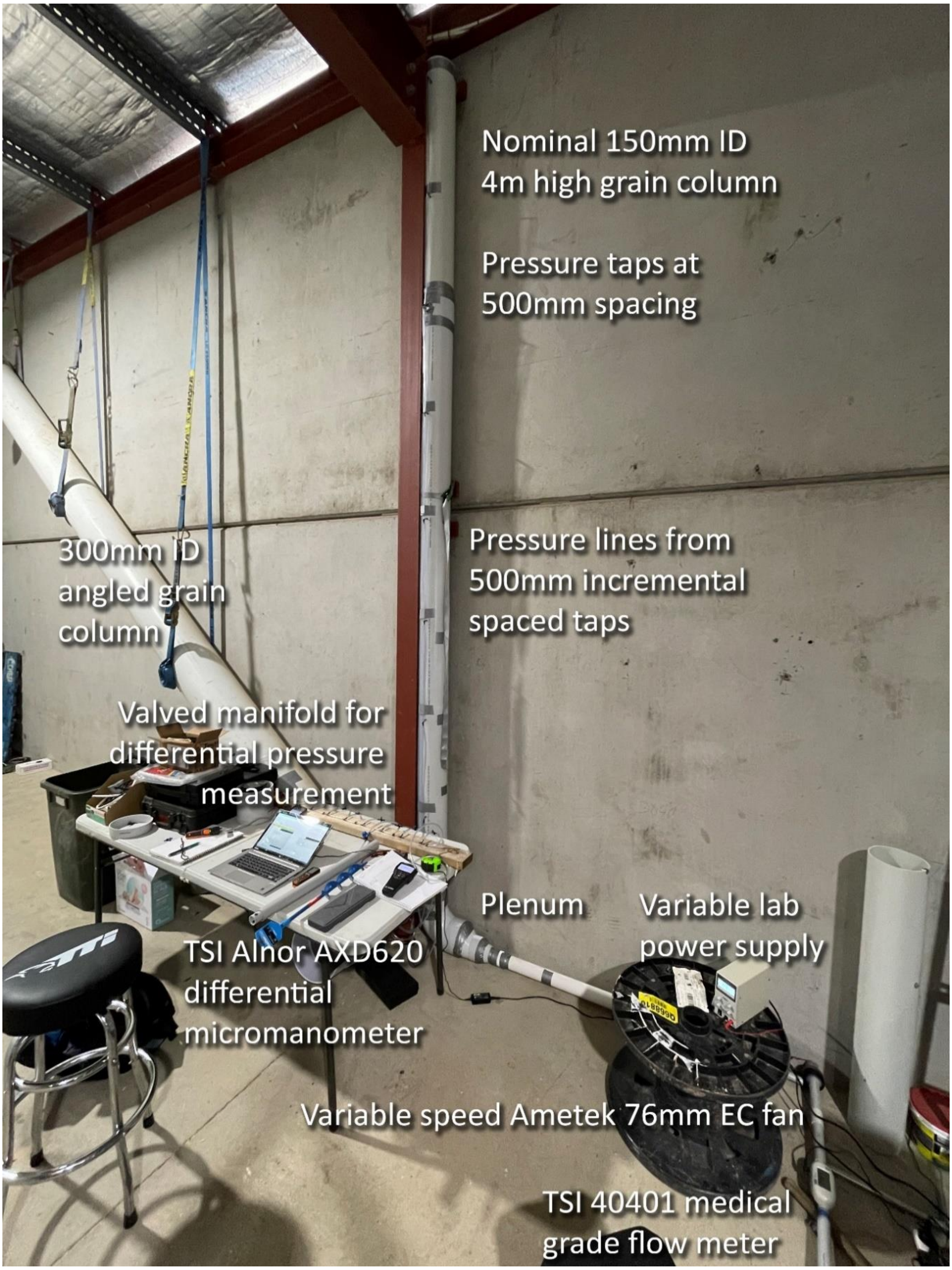
These taps allow for the measurement of differential pressure to align with previous research on airflow resistance through grain. When plotted in a log-log format, differential pressure vs grain depth provides a linear relationship which can be used to extrapolate backpressure at grain depths greater than 4m.

Differential pressure taps were plumbed into a valved manifold at ground level to allow switching between taps up the column height.

The entire apparatus was capped and pressure tested using a half-life pressure test. Any minor leaks that may influence the results were located using soapy water and addressed using a combination of duct tape, silicone sealant to ensure the test apparatus was hermetically sealed.

The apparatus was mounted to a 200mm shed I-beam column (see figure 3)

Figure 3: Test apparatus



Test method

Grain bulk-density was measured using an 18-litre (1m long capped 150mm PVC length section) and scales precise to 10g.

Grain was then measured in appropriate masses to provide 500mm fill increments and loaded into the grain column.

Grain depth was checked using a laser distance measure to ensure accurate depth of fill. Minor adjustments to maintain a precise depth were added if required.

Fan speed was adjusted via the supply voltage from the laboratory power supply to deliver the nominal flow rate required to emulate aeration cooling and drying rates (1, 2, 3, 4, 5, 7, 10, 15 and 20l/s/t).

Once the nominal air flow was steadily maintained and back pressure reached a steady state, pressure readings were taken from the plenum.

This process was repeated for each 500mm fill increment to a final grain depth of 4m.

Once filled to 4m, differential pressure measurements between the plenum and pressure taps was measured at the same range of flow rates.

Three grains (wheat, sorghum and canola) were tested to confirm the suitability of the test apparatus and evaluate the quality of data obtained.

Results

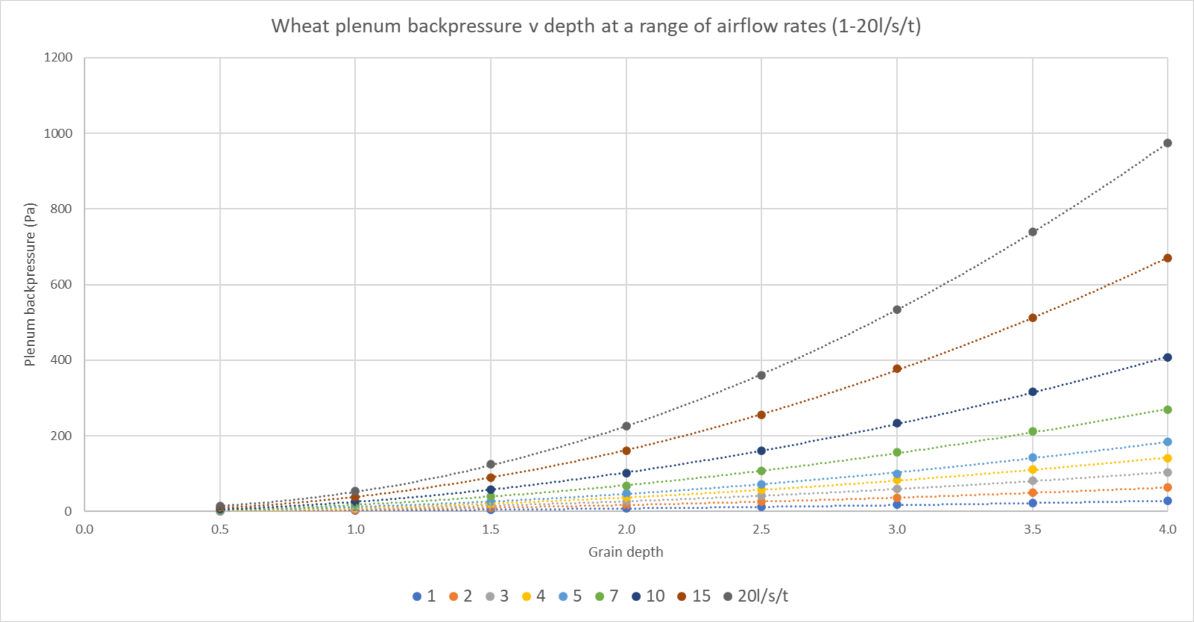
Results of plenum backpressure and depth can be seen in figures 4, 5 and 6 for wheat, sorghum and canola respectively. Plotted on a standard scale, backpressure increases as depth increases can be seen to be exponential.

Plotted on log-log scale, this relationship can be demonstrated as a linear relationship as expected and in accordance with the results determined through previous research uncovered in the literature review development activity. See Figures 7, 8 and 9.

This provides confidence the data can be accurately extrapolated to meet the backpressure design information needed for the majority of grain storage facilities in Australia.

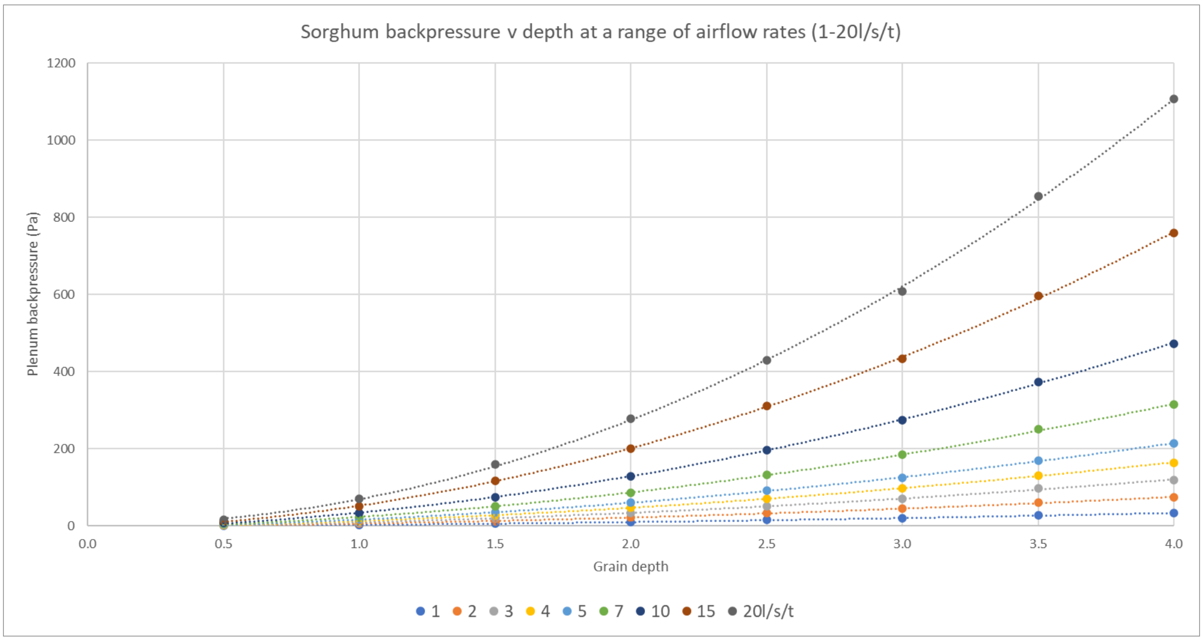
Differential log-log plots also provided linear relationships and emulate that of previously published results. See Figures 10, 11 and 12.

Figure 4: Wheat plenum backpressure with depth at 1-20l/s/t airflow.



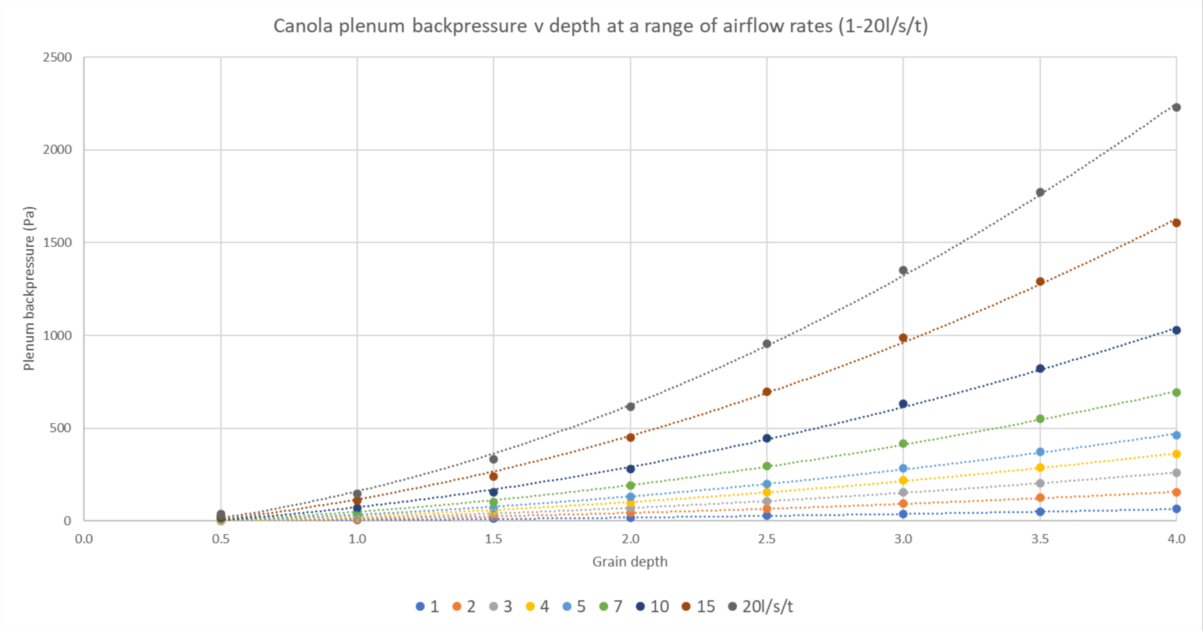
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 5: Sorghum plenum backpressure with depth at 1-20l/s/t airflow.



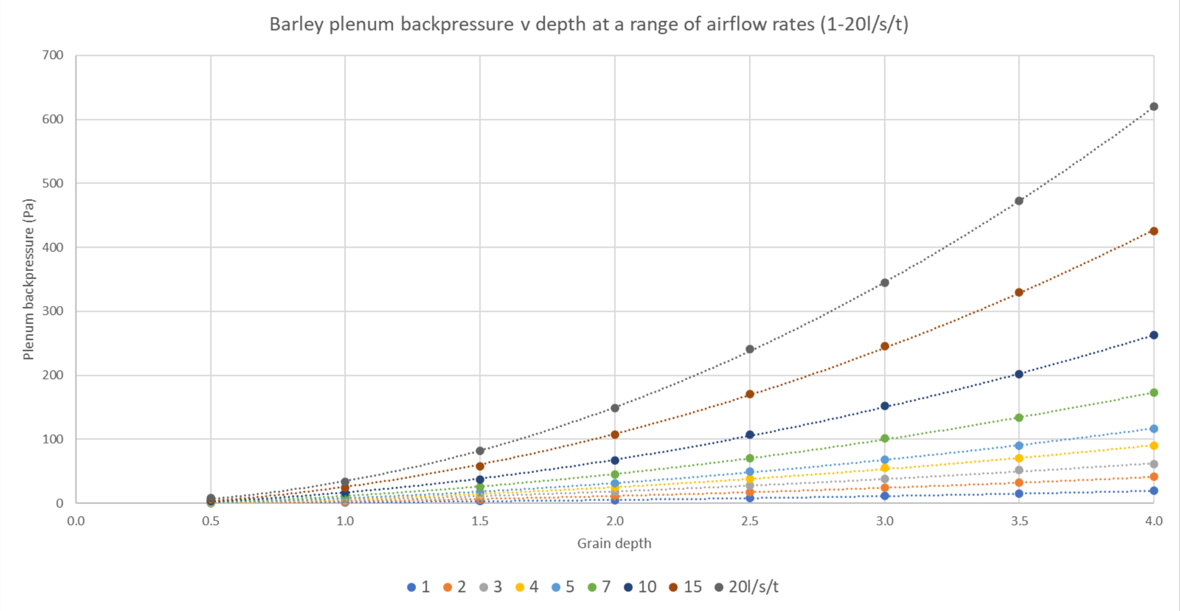
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 6: Canola plenum backpressure with depth at 1-20l/s/t airflow.



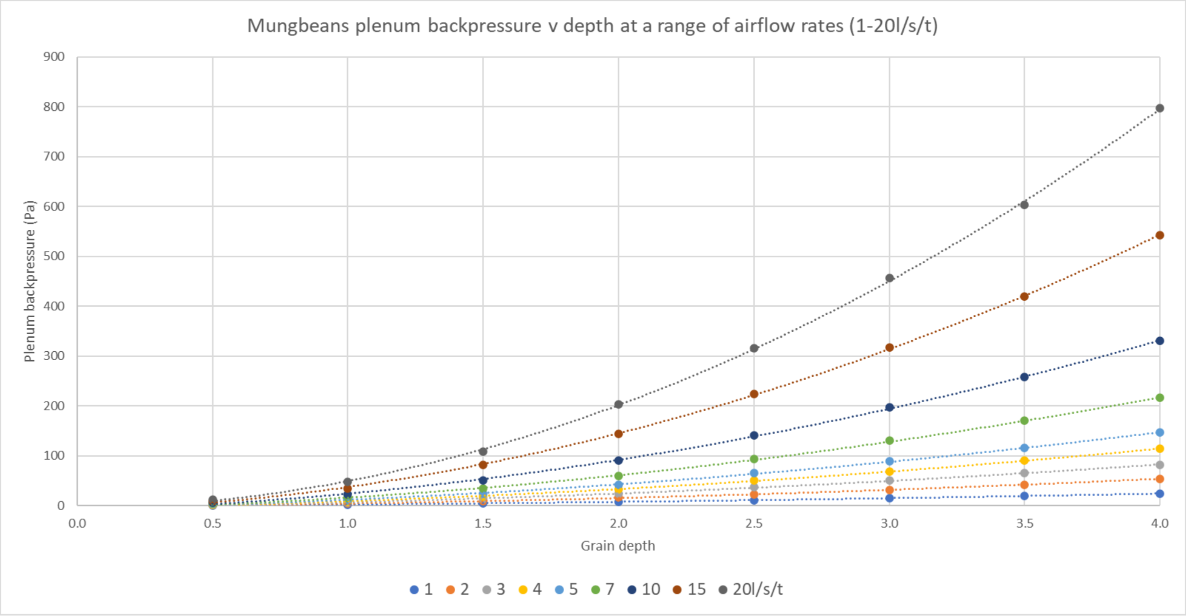
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 7: Barley plenum backpressure with depth at 1-20l/s/t airflow.



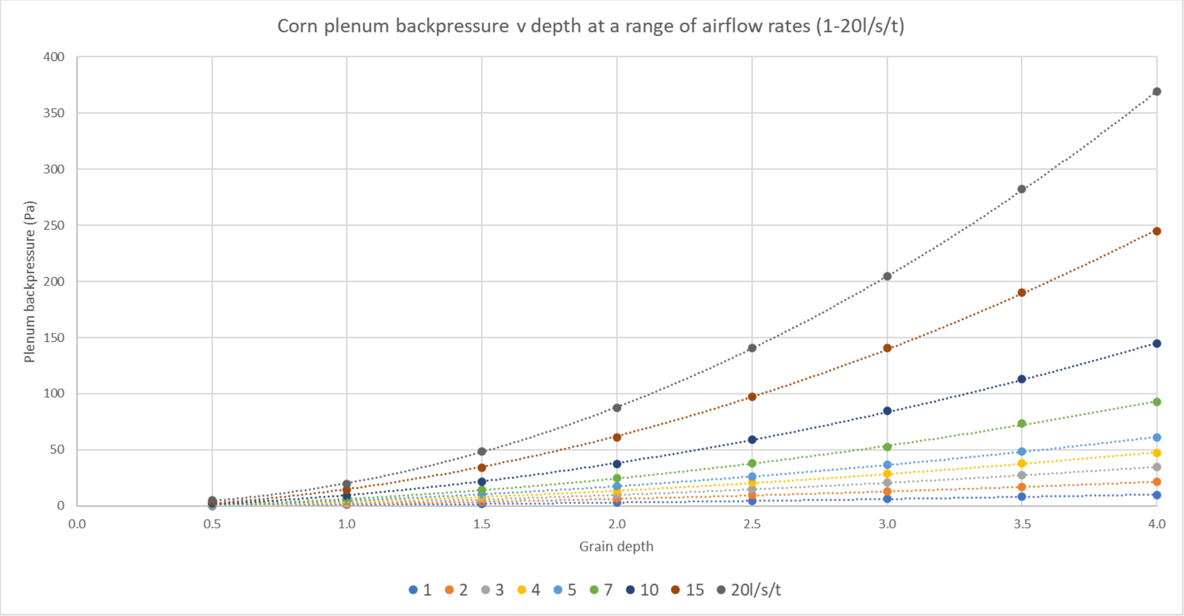
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 8: Mungbeans plenum backpressure with depth at 1-20l/s/t airflow.



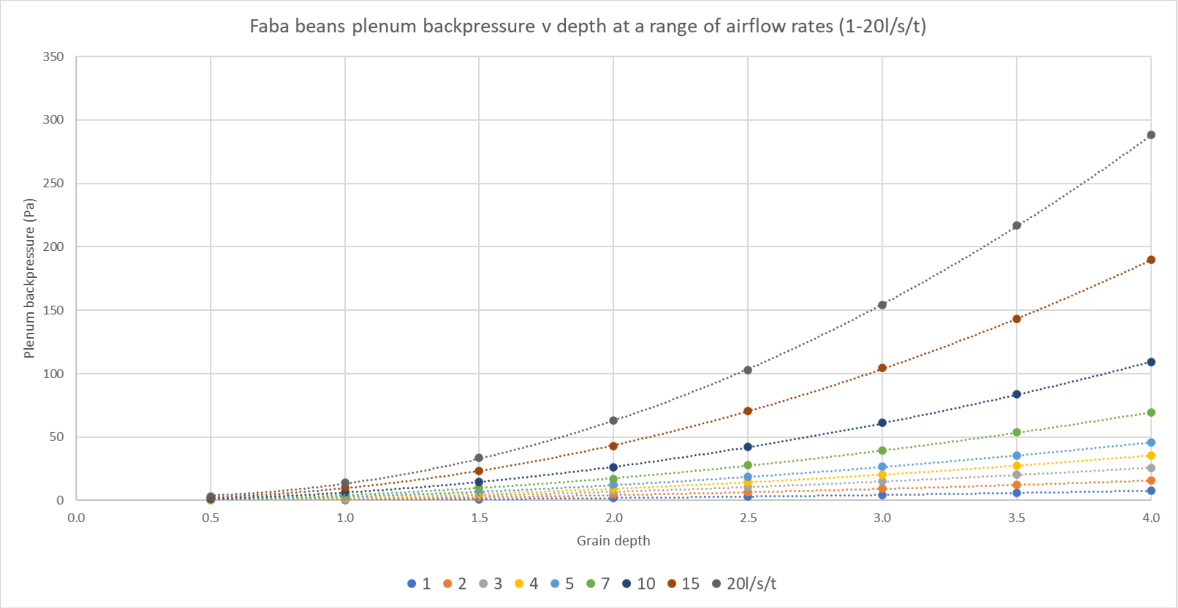
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 9: Corn plenum backpressure with depth at 1-20l/s/t airflow.



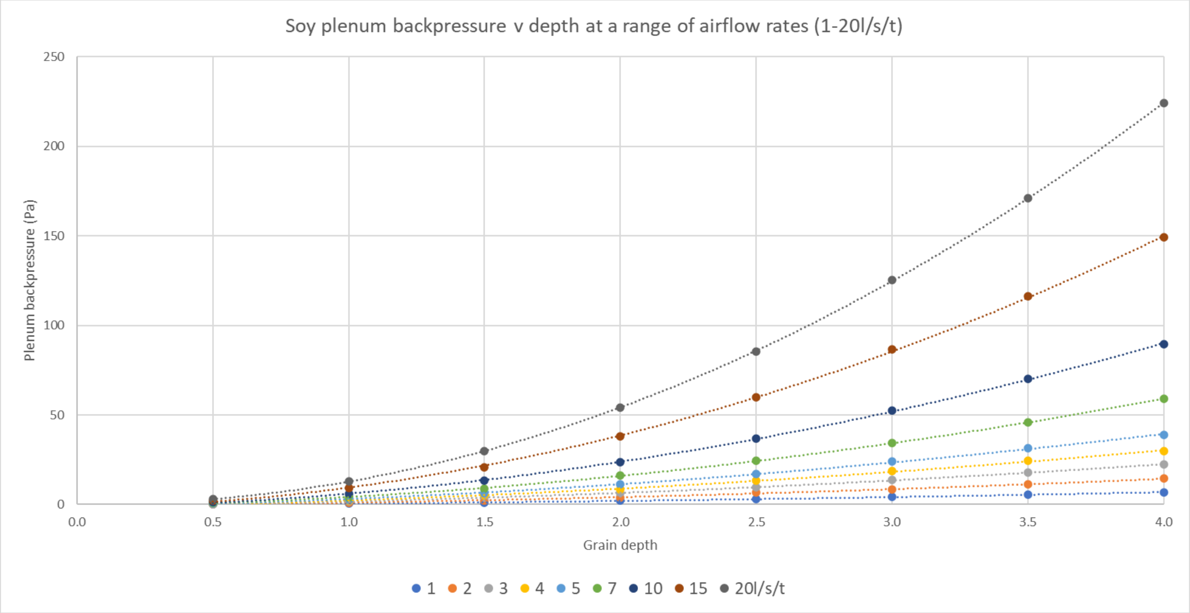
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 10: Faba beans plenum backpressure with depth at 1-20l/s/t airflow.



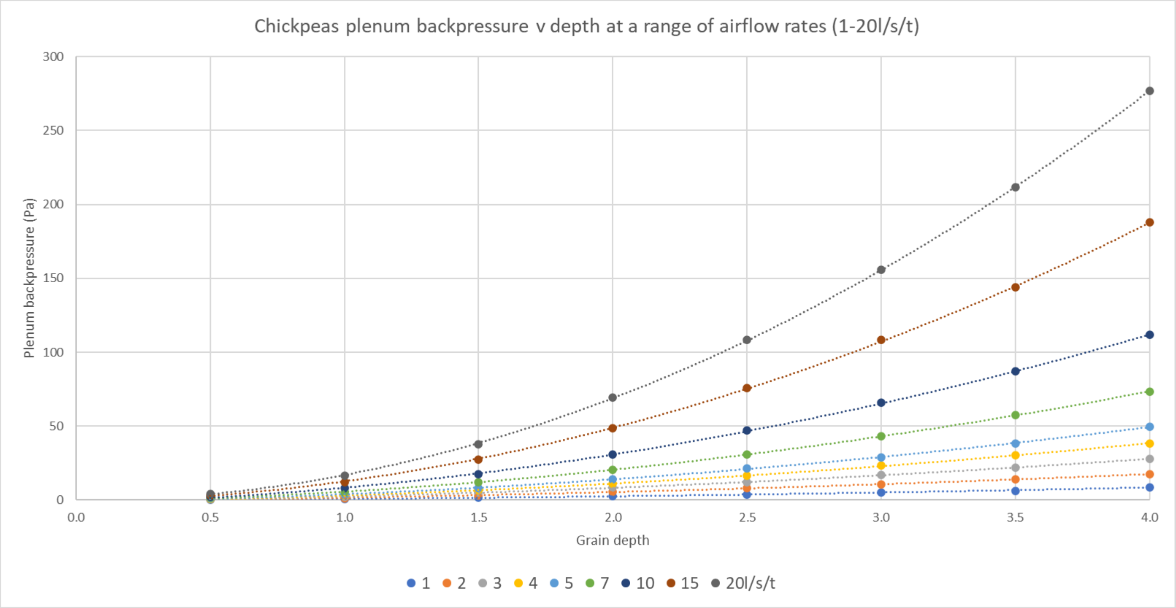
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 11: Soybean plenum backpressure with depth at 1-20l/s/t airflow.



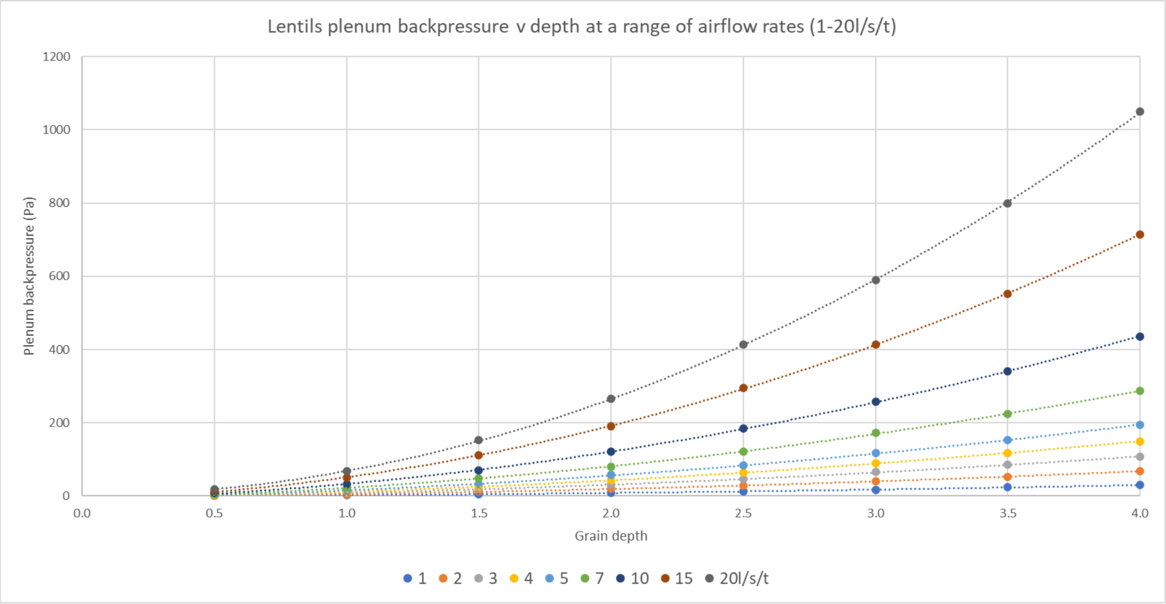
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 12: Chickpea plenum backpressure with depth at 1-20l/s/t airflow.



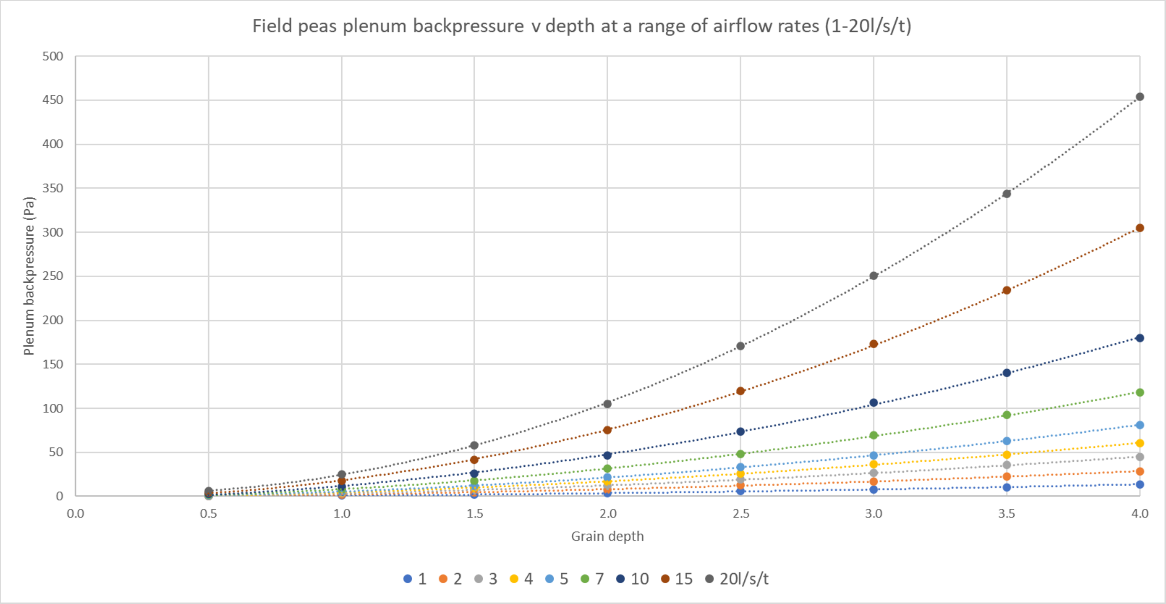
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 13: Lentil plenum backpressure with depth at 1-20l/s/t airflow.



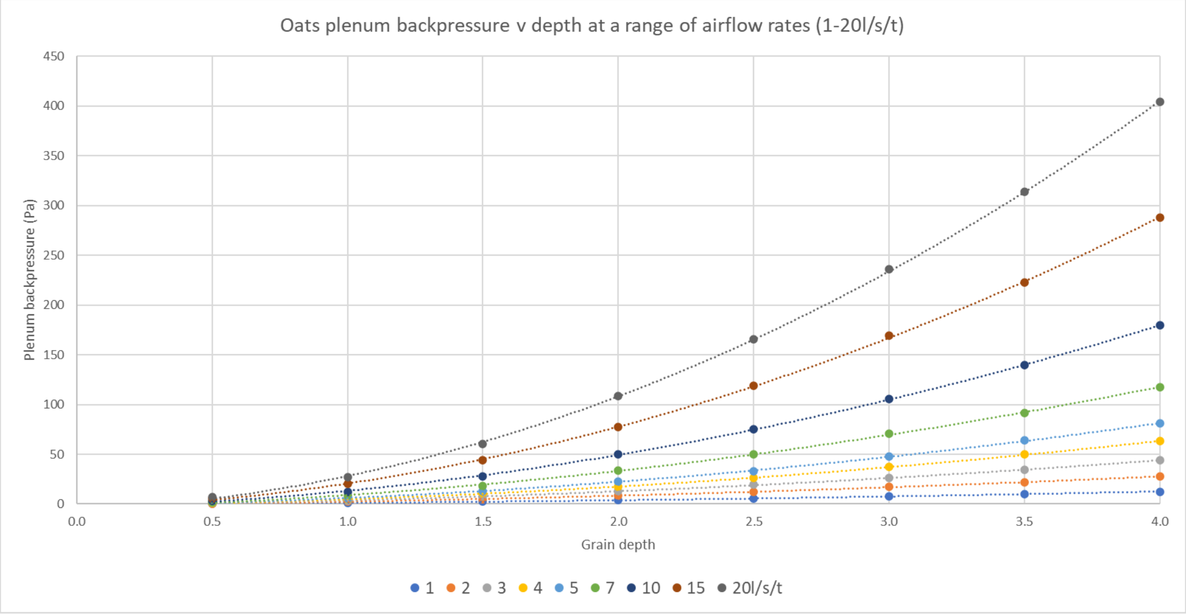
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 14: Field pea plenum backpressure with depth at 1-20l/s/t airflow.



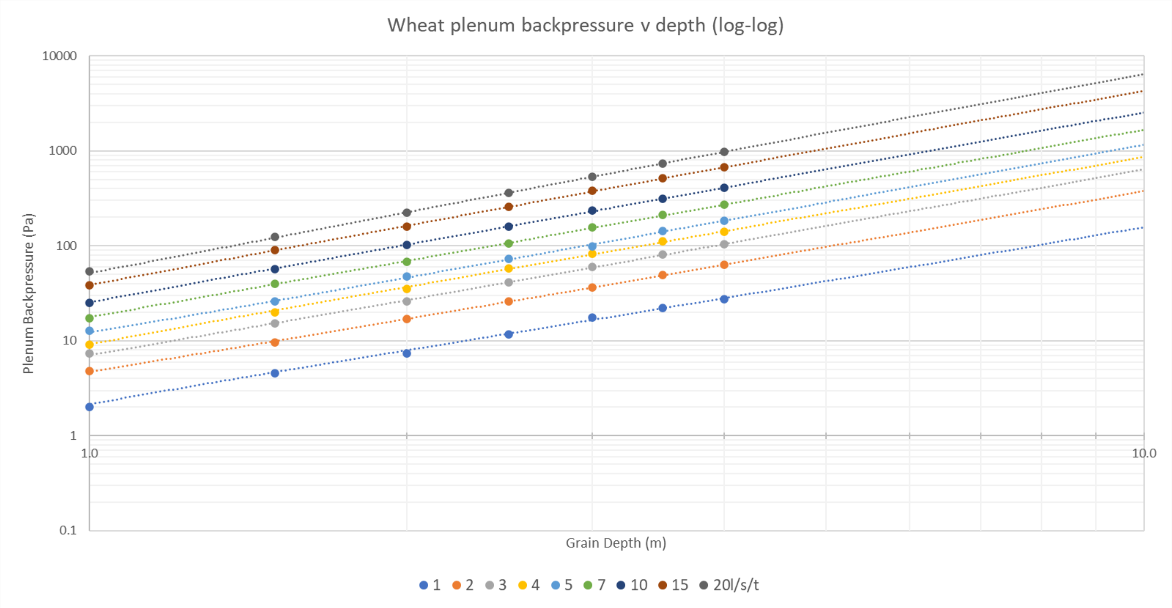
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 15: Oats plenum backpressure with depth at 1-20l/s/t airflow.



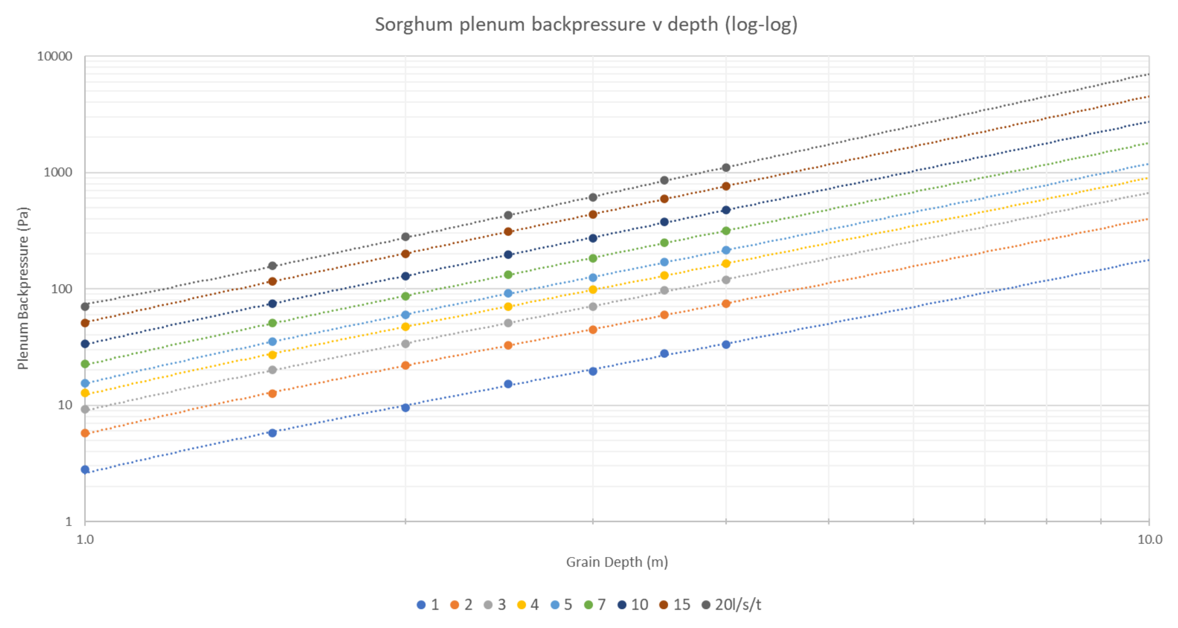
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 16: Logarithmic wheat plenum backpressure with depth at 1-20l/s/t airflow.



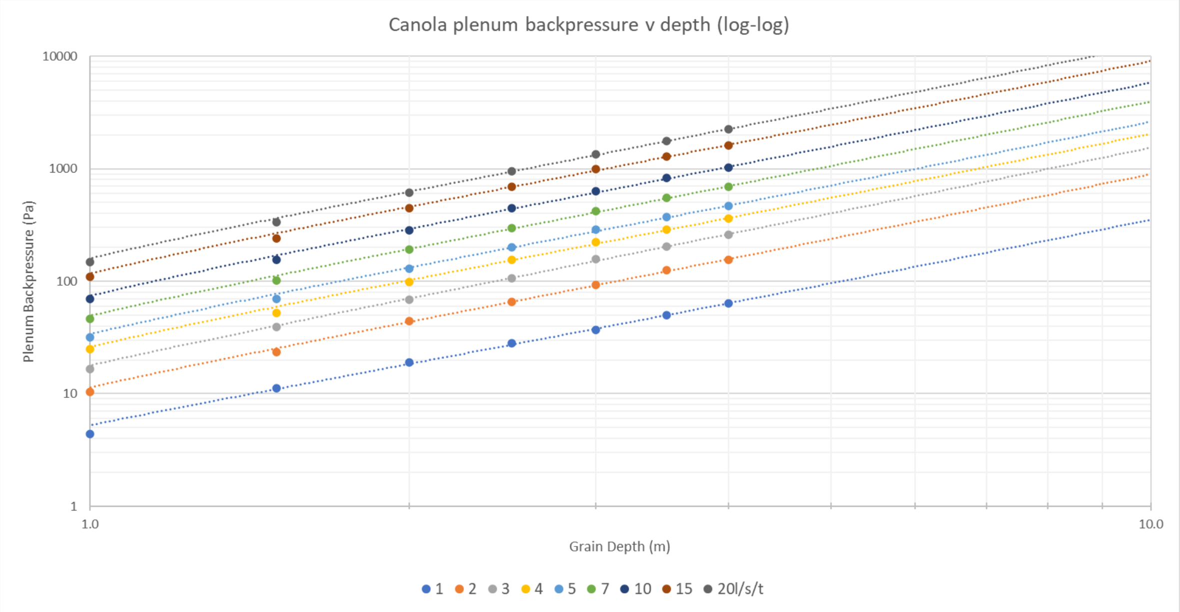
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 17: Logarithmic sorghum plenum backpressure with depth at 1-20l/s/t airflow.



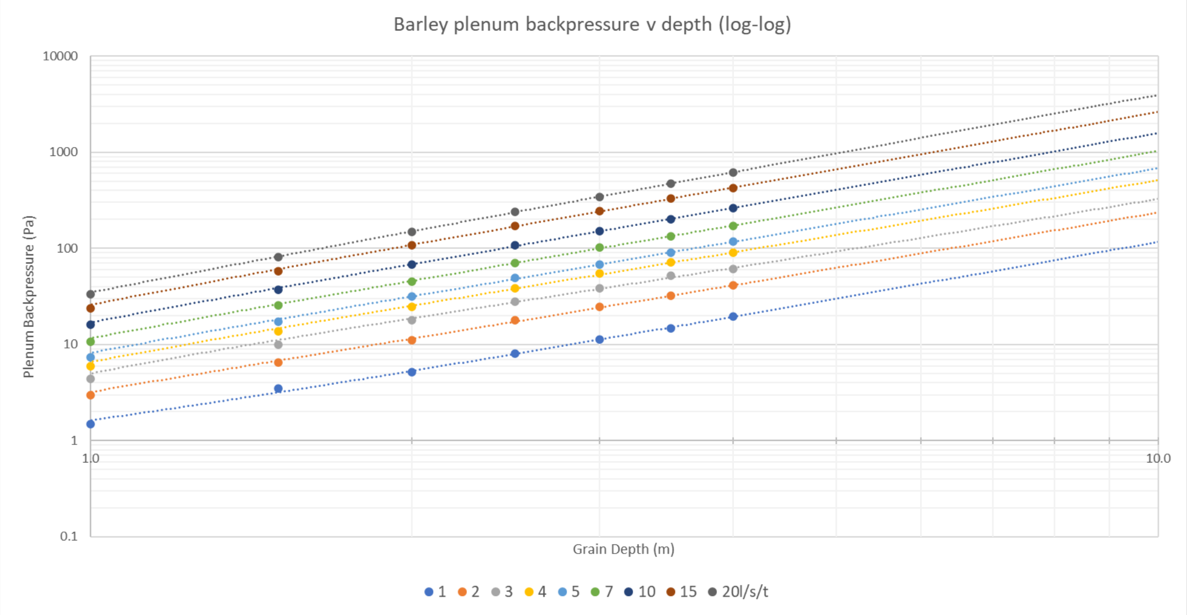
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 18: Logarithmic canola plenum backpressure with depth at 1-20l/s/t airflow.



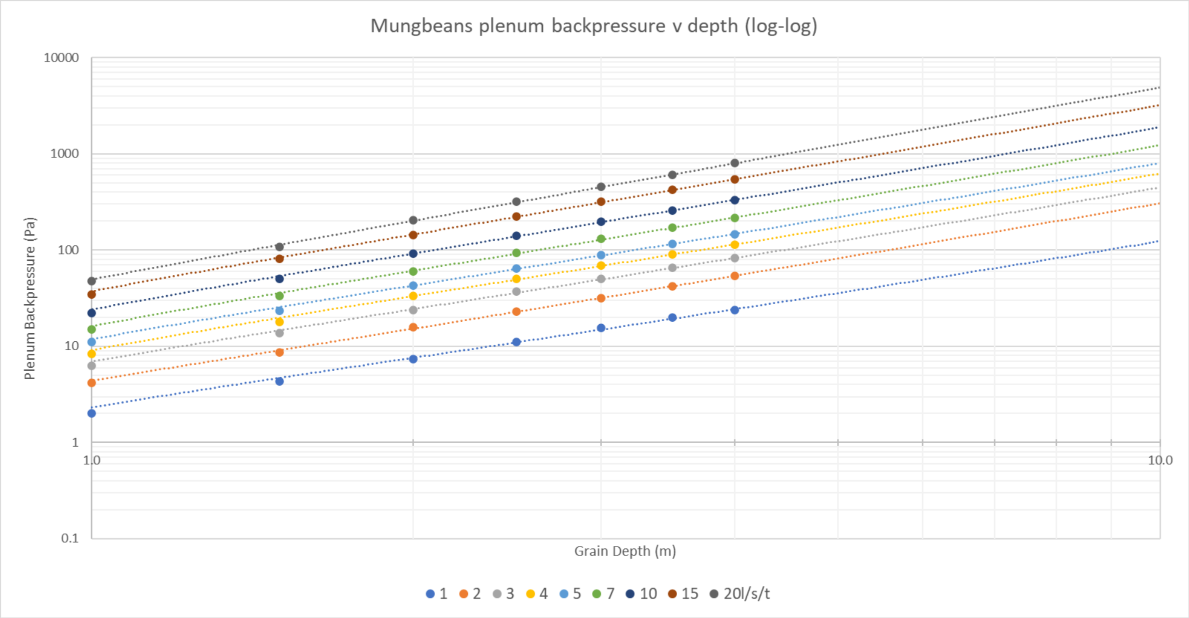
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 19: Logarithmic barley plenum backpressure with depth at 1-20l/s/t airflow.



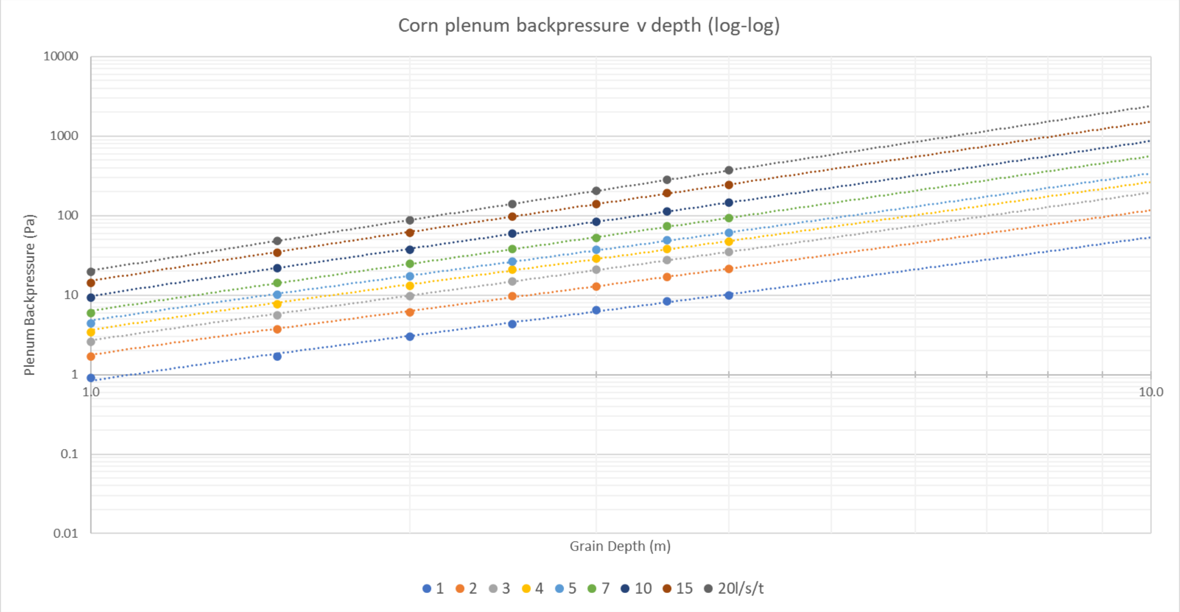
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 20: Logarithmic mungbean plenum backpressure with depth at 1-20l/s/t airflow.



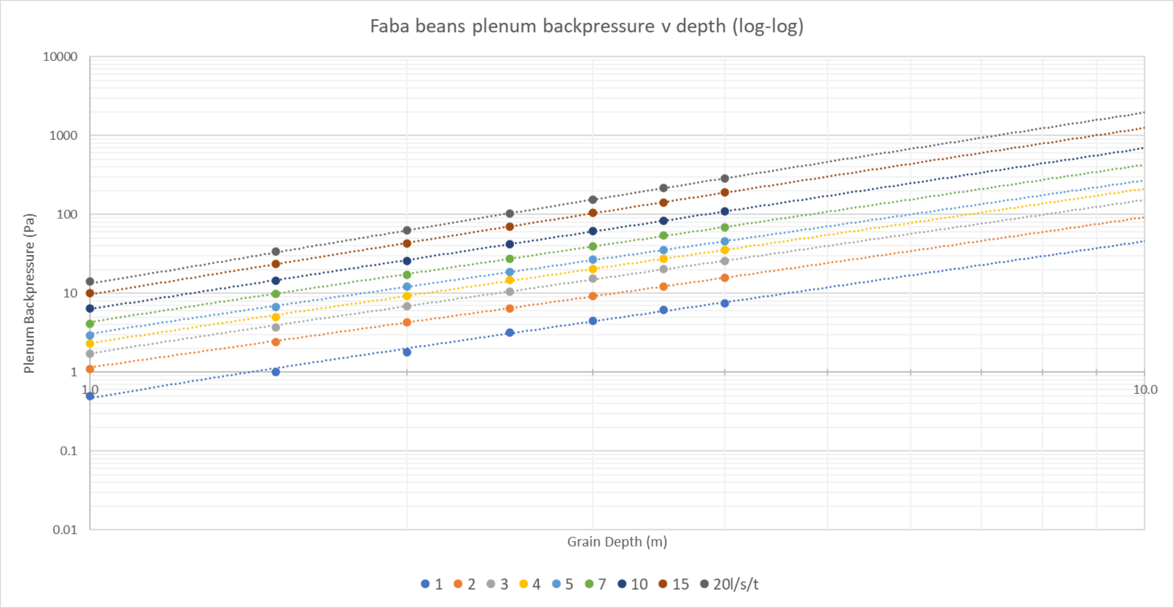
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 21: Logarithmic corn plenum backpressure with depth at 1-20l/s/t airflow.



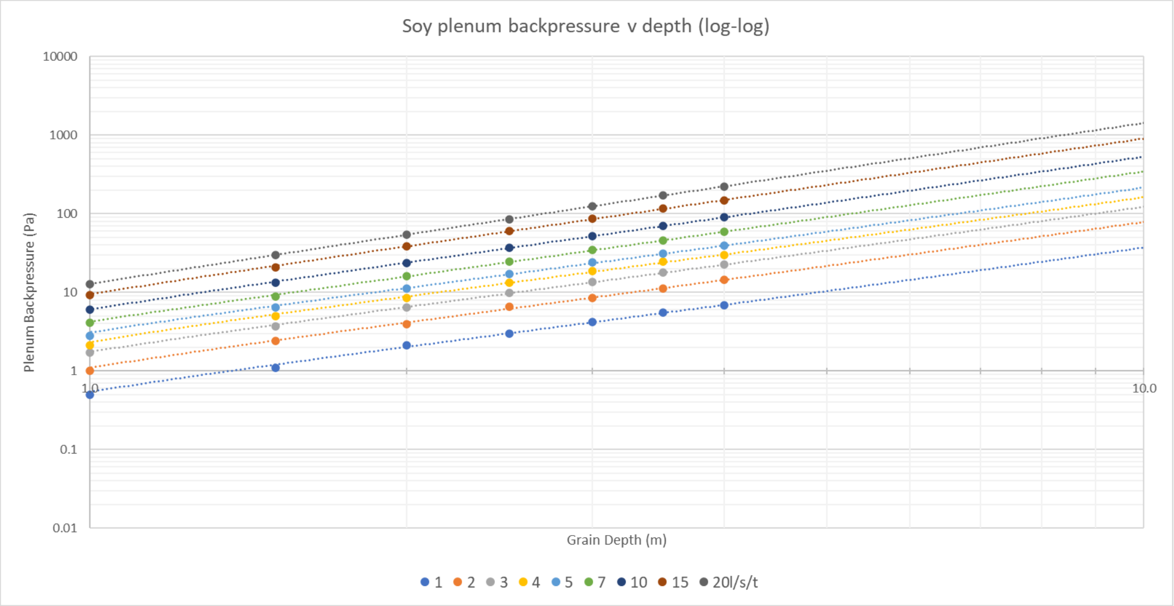
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 22: Logarithmic faba bean plenum backpressure with depth at 1-20l/s/t airflow.



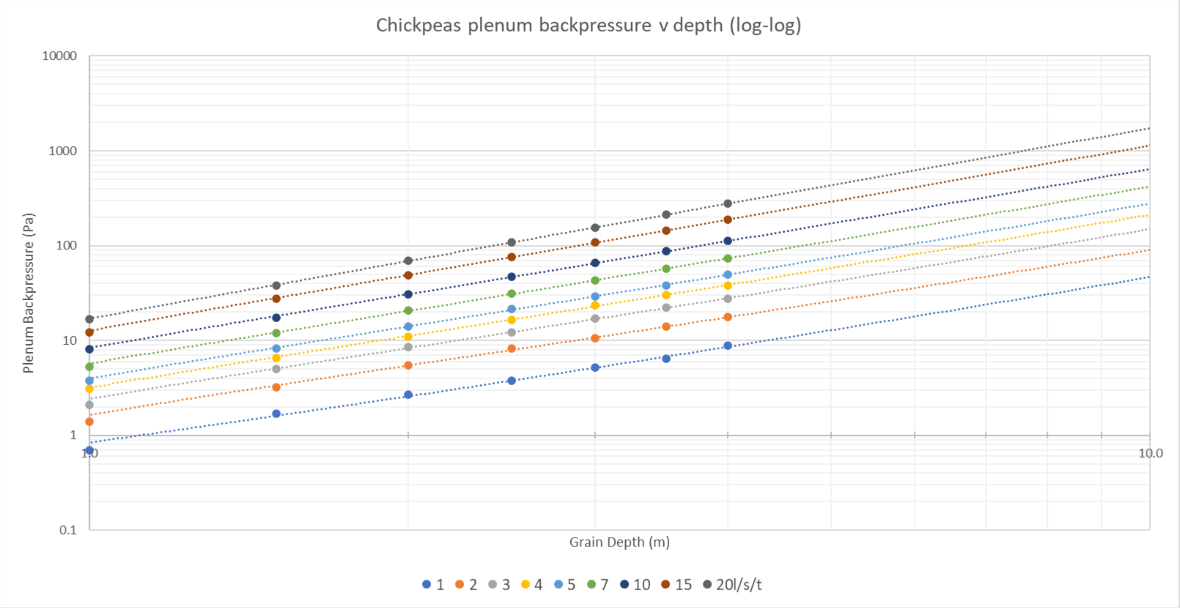
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 23: Logarithmic soy plenum backpressure with depth at 1-20l/s/t airflow.



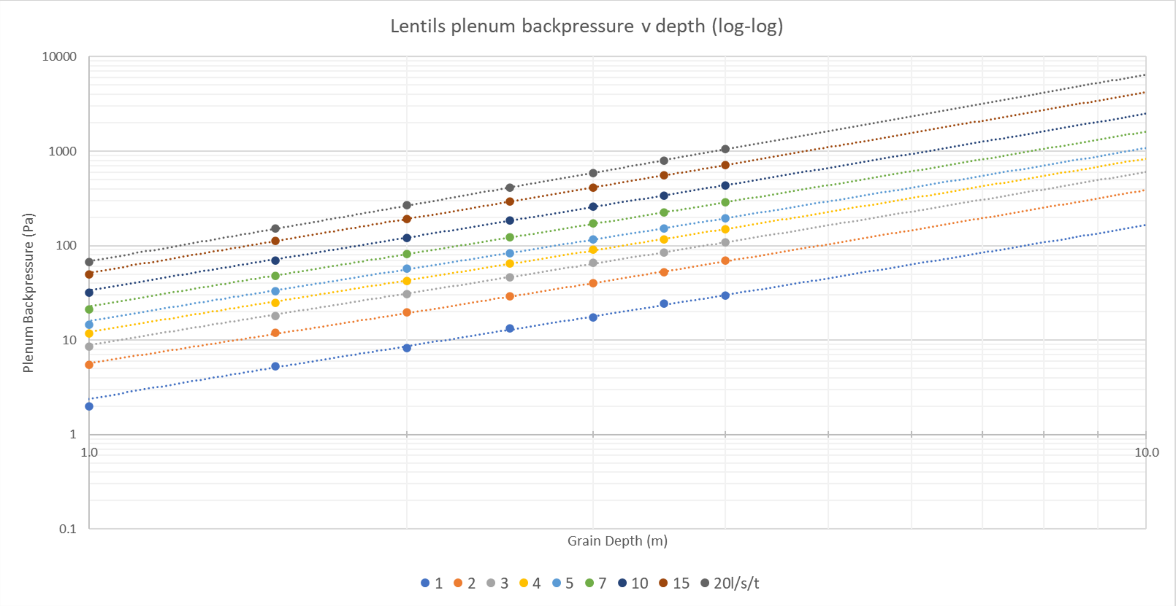
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 24: Logarithmic chickpea plenum backpressure with depth at 1-20l/s/t airflow.



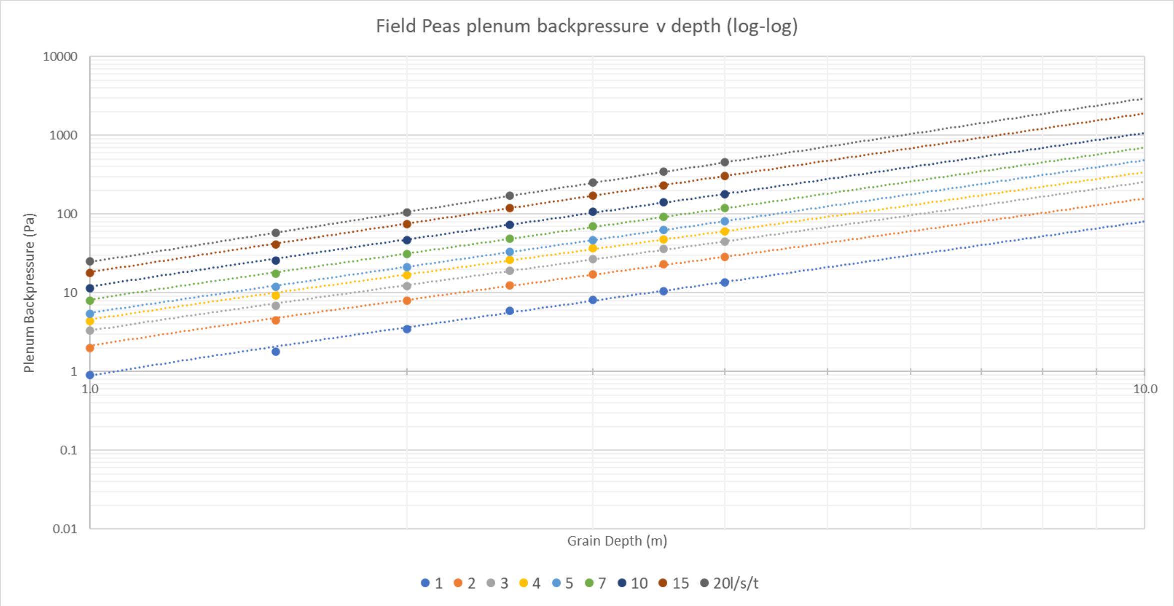
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 25: Logarithmic lentil plenum backpressure with depth at 1-20l/s/t airflow.



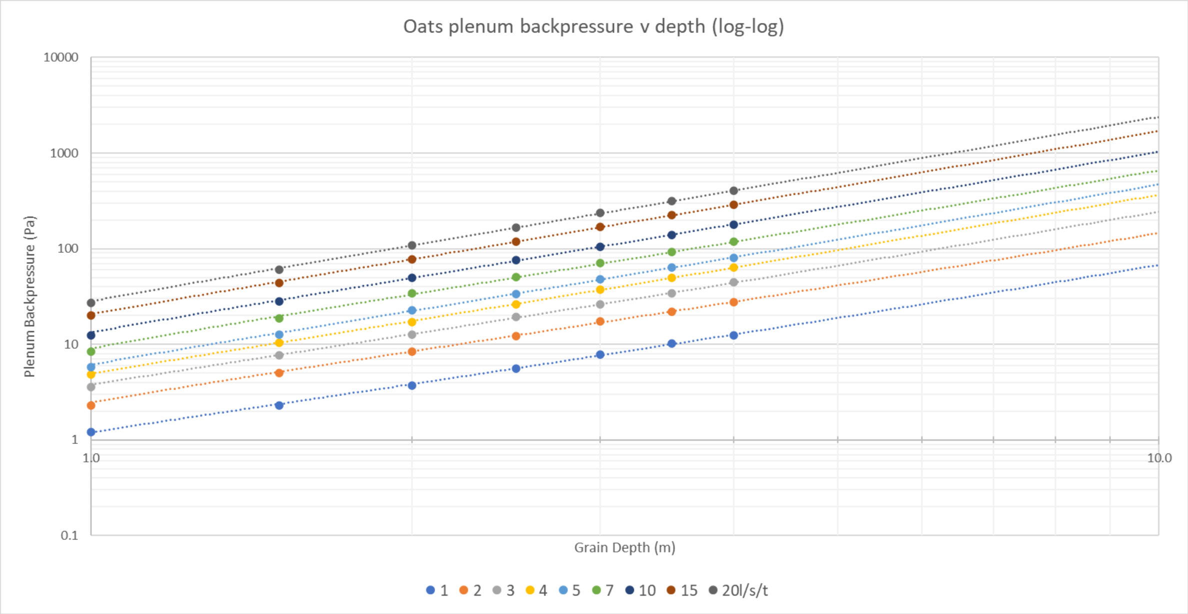
Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 26: Logarithmic field pea plenum backpressure with depth at 1-20l/s/t airflow.



Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

Figure 27: Logarithmic oat plenum backpressure with depth at 1-20l/s/t airflow.



Note: Backpressure indicated is for a loose fill (not consolidated) sample. Additional backpressure induced through grain consolidation, aeration fittings, plenums, ducting and screens. These factors should be considered in the context of aeration system design. Note log-log scaling.

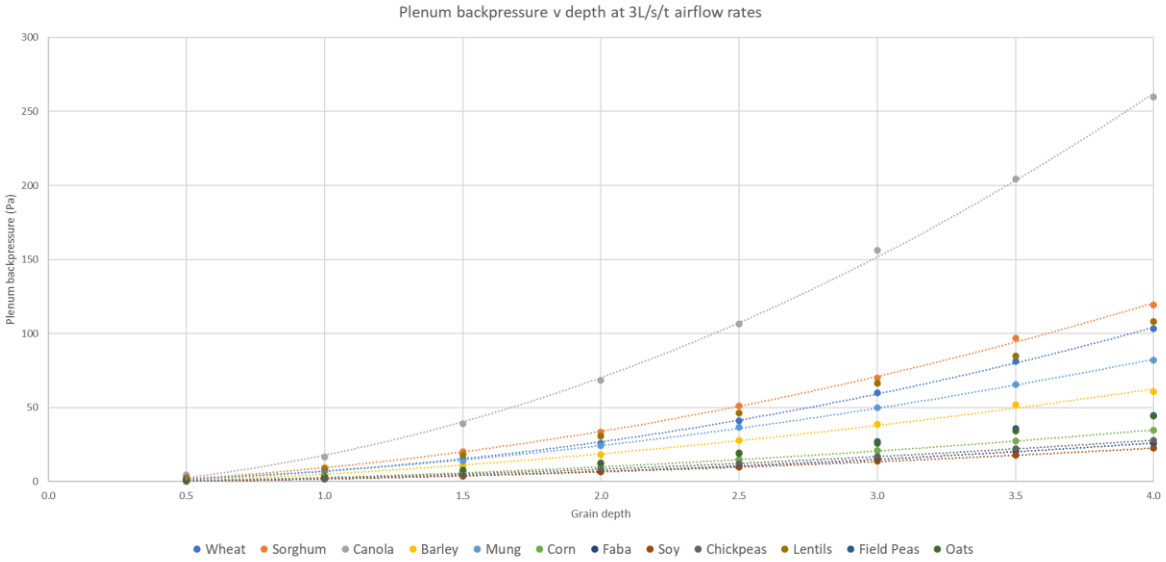
Results

Data obtained through the apparatus appears to have provided sound and repeatable results. But this should be verified in future Development Activities which will verify backpressure in silos on-farm.

The scale and range of testing and measurement equipment is sufficient to emulate recommended cooling rates (2-4l/s/t) and drying (15-20l/s/t) of air flows in a full grain silo.

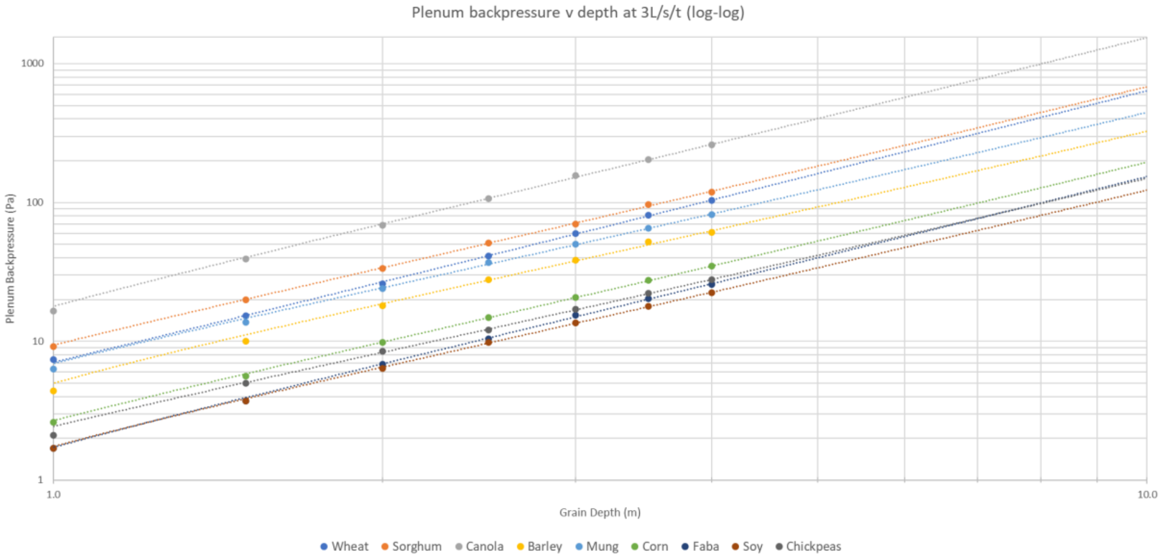
The variation in backpressure between grains was significant at a modest aeration cooling flow rate of 3L/s/t as expected. (See Figure 28)

Figure 28: Pressure v depth at 3l/s/t



Linear trends in log-log graphs can be used to derive back pressure expected in grain silos up to 10m in height using the 4m grain column which also allows for adequate precision of measurement and flow delivery. See Figure 29 illustrating log-log relationships for the range of grains tested at 3L/s/t.

Figure 29: Logarithmic comparative plenum backpressure with depth at 1-20l/s/t airflow.



Grain volume requirement is around 100 litres per test using the 4m column. Grain not native to the testing region can therefore be shipped for testing if needed.

Initial field checks using a silo of sorghum and four aeration fans have indicated a close correlation with backpressure and flow rates using the data obtained using the test column.

Given the success achieved with the apparatus, curves for other Australian grains can be developed if the opportunity exists including:

- Lupins
- Flax
- Popcorn
- Vetch
- Sunflowers
- Triticale
- Cotton seed
- Cavalcade
- Grass seed

Outcome and Recommendations

Data obtained through the apparatus appears to have provided sound and repeatable results. But this should be verified in future Development Activities which will verify backpressure in silos on-farm.

Once verified, tabular reference tables could be generated as a ready-reckoner for growers, silo manufacturers and aeration fan retailers.

4a. Part 1 Quantifying Opportunity for Aerated Grain Storage in Northern/Tropical Regions of Australia (DA2022-2)

Objectives

Part 1: Evaluate the suitability of climatic conditions for effective aeration cooling of grain storages in northern/tropical regions of Australia. The need for improvement or alteration of typical aeration practices will be evaluated throughout this project.

Part 2: Trial a method to measure airflow of large fans used on flat bottom silos in the far north and determine if a length of 10x diameters of pipe is required for accuracy and consistency.

Background

Interest in cereal crop production in the northern regions of Australia has increased considerably in recent years. This production will undoubtedly involve a reliance in on-farm grain storage that is heightened by factors such as greater distance to bulk handlers, reliance on stock feed capacity and transport costs.

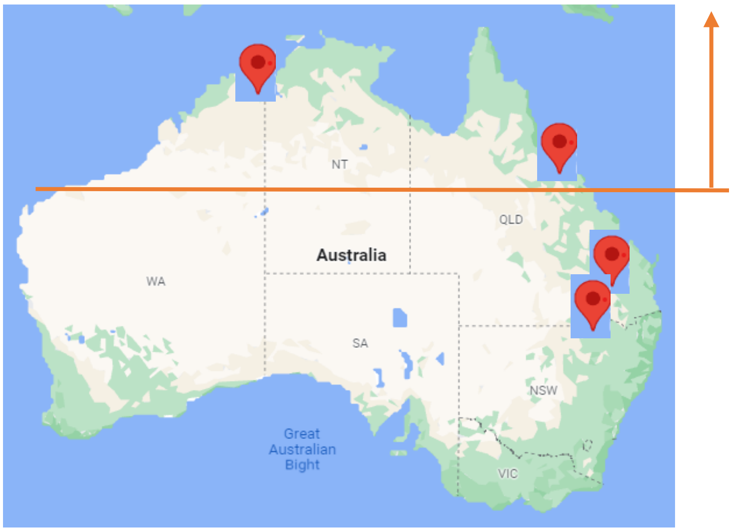
However, the suitability of current grain storage aeration processes used in the rest of Australia is unknown. Considerably higher temperatures, relative humidity and seasonal extremes experienced in northern regions add challenges to conventional grain storage strategies.

This activity aims to evaluate the effectiveness of standard grain storage aeration practice to be applied to tropical regions of Australia and identify potential alterations if required.

Development activity methodology

Data has been compiled from several on-farm locations across Australia for comparison (Figure 1):

- Kununurra, WA.
- Home Hill, QLD.
- Oakey, QLD.
- Boomi, NSW.



Areas above this line are considered the 'Northern' region for the purpose of this study.

Figure 1: Data collection locations used for initial investigation

Both Home Hill and Kununurra weather data has been interrogated and is considered representative of northern conditions. While Oakey and Boomi are used as a typical southern storage region comparison. The reference data spans from 2020 to 2022 and analyses the warmest and typically wettest 6 months of the year from October 1st through to March 31st.

Effective aeration cooling is dependent on several key climatic metrics that have a considerable impact on grain temperature, moisture and quality. These metrics have been used as the basis of this investigation and are summarised below:

- Relative Humidity: the amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature.
- Specific Humidity: a finite metric measuring the mass of water vapour in a unit mass of moist air. Expressed as grams of vapour per kilogram of air.
- Wet bulb temperature: Defined as the temperature of a parcel of air cooled to saturation by the evaporation of water into it. This metric is used in place of the conventional dry bulb temperature as moisture is a component of this measurement. Given that grains naturally have a moisture component, wet bulb temperature provides the most accurate representation of how the ambient air will interact with a grain mass.
- Relative humidity override (a relative humidity at which fans cease operating to avoid introducing high humidity air into the grain mass).

Results

Initial investigation was conducted looking at basic weather metrics to gauge the extent of variance between northern and southern grain storage regions. Specific humidity and wet bulb temperature data in figures 2 and 3 below illustrate the considerable difference in climatic conditions.

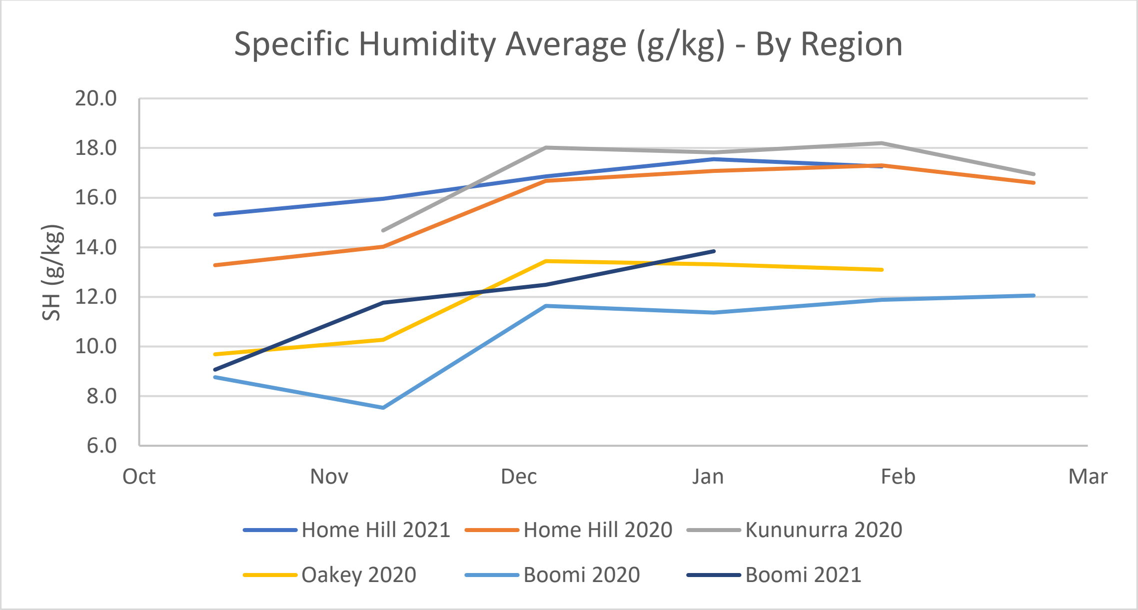


Figure 2: Average monthly specific humidity in all regions

Figure 2 illustrates the consistent variation of water vapour present in the air between the two regions. There appears to be an additional average of 3-5 grams of moisture per kilogram of air in the northern regions. On average, this is around 33% higher than the ambient conditions experienced in the established southern storage regions.

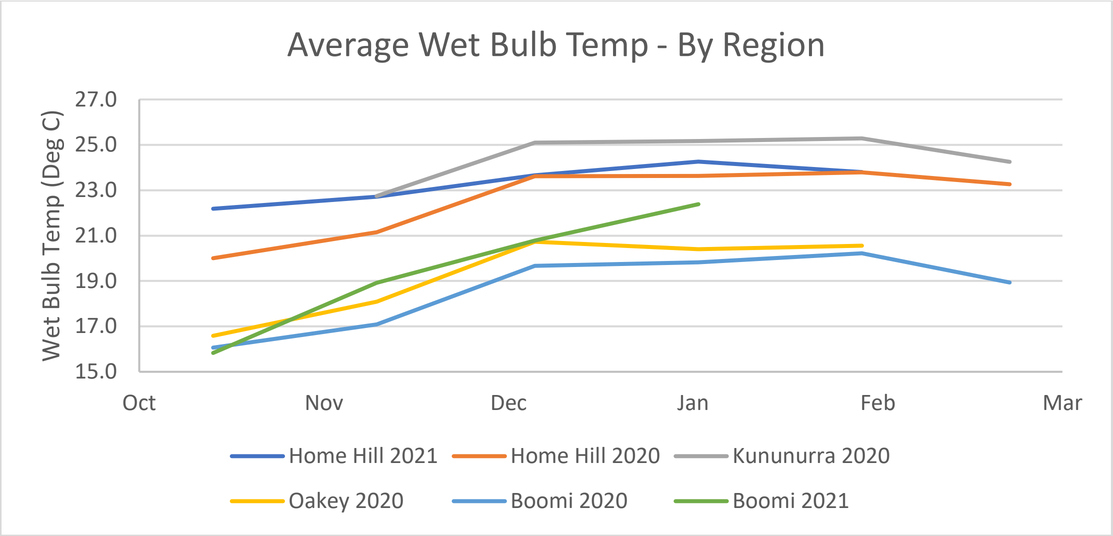


Figure 3: Average monthly wet-bulb temperature experienced in all regions

The average ambient temperature on a wet-bulb basis in the northern regions over a typical storage period of October to March is around 2.5 to 4 degrees higher than the southern region. This represents a 15% increase in typical ambient temperature conditions in tropical regions and is expected to have a negative impact on the process of equilibrating or reducing grain temperature with aeration fans.

Implications

A ‘Time Proportioning Aeration Control’ algorithm was applied to the data to reflect the air that would typically be captured and introduced into the storage using conventional aeration control methods. This algorithm targets the coolest 100 hours per month on a wet-bulb basis and is bound by a relative humidity override that inhibits fan operation above 85% RH.

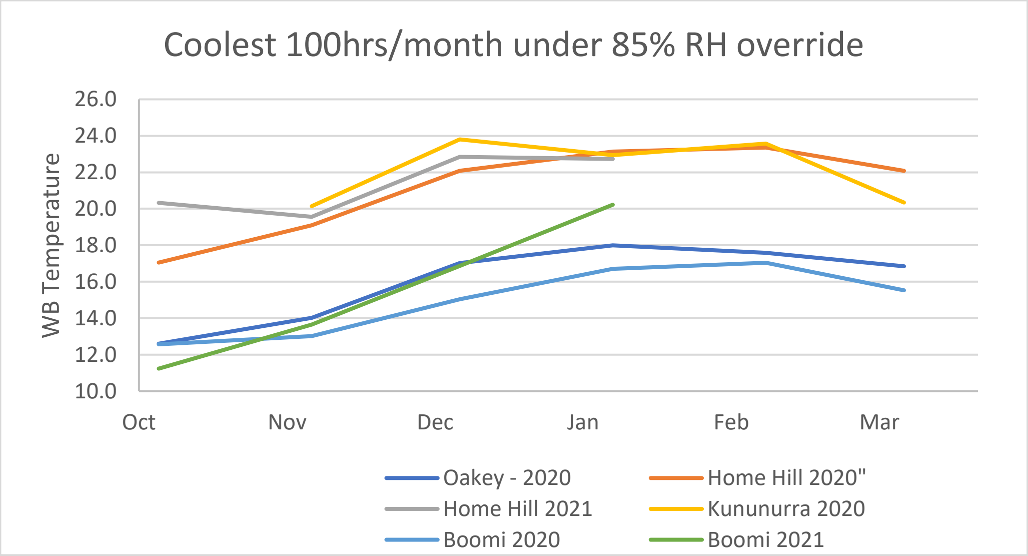


Figure 4: Monthly average temperature when time proportioning control method is applied with 85% RH override

Figure 4 illustrates air introduced into grain storages each month will be around 5 to 6 degrees warmer in the northern regions when using conventional aeration control methods at recommended flow rates of 2-4l/s/t.

Higher ambient temperature air used for aeration cooling will impact aeration cooling performance and may be unable to cool grain sufficiently or as rapidly as required.

Reduced aeration cooling performance have a significant impact on grain insect pest population growth and may also impact germination and grain quality.

These trends are supported almost identical variations in a TPC aeration controller's internal setpoints as indicated in Figure 5.
These setpoints are the temperatures at which aeration events are triggered. Once again reflecting a typical 5-to-6-degree higher setpoint that will impact aeration cooling performance and the resulting stored grain temperature.

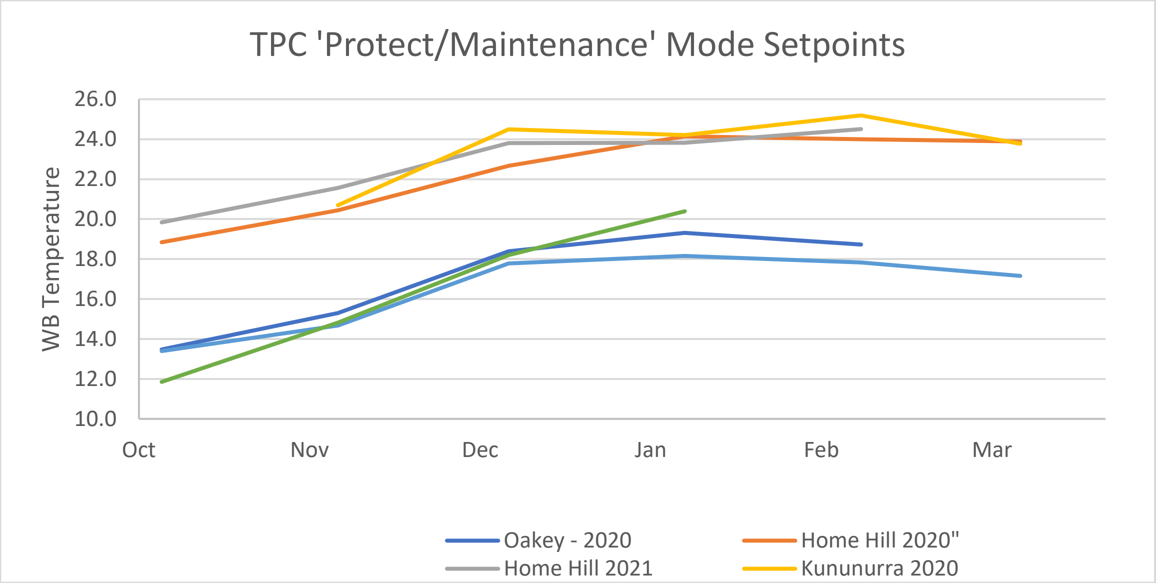


Figure 5: Monthly average aeration trigger setpoint from TPC Controller.

Investigated Solutions

Lowering fan run time in conjunction with increased airflow rates:

It has been hypothesised that decreasing the fan run time each month to target cooler conditions may improve aeration cooling performance and result in a reduction in grain temperature.

This method should only be considered if applied in conjunction with an increase in airflow (i.e. from 2l/s/t to 4l/s/t) to ensure the cooling front still has sufficient time to pass through the grain stack.

Figure 6 below suggests this approach could achieve 1 to 1.5 ^{0}C cooler air than the standard process.

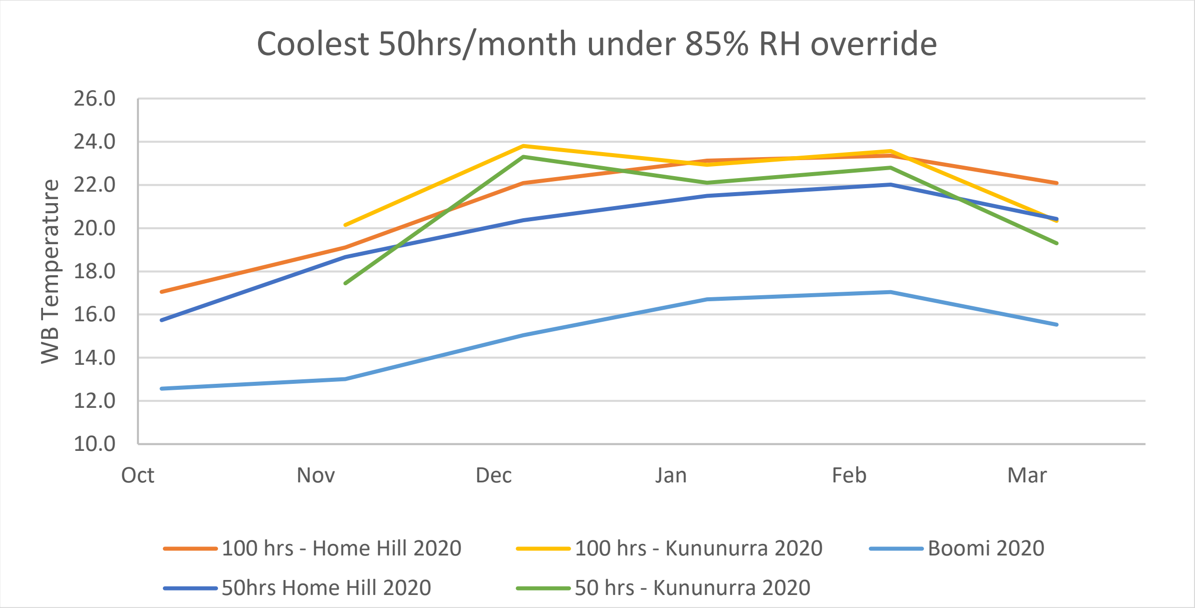


Figure 6: Monthly average WB Temperature if operating TPC method for 50 hrs per month

Increasing RH override to 90%:

Further analysis is required to determine any impact this may have on stored grain in the northern regions.

However, the wet bulb analysis suggests typical aeration methodology may need some adjustment to achieve better results in the north.

Figure 7 indicates an increase in the relative humidity override setpoint could lower the average temperature of available air.

The results suggest a 5% increase in the RH override resulted in a 1-degree reduction to the average monthly temperature selected by an aeration controller.

While this is only a small improvement, it is an indication that adjustments to the typical aeration control method could improve grain aeration results in the north, but the resulting grain condition would need to be assessed through demonstration.

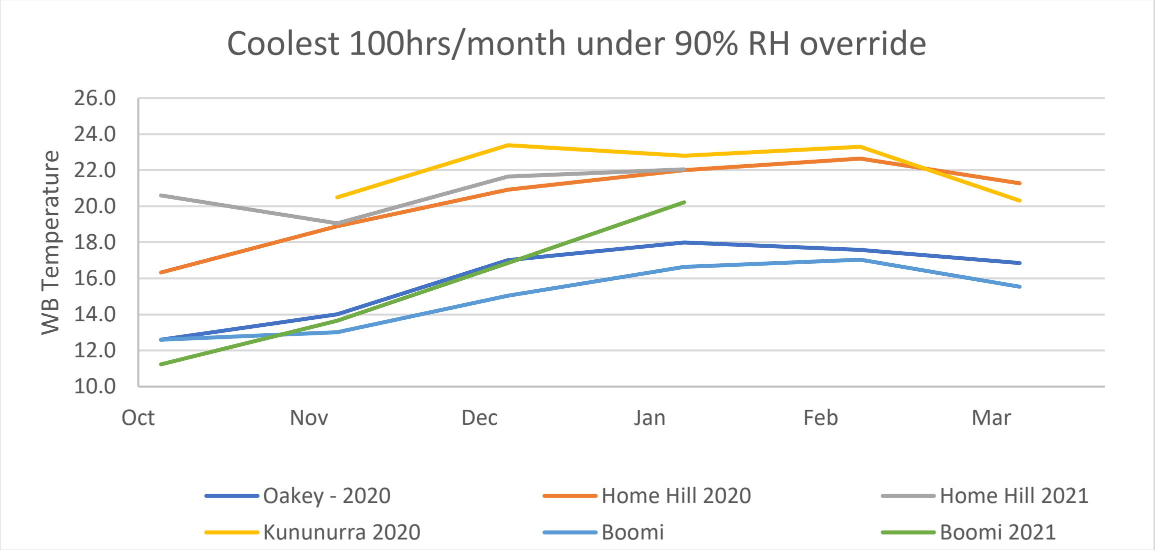


Figure 7: Monthly average temperature when time proportioning control method is applied with 90% RH override

Outcome and Recommendations

This initial investigation confirms that there are some key differences experienced in the climatic conditions between the northern and southern grain growing regions.

The 2.5 to 4 ^{0}C higher WB temperatures (≈15%) and 3 to 5 g/kg higher specific humidity (≈33%) will make conventional aerated grain storage more difficult with a likelihood of poorer results.

This initial study suggests successful aeration cooling in the far north is possible, albeit with the theoretically achievable grain temperature being 5-6 ^{0}C higher than in southern Queensland.

While a grain temperature below 20 ^{0}C is ideal for insect pest mitigation, grain temperatures in the mid 20 ^{0}C range would be manageable and significantly better than the anticipated temperature without aeration (high 30 ^{0}C range).

This study also suggests that changes to typical aeration methodology could improve these outcomes. Further research is recommended to quantify exactly what grain temperatures can be achieved.

These include investigating if increasing airflow and reducing run-time delivers reduced grain temperatures in practice and if increasing the relative humidity override affects results and grain condition.

The GRDC Grain Storage Extension Team is currently undertaking further research to discern the connection between ambient air and airflow rates, and how this influences grain temperature.

4b. Part 2 Quantifying Opportunity for Aerated Grain Storage in Northern/Tropical Regions of Australia (DA2022-22)

Background

Past research has identified a practical method of measuring airflow of small fans (250mm diameter) with an acceptable level of accuracy. https://storedgrain.com.au/testing-aeration/

The challenge for measuring airflow in large fans used in the far north and in flat bottom silos is the engineering standard of using pipe that is ten times the diameter of the fan intake to ensure laminar flow for an accurate and repeatable measurement. With large aeration fans often having an intake of 600-800mm diameter, the expense, availability and practicality of using a 6-8m length of pipe is impractical.

Development activity methodology

Priority was given to methods of creating a large pipe of variable diameters that could be handled and transported.

For this experiment, 3.2x1.2m zinc sheet metal was used. One steel ring per sheet was rolled and welded to match the diameter of the fan being measured, so the zinc sheet could be manually rolled around the fan intake and the flat steel ring to create a pipe.

With 100mm overlap, each additional zinc sheet added 1.1m of pipe length. Timber supports were added to the outside of the pipe for extra support where required. See image 1 below.

Image 1: 8m pipe made of sheet metal to measure airflow on an 800mm diameter aeration fan.

Airflow was measured using a hotwire anemometer averaging seven readings across the diameter of the pipe and repeated on a horizontal and vertical cross section. See Images 2 and 3 below.

The airflow measurements were taken in three places along the pipe; centre, one-third the length from the fan and one-third the length from the intake end of the pipe.

Image 2: Hotwire anemometer used to take airflow measurements.

Image 3: Hotwire anemometer reading at seven places across the diameter of the pipe.

Results

Airflow measurements were most reliable and consistent when taken in the middle of the length of pipe. There was little difference in airflow readings taken on the horizontal vs the vertical cross section of the pipe diameter indicating a uniform flow. Note the fan was an axial flow style so results may vary with other fan typestyles, for example, backward curved centrifugal fans.

Airflow readings for an 800mm intake were stable and consistent when using the 8m pipe (10x diameters) and also at 6.9m of pipe (8.6x diameters) but became unstable and unreadable when the pipe was shortened to 5.8m (7.25x diameters)

The airflow readings were averaged across the pipe, resulting in 2.4 meters per second through the 800mm pipe, which in this case equated to 1.6 litres of air per second per tonne of canola in the silo at the time of testing.

Outcome and Recommendations

The method of creating the large diameter pipe was successful and repeatable although required significant preparation and time to setup with two people.

The main advantage of this method is that it can be stored and transported flat and used on a range of fan sizes if steel rings are made to suit each fan size.

Airflow readings are most reliable if taken at the middle of the length of pipe and 8.5 to 10x diameters are required.

The development of a more practical measurement method would be beneficial to enable researchers to measure airflow in large fans.

5. Field Testing Aeration Backpressure (DA2022-4)

Objectives – (Question or information gap to answer)

The objective of this development activity is to field-measure backpressures, aeration fans are typically working against in silos. Data gathered can be used to compare with results from 'bench testing' aeration backpressures with the rig built in 2021 and to provide typical operating backpressures for bench testing fan performance.

Background

It is known some fan manufacturers performance test fans while others rely on calculated theoretical performance. Manufacturers rarely, if ever, actively test fan performance in operation on silos.

Prior to this research, manufacturers rely on backpressure data generated in 1952 in the USA combined with theoretically calculated fan performance to estimate the airflow that will be achieved in operation on a silo.

In 2021 the extension team built a bench test rig to measure the backpressures of various types of grain, at a range of depths. It was agreed these results should be compared to field collected data for verification and confirmation they represent an accurate picture of grain backpressure during aeration in silos. Alternatively, a variation may need to be applied to account for field influences.

Development activity methodology

A range of silos, grain types, depths and aeration systems were identified to collect backpressure measurements from. Airflow was also measured to determine backpressure relativity.

Backpressure was measured using a digital manometer to measure ambient pressure differential in Pascals (PA) at the transition between the fan and the silo. On several occasions, the device used was swapped to ensure equipment accuracy. The location to take the pressure measurement was also tested on several occasions.

Measuring airflow through large aeration fans was found to be both laborious and challenging. The method employed was to attach a pipe to the fan that was equal to or larger than the inlet diameter, and ten times the pipe diameter in length, see Figure Group 1.

Many silos could not be tested with this method due to obstructions including other silos, sheds, silo legs and switch boxes preventing the pipe being positioned on the fan inlet.

A hotwire anemometer was used to measure air velocity to calculate airflow in the pipe, taking the average of around a dozen readings across two orthogonal cross sections within the pipe. While the airflow velocity measurements through the pipe were taken in meters per second, they were then calculated to the industry standard litres per second per tonne (l/s/t) of grain in storage at the time.

The third critical component to be measured for relativity was the depth of grain in metres (m) and quantity in metric tonnes (t).

Dimensions of the grain stack inside the silo were measured using measuring tapes and laser distance measuring devices. In most cases the growers had records of the quantity of grain in storage, but in each instance, this was cross checked against a calculated volume according to the dimensions of the grain stack and the known or common bulk density of that grain type.

Thanks to the learnings from development activity 2023-5; Airflow within silos, the team established that the most relevant grain depth is the minimum depth, (shallowest point) above the aeration duct as that is where majority of the airflow passes through the stack.

In situations where silos had multiple fans that could be accessed for measurement, each fan was isolated, and measurements taken while all combinations of individual fan engagement. This approach enabled the collection of backpressures at various airflows through the same stack of grain.

One location also used a petrol-powered fan, which meant engine speed and resulting airflow could be varied to measure backpressures at a range of airflows through the stack.

Figure Group 1: Measuring airflow using a pipe on the fan inlet, so backpressure readings could be recorded relative to airflow.

Results

A full table of results can be found in Appendix 1, detailing all 46 tests conducted across nine sites and include eight different grain types.

There were additional findings made while conducting this activity that, while not included in the aim, have guided and refined these backpressure and aeration learnings.

Variables

During testing it was hypothesised that variables including duct type and format, grain size, bulk density and transition points may impact backpressure more than initially thought.

For this reason, priority was given to silos containing wheat, in attempt to identify the influencing variables by applying a greater depth of data.

The data collected for wheat includes flat bottom silos with trench ducting and with full floor formats, cone bottom silos with perforated tube plenums and shelter-style formats, grain bulk densities ranged from 0.75 to 0.81t/m^3, grain depths from 3.1 to 11.8m and airflow from 0.8 to 8.9l/s/t.

Pressure reading location

Where possible, pressure readings were taken at various locations within the aeration trench or duct. It was determined variations in the pressure at the fan transition compared to anywhere else in the aeration trench or duct were insignificant. As an example, one flat bottom silo with an aeration trench 13m long had a variation in backpressure of just 1.5-2.5% from one end to the other.

System designs with multiple fans per silo

Where silos had multiple fans installed, measurements were taken as each individual fan was turned on and contributing to both airflow and backpressure in the silo.

Anecdotal research determined that while additional fans can be added to a silo, additional airflow is not proportional because backpressure increases with airflow and added backpressure reduces the output of each fan.

In the data shown in appendix 1, test records P1, P2 and P3 illustrate data recorded in the same silo with one fan operating, two fans operating, and four fans operating respectively. By running the second fan, total airflow increased by 1.8 times rather than doubling, due to the second fan increasing backpressure by a factor of 1.2.

Similarly, running four fans did not quadruple total airflow of the single fan, rather, increasing it by a factor of 2.5 due the pressure increase of 1.7 times what it was with the one fan operating.

Grain settling increases bulk density

As field data was being recorded and compared to data from the 2021 bench test rig, backpressures in the field were found to be consistently higher than those measured with the bench test rig. Further investigation attempted to isolate and identify potential reasons for the variation.

An anomaly became apparent when comparing the quantity of grain claimed to be in the silos according to grower records when compared with the calculated quantity based on assumed bulk density and stack dimensions.

Growers volunteered observations noting grain in silos appeared to settle during the storage period, based on the headspace between the top of the grain stack and the silo roof increasing over time.

Outcome and Recommendations

When comparing results from the bench test rig data to field tests, ordered by grain type inducing backpressure from highest to lowest remained consistent with the exception of barley, oats and corn. These grains were measured to have higher backpressure than wheat in field testing. Further comparisons will be analysed and documented in a report summarising the relative findings of all backpressure related development activities.

Check grain settling impact on bulk density and backpressure in test rig

Grower comments relating to grain settling and variations between calculated and grower tonnage records has prompted the need to re-run grain through the bench test rig to establish if grain settling influences bulk density and backpressure. This will be conducted as development activity 2024-4.

Inform and encourage manufacturer development

Discussions are underway with manufacturers where anomalies in backpressure and aeration performance were discovered.

One manufacturer is reviewing duct design after backpressure was measured to be the same with 5.5m depth of red wheat vs 0.7m depth of oats. This is a stark example of an aeration system installed on thousands of silos, but never tested against the intended performance.

Alarmingly, at the time of installation, the manufacturer recommended the grower use cover plates on the aeration fan to restrict airflow as their calculated output was 5l/s/t, which was subsequently tested to in fact only be 1.2l/s/t.

This activity in combination with others, has revealed an industry-wide shortfall of knowledge and testing of aeration system performance and lack of manufacturer accountability. Once all manufacturers have been notified of these findings, there is no excuse for complacency around claimed aeration system performance.

Organisations such as the Kondinin Group could become involved as a means of independently and publicly holding manufacturers accountable and knowing the performance of the aeration equipment they sell to growers.

The onus is now on manufacturers to quantify the impact of the factors influencing the performance of their aeration system.

Factors impacting any aeration system performance have been established through the GRDC extension team’s development activities including:

1. Back pressure of all the commonly stored types of grain at various relevant depths is due for public release in the coming months.
2. Reliable methods for measuring fan performance and airflow of an in-field system are known and not overly difficult or expensive.

The remaining aeration system components impacting the performance of an aeration system are manufacturer specific.

1. Fan performance.
2. Transition between the fan and the silo.
3. Ducting perforation design, surface area and layout within the silo.

Optimum airflow for cooling

Having found many aeration systems deliver less than specified airflow, questions have been raised if the “ideal” airflow rate of 2-4l/s/t is in-fact required, or, if cooling can be achieved with lower airflow rates.

Comparisons of aerated vs non-aerated silos have been performed with confirmation of optimal grain temperatures achieved through aeration cooling. A search for a source of the industry-adopted 2-4l/s/t recommendation and comparisons of cooling performance with varying airflows may be warranted.

It would appear the key metric for the optimal grain cooling efficiency may be total volume of suitable quality air over the storage period. In cool, dry regions this may be achieved efficiently with lower airflow rates over additional hours, compared to warm, humid regions that might require higher airflow rates over fewer hours when ambient conditions are advantageous.

Appendix 1: Table of results from field tested backpressure

Test ID	Grain Type	Grain Depth (m)	Total Airflow (l/s/t)	Backpressure (Pa)	Silo Type	Aeration Type	Grain Quantity (t)	Bulk Density (t/m^3)
L8	Canola	9.5	2.0	1080	Flat bottom	X Trench	792.0	0.69
S2	Canola	11.4	2.6	1520	Flat Bottom	Full Floor	764.0	0.67
R6	Lentils	5.8	0.6	154	Cone Bottom	Shelter Format	123.0	0.85
M5	Lentils	6.2	1.4	538	Cone Bottom	V Channel	95.0	0.83
M6	Lentils	6.2	1.8	846	Cone Bottom	V Channel	95.0	0.83
M7	Lentils	6.2	2.6	1317	Cone Bottom	V Channel	95.0	0.83
M8	Lentils	6.2	2.8	1523	Cone Bottom	V Channel	95.0	0.83
M9	Lentils	6.2	3.2	1977	Cone Bottom	V Channel	95.0	0.83
S4	Sorghum	9.5	2.6	1405	Flat Bottom	Full Floor	848.0	0.73
A1	Wheat	5.3	0.8	54	Cone Bottom	Perforated Tube	156.3	0.77
A2	Wheat	5.3	2.5	266	Cone Bottom	Perforated Tube	156.3	0.77
D1	Wheat (Red)	5.5	1.2	428	Cone Bottom	Shelter Format	68.2	0.75
L2	Wheat	3.1	3.1	440	Flat Bottom	V trench	442.5	0.78
P4	Wheat	8.7	2.2	450	Flat Bottom	Full Floor	700.0	0.79
S6	Wheat	11.8	1.4	540	Flat Bottom	Full Floor	985.2	0.81
L5	Wheat	6.8	3.1	575	Flat bottom	Trench	451.0	0.78
L4	Wheat	8.4	2.4	603	Flat bottom	Trench	546.0	0.78
A3	Wheat	5.3	4.8	625	Cone Bottom	Perforated Tube	156.3	0.77
L6	Wheat	8.8	2.5	690	Flat bottom	Trench	534.0	0.78
L1	Wheat	10.0	1.3	701	Flat Bottom	V trench	1091.3	0.78
L7	Wheat	8.7	2.7	710	Flat bottom	Trench	531.0	0.78
S5	Wheat	11.8	2.0	812	Flat Bottom	Full Floor	985.2	0.81
P5	Wheat	8.7	3.8	880	Flat Bottom	Full Floor	700.0	0.79
S1	Wheat	6.3	3.2	920	Flat Bottom	Full Floor	684.0	0.81
S3	Wheat	9.1	2.5	975	Flat Bottom	Full Floor	815.0	0.81

R4	Wheat	7.3	1.9	1065	Flat Bottom	Parallel trench	906.0	0.76
A4	Wheat	5.3	7.2	1132	Cone Bottom	Perforated Tube	156.3	0.77
R5	Wheat	7.3	3.7	1307	Flat Bottom	Parallel trench	906.0	0.76
A5	Wheat	5.3	8.9	1873	Cone Bottom	Perforated Tube	156.3	0.77
K1	Barley	6.0	6.1	485	Flat Bottom	Full Floor	352.0	0.70
L3	Barley	4.3	2.8	666	Flat Bottom	V trench	492.0	0.62
P1	Barley	12.2	1.0	947	Flat Bottom	Parallel trench	1250.0	0.62
P2	Barley	12.2	1.8	1153	Flat Bottom	Parallel trench	1250.0	0.62
P3	Barley	12.2	2.5	1667	Flat Bottom	Parallel trench	1250.0	0.62
R1	Barley	10.3	1.4	1835	Flat Bottom	Parallel trench	1119.1	0.63
R2	Barley	10.3	2.5	2024	Flat Bottom	Parallel trench	1119.1	0.63
D2	Oats	0.7	16.2	417	Cone Bottom	Shelter Format	6	0.73
R2	Oats	6.2	2.4	1559	Flat Bottom	Parallel trench	668.5	0.47
R3	Oats	6.2	4.5	1668	Flat Bottom	Parallel trench	668.5	0.47
W1	Corn	10.8	2.7	1010	Flat Bottom	Full Floor	1351.0	0.81
W2	Corn	0.5	14.6	1020	Flat Bottom	Full Floor	256.0	0.81
W3	Corn	9.4	3.0	1235	Flat Bottom	Full Floor	1195.0	0.81
M1	Faba Beans	6.0	1.8	215	Cone Bottom	V Channel	90.4	0.83
M2	Faba Beans	6.0	2.8	445	Cone Bottom	V Channel	90.4	0.83
M3	Faba Beans	6.0	3.6	640	Cone Bottom	V Channel	90.4	0.83
M4	Faba Beans	6.0	4.2	815	Cone Bottom	V Channel	90.4	0.83

6.Performance testing aeration fans (DA2023-2&3)

Objectives – (Question or information gap to answer)

The key objective of this development activity is to ascertain the performance of a range of single and three phase aeration fans relative to manufacturer specifications, so can therefore be appropriately matched to grower's storage requirements.

The extension team are not aware of any surreptitious activity or deliberately misleading claims around fan performance, so there is no intention for this independent test to be an exercise in public humiliation. (Manufacturers supplied fans for testing on the basis they would be provided with the performance results of their fans and any brand identifiable results would not be made public)

As a collaborative learning exercise, the team aims to assist and encourage manufactures to continue development to better meet grower requirements. An implied accountability should be motivation enough for manufacturers found to be selling fans with significantly inaccurate performance claims to make changes before a potential retest.

Background

Some fan manufactures have not tested the performance of their fans, relying solely on calculated theoretical output. Other manufacturers test only a selection of their fan range as a way of checking their output calculations are representative. Retailers and silo manufacturers may also sell fans made by another company so rely on the data provided by the original manufacturer.

With an unpoliced industry and many unknowns , the extension team consider it beneficial for growers to purchase fit for purpose equipment.

Adding to the need for clarity around fan performance, is the anecdotal increased rate of growers installing and utilising aeration cooling. This is supported by an increase in information requests to the GRDC grain storage extension team.

Used traditionally for managing mould, pests and grain quality characteristics, aeration is increasingly being used for temporarily holding over-moisture grain and for venting after fumigation. All aeration applications rely on adequate airflow to achieve reliable results and avoid costly losses in degraded grain and rejected deliveries.

Development activity methodology

A range of aeration fans commonly used by growers were sourced from manufactures, except for a couple who after several attempts by extension team members, were not willing to participate.

Most of the fans tested were under 3kW and represent the majority of the market share of models used in cone-bottom silos on-farm. A selection of popular larger aeration fans were also tested but project scope and budget limited these with the hope that the testing initiates motivation for manufactures to do their own testing and development.

Members of the extension team have been involved in independent testing of the German manufactured, Ziehl-Abegg fans in the past and found performance to match manufacturer claims, as such, these were not included for retesting in this activity.

Each fan performance test was undertaken by attaching the fan outlet to the test pipe as seen in Figure 1.

The larger 3kW and 5.5kW fans were tested using larger diameter and length pipe to ensure unrestricted, laminar flow could be measured, see Figure 1A.

Custom-built transitions were made to attach and seal each fan to the test rig to ensure all airflow was captured for accurate measurement. The test pipe provided a level of laminar flow allowing accurate airflow rate measurement using a hotwire anemometer through the wall of the pipe.

Backpressure was then incrementally inflicted on each fan by winding a threaded cone at the opposite end of the test pipe to restrict fan airflow. Backpressure was measured using a pitot tube and differential manometer through the wall of the test pipe.

Both airflow rate in litres per second (L/s) and backpressure in Pascals (Pa) were recorded at each airflow restriction interval. A third order polynomial was then applied to the data points to generate a fan performance curve.

A clamp-style energy meter was used during testing to measure fan power draw in kilowatts (kW), current in amps (A), voltage (V) and a power factor (PF). While this additional information was not included in the aim, the opportunity did provide valuable additional data for little extra work.

Figure 1: Test apparatus used for performance testing small fans.

Figure 1A: Test apparatus used for performance testing larger fans.

Several verification steps were taken before and during testing, to determine the most accurate and repeatable test method and ensure equipment accuracy.

These checks are outlined below:

- The more accurate and repeatable method for determining airflow rate through the test pipe was initially determined. A hotwire anemometer in addition to a pitot tube attached to a differential manometer was used to test the airflow rate. After a series of tests, it was determined that the hotwire anemometer was most repeatable and reliable for this series of tests. The pitot tube was more sensitive to precise alignment within the pipe, which increased the chance of error in measurements.
- The velocity profile appeared consistent across the section of the pipe. A verification test comparing the vertical and horizontal profiles found a 0.95 m/s average when measured vertically and 0.97 m/s average when measured horizontally. As a result, airflow measurement averages on one axis were assumed to be suitable for all tests.
- A selection of differential manometers were tested for backpressure accuracy measurement No discrepancy was found between the various devises and the ‘Alnor’ was selected due to its known reliability.
- An airflow testing pipe (A-flow device) was placed over the fan inlet to replicate fan testing in the field. A 2 to 3% difference was noted between the two measurements (inlet and outlet) across several fans where this method was tested. The inlet flow rate was measured

consistently higher, possibly due to airflow characteristics being more laminar on the inlet than the outlet of the fan.

- A minimum of 6-10 backpressure data points ensured errors or outliers in the data set could easily be identified prior to the generation of the performance curve.

Results

Results below have been grouped by fan motor size.

Manufacturers have been provided with their own fan performance results exclusively.

0.37kW/0.55kW Fans

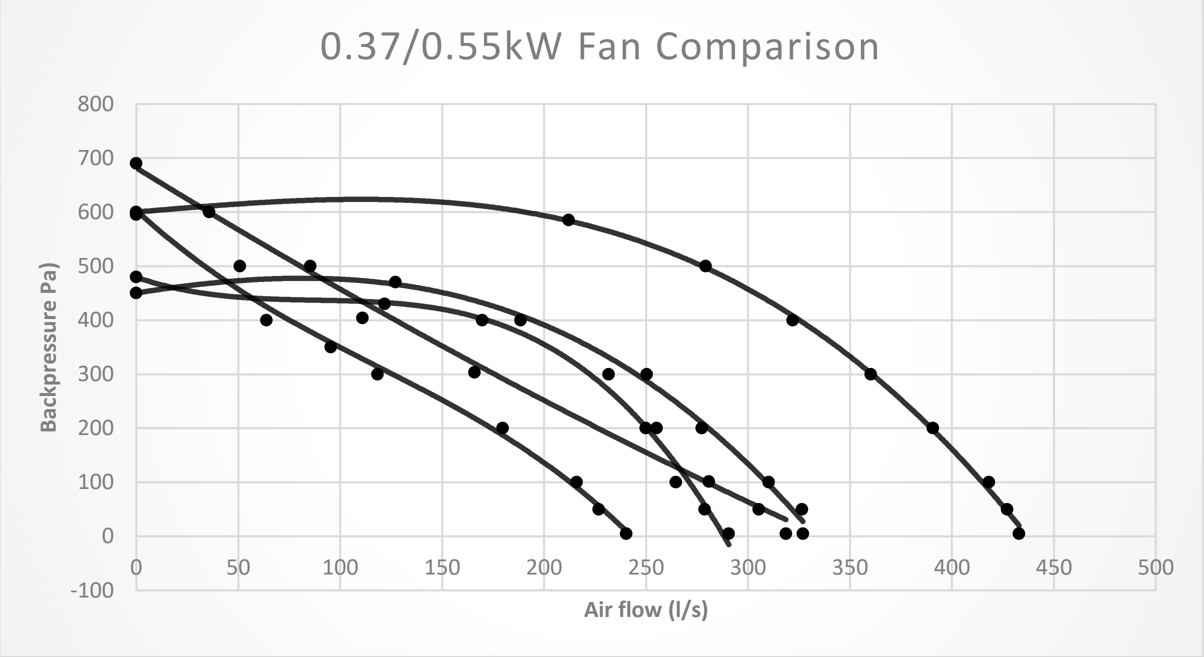


Figure 2: Results of 0.37kW and 0.55kW aeration fan performance from various manufacturers.

1.5kW Fans

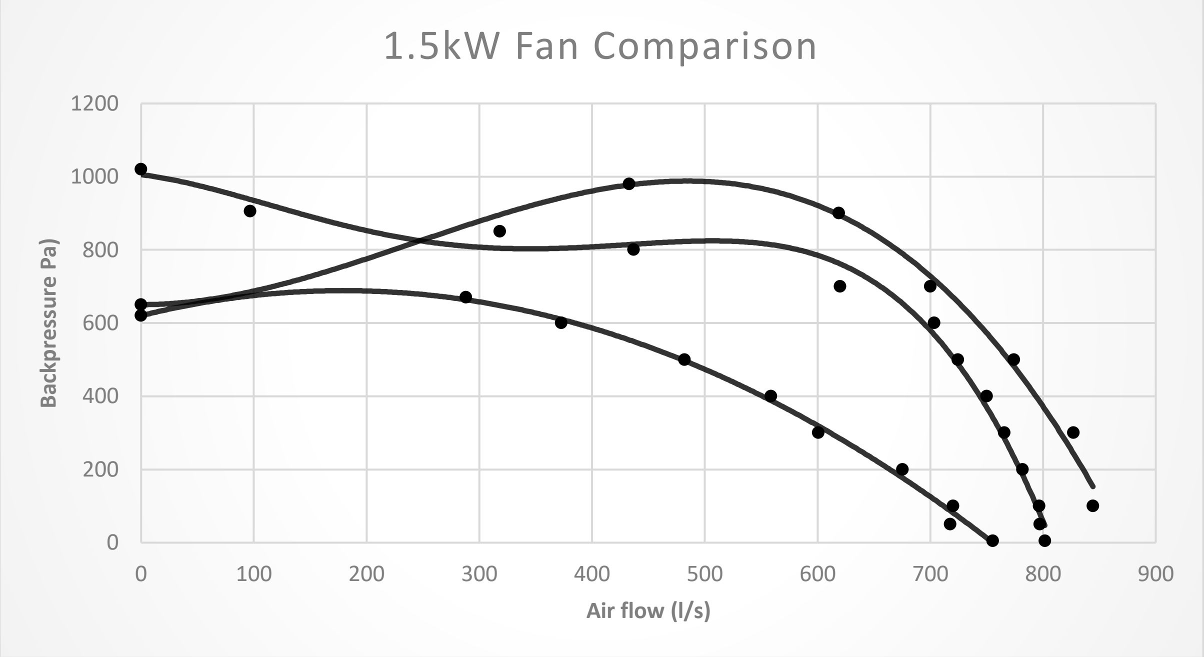


Figure 3: Results of 1.5kW aeration fan performance from various manufacturers.

2.2kW Fans

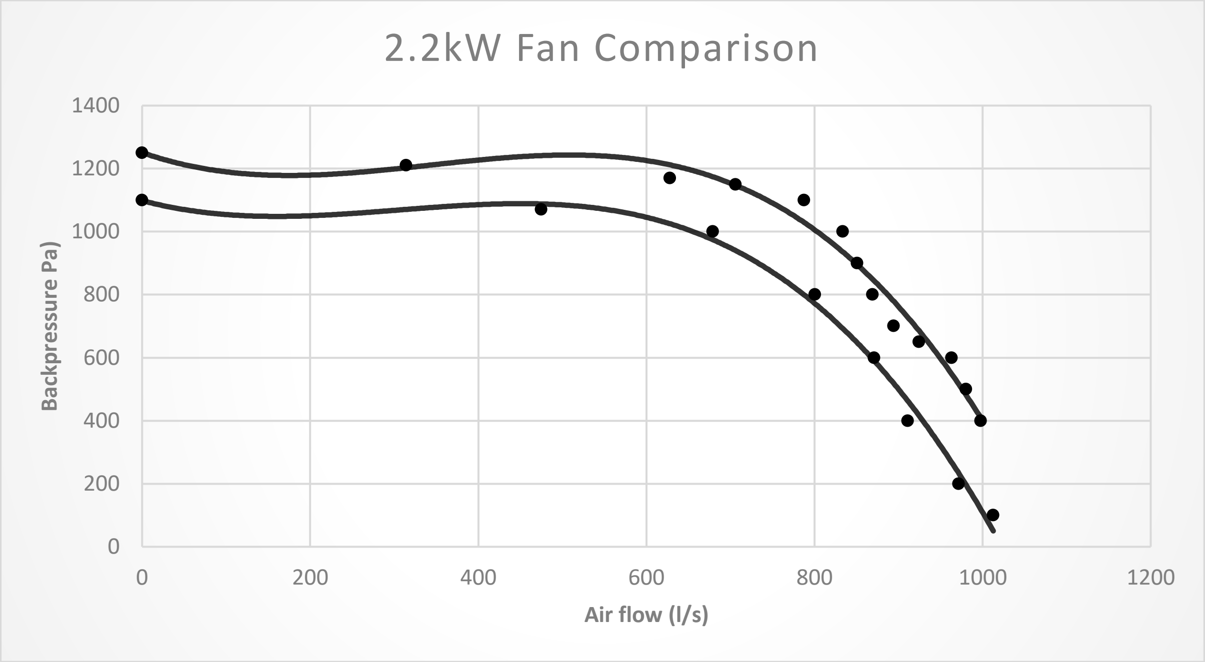


Figure 4: Results of 2.2kW aeration fan performance from various manufacturers.

3kW Fan

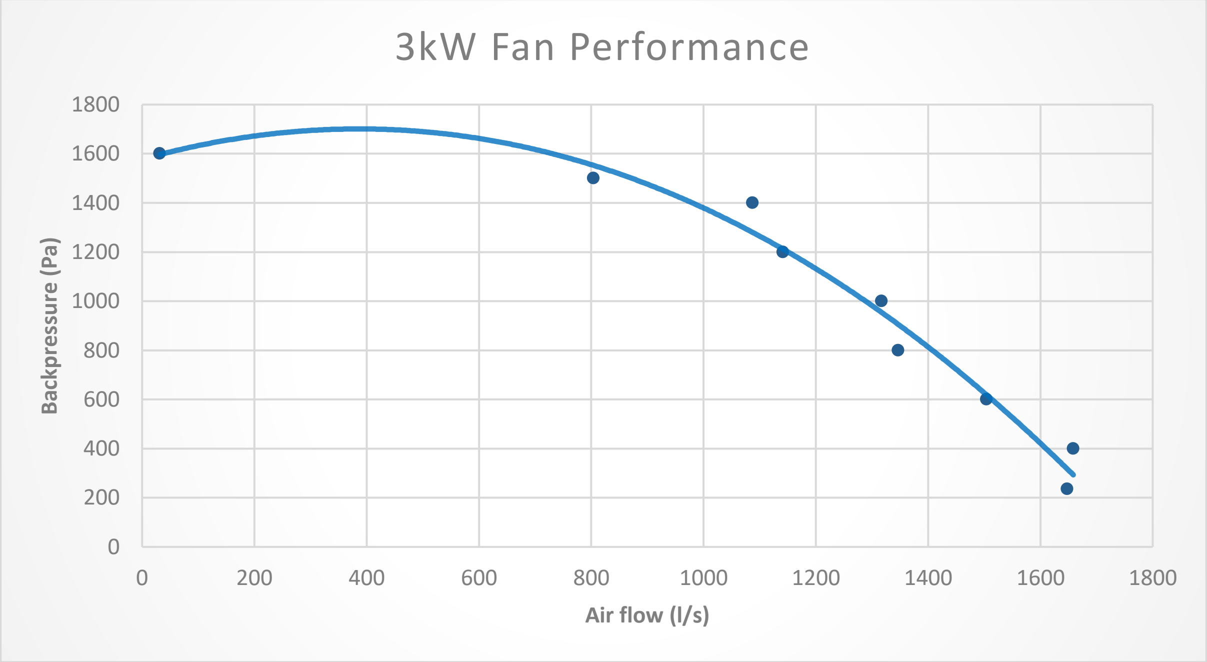


Figure 5: Results of 3kW aeration fan performance.

5.5kW Fan

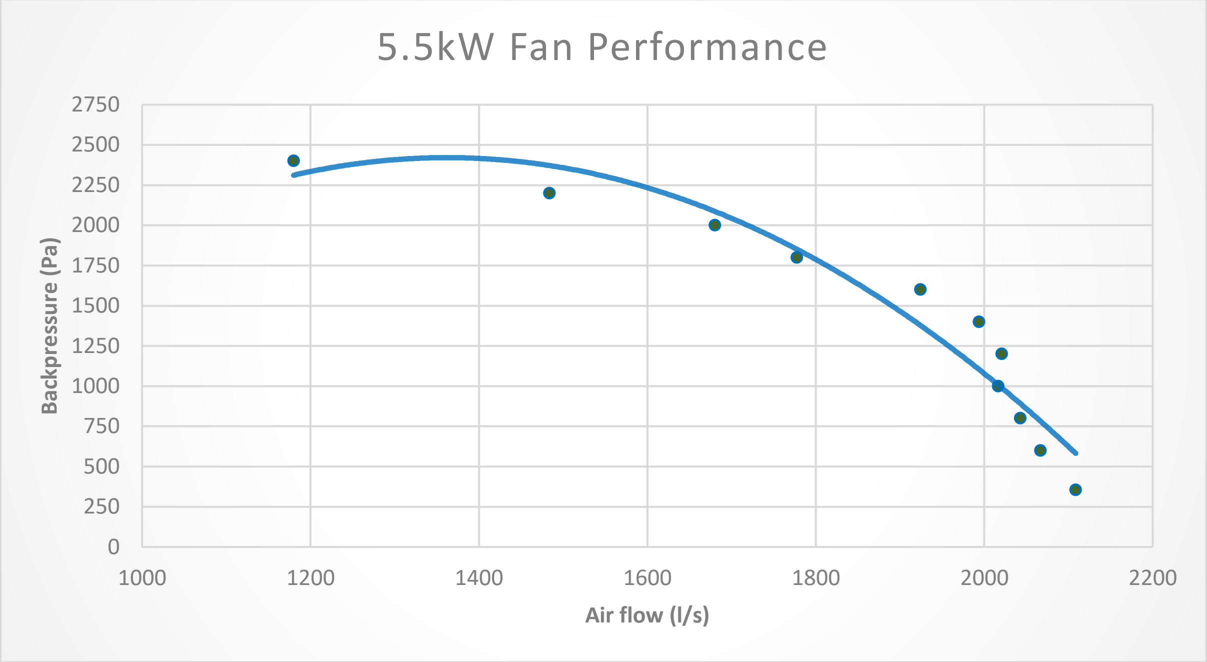


Figure 6: Results of 5.5kW aeration fan performance.

Energy consumption

Continued analysis of energy meter data will ensure a complete understanding and accurate interpretation.

Measurements of current draw in some cases were higher than specified motor ratings and typically occurred in the lower pressure operating range. If this scenario was replicated in practice, fans operating with low levels of backpressure, for example, with large grain types or partly filled silos, could see the fan motor overload and burn out.

Further investigation will continue and communication with manufacturers will be extended to ensure motor burnout and safe operation is not a risk.

7.5kW Fan

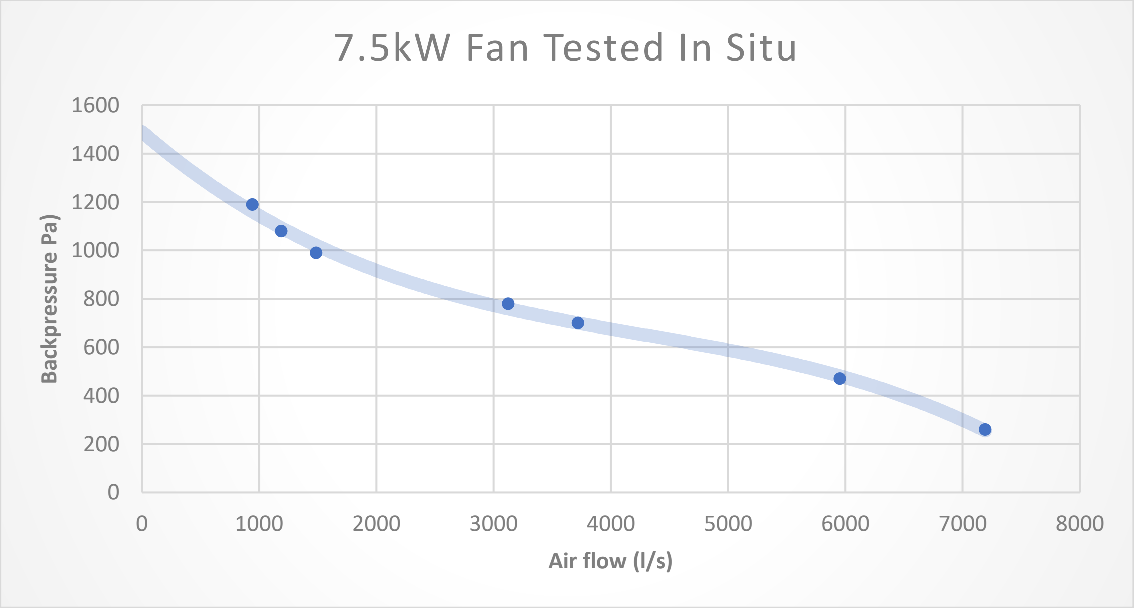


Figure 7: Results of 7.5kW aeration fan performance.

Due to application frequency, the extension team were keen to include test data from an axial flow fan, but due to the large physical size of these fans, workshop testing was not feasible. Alternatively, the team attempted testing a commonly used axial fan in-situ, selecting one that had been tested against the backpressure of a silo filled with canola to be used as a second backpressure reference point.

The test method used for measuring airflow when the silo was full of canola involved building an 800mm diameter pipe to match the fan inlet, 8m in length, (as seen in Figures 8 and 9 below). Airflow was measured with a hotwire anemometer at seven points on a horizontal and vertical cross-section of the tube. Backpressure was measured at the fan transition into the silo using a differential pressure manometer.

Figure 8: Pipe on fan inlet to measure airflow while silo was full of canola.

Figure 9: Hotwire anemometer used to take airflow measurements.

To measure performance of the large axial flow fan at a range of backpressures, the silo was revisited when empty and a makeshift tunnel and method for inducing backpressure was trailed.

Two sections of ducting were removed from the aeration trench inside the silo and replaced with ply-board to create a rectangular tunnel (Figure 10). Backpressure was induced by incrementally blocking the airflow from exiting the aeration duct with bags of concrete and blocks of wood (Figure 11).

Airflow was measured by taking hot-wire anemometer measured air velocity readings at various points in the tunnel cross-section at the mid-point of its length. Backpressure was measured both at the transition into the silo and at the mid-point of the tunnel using a pitot to cross check readings.

Results from this trial are graphed above in Figure 7.

Figure 10: In-situ testing performance of the axial flow fan using the aeration trench coved with ply-board to create a tunnel to measure airflow.

Figure 11: Bags of concrete and blocks of wood used to induce backpressure in the aeration trench of the axial flow fan.

It is acknowledged that the in-field method applied for testing fan performance via the aeration duct may have introduced some additional variables. But there is confidence in the airflow measured with the more reliable and accepted method using the 8m pipe on the fan inlet when the silo was full. This approach yielded similar airflow results at the same back pressure.

Outcome and Recommendations

This testing revealed that not all fans are created equal and motor size by itself is not an accurate indication of performance. Some fans handle pressure variation better than others and the results will greatly assist the extension team's work on understanding the backpressure of different grains at varying depths.

Early indications suggest optimising aeration delivery may require the fitment of multiple fans on a silo, running each fan according to the type and depth of grain being stored at the time. These findings may also spur further the development and application of variable speed brushless DC motors for aeration fans such as those found on the Ziehl-Abegg range.

Upon completion of the performance testing, manufacturers have been provided with their fan performance curves for review and comparison to any existing data they may have had. Differences between manufacturer specified performance and these test results were found.

Conversations with manufacturers will continue, encouraging them to test and better understand the performance of the fans they offer, ensuring they are appropriately matched to aeration systems and meet growers needs. A lack of change in either fan design or claimed performance by manufacturers could warrant repeat testing and consumer alerts relating to manufacturers knowingly making inaccurate claims about fan performance.

This development activity raised doubt regarding the credibility of manufacturers refusing to supply fans for testing. Equally for those who were unable to or chose not to supply fan performance information. Continued refusal to participate with the extension team or overstating fan performance in light of this test data may result in pressure from industry to comply and potentially issue a consumer alert.

As good practice, the GRDC grain storage extension team encourages growers to question manufacturer claims on all products related to grain storage. Fan performance can now be added to the list to check. Particularly given there is no excuse for manufacturers not to have access to independent testing and a method they could replicate for further inhouse testing and development.

To their credit, some manufacturers embraced the opportunity to participate and learn how to performance test fans, acknowledging limitations in their existing fan performance information.

Work will continue to improve knowledge of energy consumption and potential for electric motor current draw where backpressure is insufficient to operate within a safe operating range of a given fan.

7. Airflow Distribution in Grain Silos (DA2023-5)

Objectives

To identify how aeration airflow interacts within a grain stack, specifically looking at the velocity and distribution characteristics as it exits the grain mass. Airflow distribution characteristics were measured using the German-made Ambros Schmelzer analogue Air-Flow meter for measuring total airflow through a stack of grain.

Background

Previously completed development activities have placed considerable focus on understanding the airflow through a silo, and how varying grain backpressures will impact aeration performance.

A requirement for additional knowledge around air movement through the grain mass was required.

In exploring this issue, a German-built Air-Flow meter by Ambros Schmelzer (Figure 1) was identified as an option for measuring air flow exiting the grain stack surface.

This device has been designed specifically for measuring airflow rate through grains and seed. There are two different sized cones available for the Schmelzer meter: the Blue cone having a diameter of 302mm and the Red cone having a diameter of 502mm. The larger diameter cone allows the device to be more precise at lower airflows.

Figure 1: Schmelzer airflow meter in use.

Development activity methodology

Several sites were identified offering a variety of airflow characteristics, grain depths and grain surface conditions.

It was assumed grain depth across the stack surface had the greatest influence on the air pathway when moving through the grain.

Therefore, a variety of grain surface level conditions, typically found in storages were identified to allow the flow characteristics to be quantified:

- Convex peak
- Concave peak
- Intermediate peak (several loads removed).

These grain surface level conditions allowed the influence of height to be quantified as the deepest point was either at the centre (convex), edge (concave), or midpoint (intermediate peak) of the silo. To isolate the variable of aeration duct type, each of the tests were conducted in silos with full-floor style ducting, assuming that style would provide the best chance of uniform airflow through the grain stack.

Testing was undertaken using the Schmelzer meter where either a 302mm or 502mm cone was used. This began at the wall of the silo, moving the Schmelzer in towards the centre one cone width at a time, then repeating the process from centre to wall, perpendicular from the original path.

Data collected from the Schmelzer meter is in meters per hour (m/h) which can then be used to calculate a volumetric flow rate (m^3/hr) given the surface area of each cone is known. However, for the purpose of this experiment the data will be analysed as a percentage variance from the average (mean) flow rate measured across the surface of the grain stack being measured.

Data for the airflow entering the silo from the aeration fans was also collected to compare the Schmelzer's airflow measuring accuracy (see figure 2). This was done using a hotwire anemometer and a 400mm diameter x 4m long pipe connected to the fan inlet to achieve laminar flow.

Readings were then taken with the hotwire anemometer 1.8m from the fan inlet with a total of 10 readings taken across the cross-section, (5 vertical and 5 horizontal). The average of these readings allowed for the calculation of airflow into the silo.

Figure 2: Airflow measurements were taken at the fan inlet to evaluate the accuracy of the Schmelzer meter to measure total airflow through the silo.

Results

Convex peak

Grain Type	In Flow [m/s]	Grain Volume [m^3]	Total Tonnage [t]	Aeration Duct Type	Fan	Number of Fans
Barley	15.96	503.3	352.28	Full Floor	Grain Guard 5HP	1

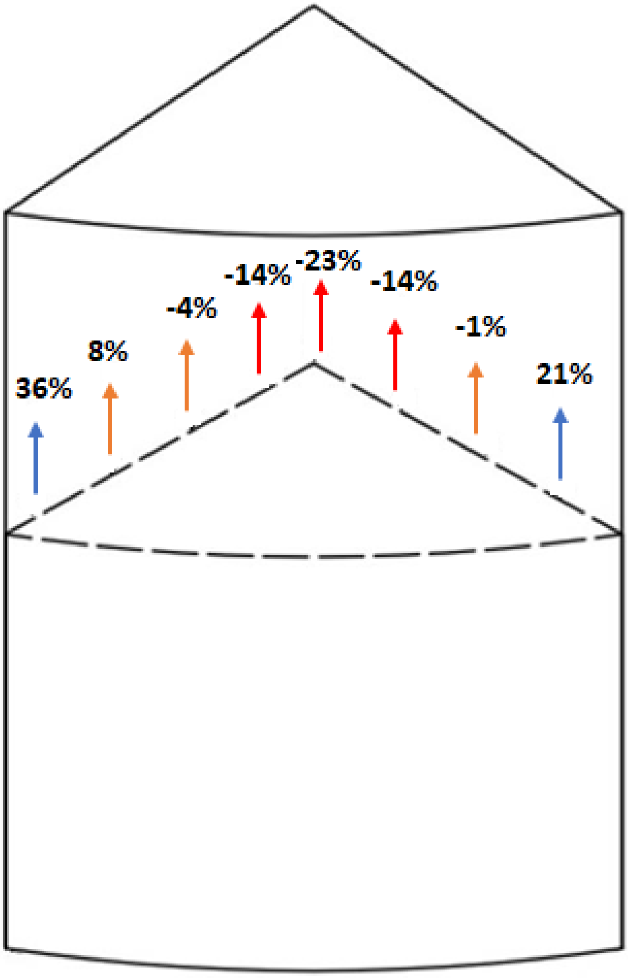


Figure 3: The percentage variance from the average airflow rate measured through the grain stack in a convex peak surface condition.

For a silo with a convex grain pile, the central peak has the least airflow, revealing the zone of lowest aeration flow to be at the deepest point of the grain stack. This observation was consistently found in multiple silos, indicating a high-risk zone for insect reproduction and mould development.

Airflow at the centre of the silo where the grain depth is highest was measured to be 23% less than the average airflow through the grain surface, while the measurement taken near the edge of the stack at the shallowest grain depth had 36% more airflow.

The two data points nearest to the silo walls have a greater airflow rate increase compared to the cumulative increase across the rest of the silo. This indicates that the shallowest 1/3rd near the silo wall receives considerably more airflow than the deepest 2/3rds.

Concave peak

Grain Type	In Flow [m/s]	Grain Volume [m^3]	Total Tonnage [t]	Aeration Duct Type	Fan	Number of Fans
Wheat	17.58	840.6	672.48	Full Floor	Grain Guard 10HP	1

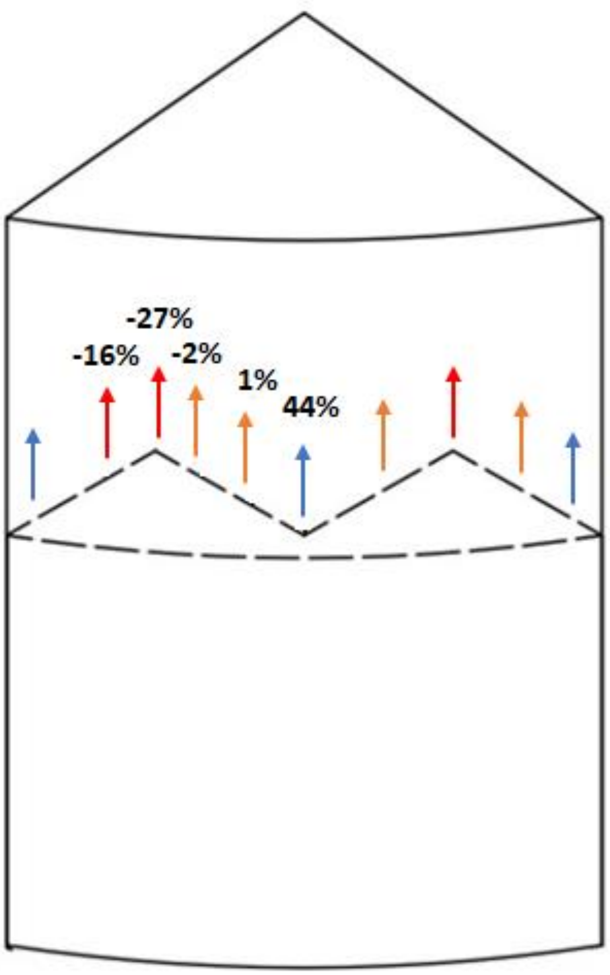


Figure 4: The percentage variance from the average airflow rate measured through the grain stack in a concave peak surface condition.

In a silo with a concave grain pile, the same trend was noted where the deepest level of grain receives the lowest airflow rate.

In this scenario the grain near the wall of the silo received an airflow rate 38% less than the average airflow through the grain stack, while the flow rate at the centre where grain depth was shallowest, had 82% more airflow.

These findings highlight the same uneven distribution of airflow that is dependent on the grain surface depth, but appears on a greater scale than the Convex peak.

Intermediate peak (several loads removed).

Grain Type	In Flow [m/s]	Grain Volume [m^3]	Total Tonnage [t]	Aeration Duct Type	Fan	Number of Fans
Wheat	15.9	1002.1	801.7	Full Floor	Grain Guard 10HP	1

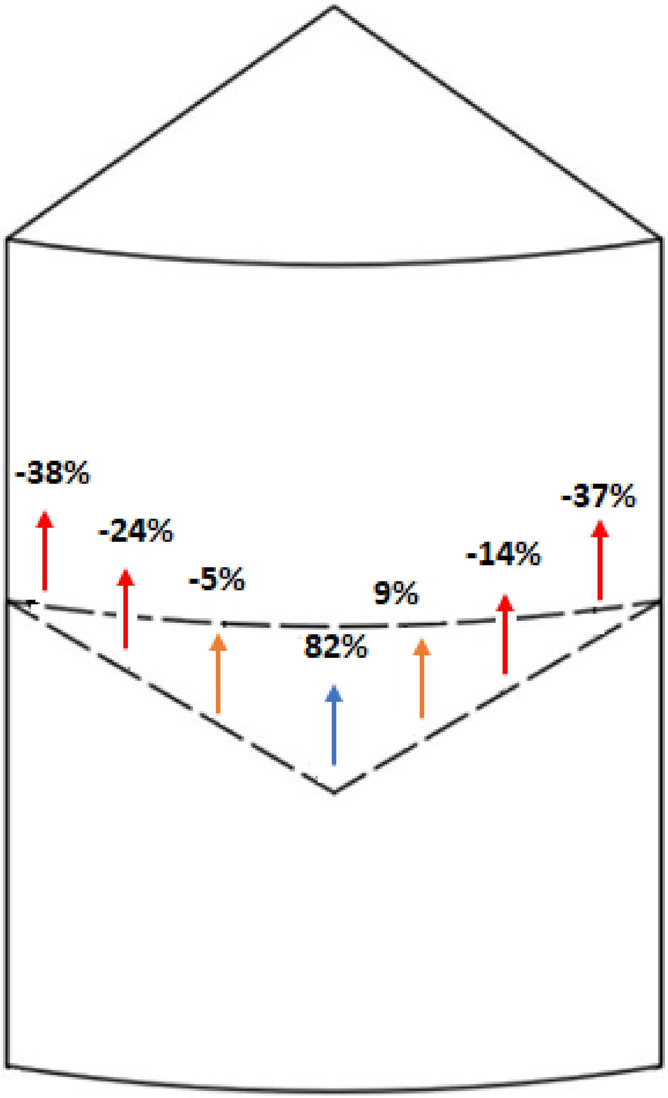


Figure 5: The percentage variance from the average airflow rate measured through the grain stack in an intermediate peak surface condition.

The deepest point of the grain stack exhibited an airflow rate 27% less than the average airflow through the surface of the grain stack. However, the centre of the silo received 44% more airflow than the average, reiterating the tendency for air to preference the path of least resistance at the shallowest grain depth. Unfortunately, there was insufficient space to get the Schmelzer meter close to the silo wall, but it is assumed a similar flow rate to the centre would be observed in this zone as they were similar depths.

Outcome and Recommendations

From the three distinct tests conducted to assess airflow through a range of grain level conditions, it was found that air follows the path of least resistance. Consequently, the shallowest grain depth exhibits the most substantial airflow, while the deepest grain depth experience diminished airflow.

The grain stack that indicated the least amount of variance from the average airflow rate (a range of 59%) was the convex peak. This characteristic can be attributed to a large surface area at the shallowest grain depth.

Alternatively, the grain surface condition that indicated the most variation from the average airflow (a range of 120%) was the concave peak. It is assumed this can be attributed to the very small surface area at the shallowest grain depth, meaning a higher volume of air is trying to travel through this location.

Ambros Schmelzer use

The Ambros Schmelzer yielded results in meters per hour (m/h) serving as the basis for calculating the total airflow exiting the grain storage system in litres per second (L/s). These computed values were compared with the hotwire anemometer airflow readings upon entry into the silo, as detailed in Table 1.

The inlet pipe and hotwire anemometer reading is an industry-accepted standard for airflow measurement that was used to assess the accuracy of the Schmelzer meter to ascertain total airflow through the grain stack. The analysis revealed that the variation of the Schmelzer measurements exceeded 60% in every test, with a peak difference of 84%.

Potential causes for variation with the Schmelzer include; reliance on being perfectly vertical during testing, an analogue scale with the markings 100mm apart, and potentially an added restriction for airflow having to be pressurised through the funnel to gain sufficient velocity to achieve a reading. The first two of these potential inaccuracies could be eliminated by replacing the analogue measuring device with a hotwire anemometer but the added airflow restriction would still exist.

Grain Formation	HotWire Anemometer total airflow [L/s]	Schmelzer meter total airflow [L/s]	Variation [%]
Convex	2004	3694	84
Concave	2209	3943	78
Intermediate	1998	3278	64

Table 1: Schmelzer Error

The Ambros Schmelzer meter proves valuable when it comes to comparing values within its own dataset, as it aids in uncovering flow characteristics and identifying airflow distribution in stored grain. However, it is an inaccurate method for measuring total airflow through a storage.

This testing successfully analysed the airflow distribution of various grain surface depths that assisted with identifying zones at a higher risk to temperature increases susceptible to mould and insect activity. This will prove invaluable information for various other tests the Grain Storage Extension Team will perform in the future.

8. Grain settling impact on aeration (2024-4)

Objectives

The goal of this development activity was to determine the extent to which settling levels/consolidation vary across different grain types. This involved quantifying how the resulting changes in bulk density influence grain backpressure and, consequently, affect aeration performance.

Background

During field testing aeration backpressure DA 2022-4, it was discovered that a significant amount of settling/consolidation could occur when grain is loaded into a silo. This could influence the aeration backpressure results from DA 2021-4 and required further investigation. Some preliminary tests using wheat in a 1m column of grain confirmed that settling influenced the backpressure induced on an aeration system. It was decided that the backpressure for loose-filled and consolidated grain conditions should be tested for each grain type to establish a minimum and maximum range for aeration backpressure.

Development activity methodology

Initial testing revealed that there were different methods that could be used to cause the grain in the test column to settle, consolidate and pack. It was identified that repeatedly striking the grain column with a mallet as it was being filled achieved peak bulk density results.

Once the optimum consolidation method had been defined, the extent of consolidation in a 1m column of grain was compared with that in a 4m test column of grain and was found to be identical. The increase in back pressures as a result of consolidating grain was also found to be consistent in 1m, up to 4m depth.

To improve testing efficiency, the 1m column was used to test aeration backpressure through packed grain.

Each grain type used in the test was sized as seed size variations are observed due to varietal and seasonal influences.

Grain Type	Seed size range (mm)
Corn	7 - 9mm
Field peas	3.75 - 3.97mm
Canola	1 - 1.8mm
Chick pea	3.75 - 3.97mm
Barley	2.5 - 3mm
Faba beans	2.2 - 2.5mm
Wheat	2.2 - 2.5mm
Soy beans	5 - 6mm
Lentil	N/A
Sorghum	2.2 - 2.5mm

Table 1: Seed size for each grain type used in consolidation tests.

An analysis of aeration through loosely filled grain saw a 1m column of grain filled from an elevation of 4m (to match previous testing).

Aeration was then introduced to the column of grain through perforated ducting at the base and backpressure measured at a range of airflow increments from 1l/s/t to 20l/s/t.

After airflow and backpressure measurements were recorded, the column was weighed to calculate a loose filled bulk density.

This process was then repeated for the consolidated grain condition, with the column of grain repeatedly tapped while loading to ensure peak consolidation was achieved.

Aeration backpressure and bulk density calculations were then performed at the same range of airflow increments from 1l/s/t to 20l/s/t.

Results

Results indicate the process of consolidation saw the bulk density of each grain increase by 7 – 11 per cent depending on grain type (see Table 2).

Consolidation is thought to have led to a more tightly packed grain sample with reduced interstitial air space, thereby restricting air flow through the stack.

Resulting backpressure increases were observed in each grain type although this varied from 13% to 59% higher than backpressure observed in the loosely filled condition.

Grain Type	Loose Filled Bulk Density (kg/m3)	Consolidated Bulk Density (kg/m3)	Bulk density increase from loose fill to consolidated	Difference in aeration backpressure between loose filled and consolidated
Corn	812.13	871.49	7%	12.8%
Field peas	850.96	912.54	7%	15.5%
Canola	639.05	690.64	8%	17.2%
Chick pea	813.24	869.27	7%	20.2%
Barley	675.11	737.80	9%	24.9%
Faba beans	806.58	855.40	6%	30.3%
Wheat	798.82	875.37	10%	40.4%
Soybeans	736.13	805.47	9%	40.9%
Lentil	830.44	919.19	11%	48.6%
Sorghum	797.71	882.03	11%	59.2%

Table 2: Results summary table.

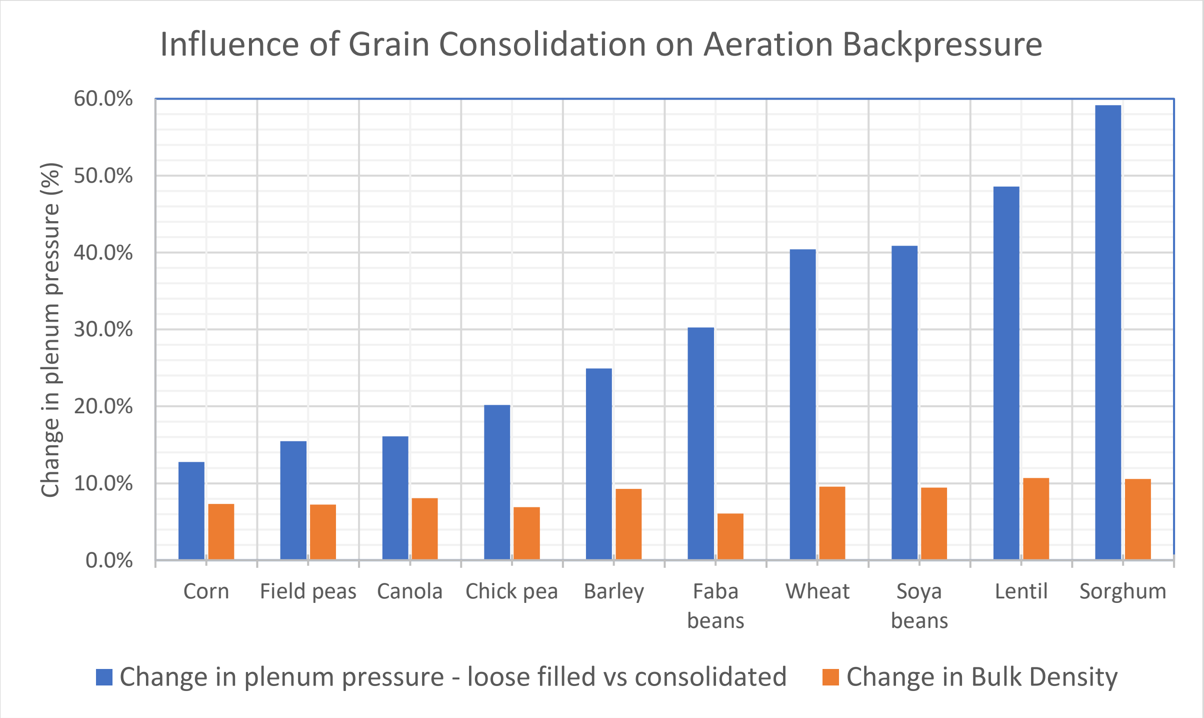


Figure 1: Comparison of the varying backpressure induced by different grain types

Outcome and Recommendations

The outcomes suggest loosely filled backpressure results from previous research should be adjusted to account for the significant influence of grain consolidation.

Subsequent testing has revealed that the consolidated backpressure results are much more representative of the backpressure observed in the field.

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