LOCKHART & TEMORA
NSW
TUESDAY 2 & WEDNESDAY 3
AUGUST 2022

GRAINS RESEARCH UPDATE

DRIVING PROFIT THROUGH RESEARCH

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GRDC 2022 Grains Research Update Welcome

Welcome to the first of our northern GRDC Grains Research Updates for 2022.

For the last two years, we've had to alter plans to host these updates virtually but thanks to the easing of COVID-19 pandemic restrictions, we're finally able to have everyone back to listen to our research, development and extension (RD&E) updates in person.

The northern region has had its fair share of challenges this year. While seasonal conditions have improved and provided reprieve for growers, advisers, agronomists and researchers, parts of New South Wales and Queensland have had to battle the implications of excessive rainfall and wet conditions.

Untimely rain has forced many growers to alter their operations and look at how they can do things differently to work with the wet conditions. Despite the difficulties, feedback from growers has still been optimistic with most supporting the notion of there being more money in mud than dust.

With that positive mindset comes a need to provide the latest information and advice from grains research and development. There's also been a significant push from the industry to make more informed management decisions to ensure productivity isn't impacted by the increasing costs of inputs.

We would like to take this opportunity to thank our many research partners who have gone above and beyond normal expectation this season to extend the significant outcomes their work has achieved to growers and advisers.

For more than a quarter of a century the GRDC has been driving grains research capability and capacity with the understanding that high quality, effective RD&E is vital to the continued viability of the industry.

Sharing the results from this research is a key role of the annual GRDC Updates, which bring together some of Australia's leading grains research scientists and expert consultants. We trust they will help guide your on-farm decisions this season and into the future.

To ensure this research answers the most pressing profitability and productivity questions from the paddock, it is critical the GRDC is engaged with and listening to growers, agronomists and advisers. To this end, GRDC has established the National Grower Network Forums and I encourage you to look out for these forum opportunities in your local area.

GRDC has also placed significant importance on having staff in the regions – whether it be travelling to events like this or being based in our regional offices across the country, including Toowoomba and Wagga Wagga.

We feel more connected to the industry than ever when we are out in the regions and encourage you all to take any opportunity to engage with us to help inform our important RD&E portfolio.

If you have concerns, questions or feedback please contact our team directly (details on the back of these proceedings) or email northern@grdc.com.au.

Regards,
Gillian Meppem
Senior Regional Manager – North

LOCKHART
GRDC Grains Research Update
Tuesday 2 August 2022

Lockhart Memorial Hall, 69-71 Green St, Lockhart

Registration: 8:30am for a 9am start, finish 3:05pm

AGENDA

Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	
9:15 AM	**Extracting more profit from farming systems -** crop sequencing, nitrogen management and early sowing	John Kirkegaard (CSIRO) & Mathew Dunn (NSW DPI)
9:55 AM	**Ameliorating sodic subsoils -** grower experience	Peter Allen (grower, Temora) & Ehsan Tavakkoli (NSW DPI) Paper page 20
10:40 AM	**MORNING TEA**	
11:10 AM	**Maximising the efficiency of lime application -** stratification, pH drivers and measurement, environment and management strategy, lime rates and incorporation	Jason Condon (CSU) Paper page 32
11:55 AM	**Capitalising on great seasons -** key levers and their interactions and managing seasonal risk. Varieties, N & fungicide lessons learnt from the hyper yielding project	Rohan Brill (Brill Ag) Paper page 38
12:35 PM	**LUNCH**	
1:25 PM	**Why legume manures?** Manure crops in continuous crop systems for farming system versatility and reducing production cost and risk	Peter McInerney (3D AG) Paper page 47
2:00 PM	**Carbon sequestration options for grain producers in NSW -** pros, cons & pitfalls	Warwick Badgery (NSW DPI) Paper page 55
2:35 PM	**Panel session** ○ Farming systems issues - pulses in the system; crop sequences; nutrition ○ Manure crops ○ Soil carbon ○ Soil amelioration	Heidi Gooden (Delta Agribusiness) & speakers
3:05 PM	**CLOSE**	

TEMORA
GRDC Grains Research Update
Wednesday 3 August 2022

Temora Ex-Services Club, 130 Baker St, Temora

Registration: 8:30am for a 9am start, finish 1:10pm

Followed by trial site inspections hosted by FarmLink Research at the
Temora Agricultural Innovation Centre (361 Trungley Hall Road), concluding at 4:20pm

AGENDA

Time	Topic	Speaker(s)
9:00 AM	**GRDC welcome**	
9:15 AM	**Carbon sequestration options for grain producers in NSW -** pros, cons & pitfalls	Warwick Badgery (NSW DPI) Paper page 55
9:50 AM	**Maximising the efficiency of lime application -** stratification, pH drivers and measurement, environment and management strategy, lime rates and incorporation	Jason Condon (CSU) Paper page 32
10:20 AM	**Why legume manures?** Manure crops in continuous crop systems for farming system versatility and reducing production cost and risk	Peter McInerney (3D AG) Paper page 47
10:50 AM	**MORNING TEA**	
11:20 AM	**Biological N banking options with summer sown hard seeded legumes and contribution to grain production in crop/pasture systems in SNSW**	Belinda Hackney (NSW DPI) & Richard Rice (JH Rice & Co) Paper page 61
12:00 PM	**Extracting more profit from farming systems -** crop sequencing, nitrogen management and early sowing	John Kirkegaard (CSIRO) & Mathew Dunn (NSW DPI)
12:40 PM	**Farming systems discussion: key issues for grower commercialisation**	Tim Condon (Delta Agribusiness)
1:10 PM	**LUNCH**	
2:20 PM	**Trial site inspections** hosted by FarmLink Research at the Temora Agricultural Innovation Centre (361 Trungley Hall Road)	
4:20 PM	**CLOSE & REFRESHMENTS**	

Contents

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Extracting more profit from farming systems - crop sequencing, nitrogen management and early sowing.

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Notes

Ameliorating sodic subsoils - grower experience

Peter Allen

Notes

Amelioration of hostile subsoils via incorporation of organic and inorganic amendments and subsequent changes in soil properties, crop water use and improved yield, in a medium rainfall zone of south-eastern Australia

Shihab Uddin[1], Wayne Pitt[1], David Armstrong[1], Shane Hildebrand[1], Naveed Aslam[1], Graeme Poile[1], Albert Oates[1], Yunying Fang[2], Roger Armstrong[4], Danial Newton[1], Yan Jia[1], Graeme Sandral[1], Adam Lowrie[1], Richard Lowrie[1], and Ehsan Tavakkoli[1, 3]

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Key words

dispersive alkaline subsoils**,** amendments, soil pH, exchangeable sodium percentage, root growth, grain yield

GRDC code

DAV00149

Take home messages

- Deep placement of organic and inorganic amendments increased grain yield in the order of 20 to 50% for five successive years on an alkaline dispersive subsoil at Rand
- Deep placement of organic and inorganic amendments increased root growth and crop water use from the deeper clay layers during the critical reproductive stages of crop development
- Improvements in grain yield with deep placement of organic and inorganic amendments were associated with a reduction in subsoil pH and improvement in soil aggregation.

Background

Sodicity, salinity and acidity are significant surface and subsoil constraints that reduce crop productivity throughout the cropping regions of Australia (Sale *et al.,* 2021). The majority of cropping soils contain at minimum one, but more multiple constraints (McDonald *et al.*, 2013). The economic impact to Australian agriculture, expressed by the 'yield gap' between actual and potential yield, attributable to subsoil constraints was estimated to be more than A$1.3 billion annually by Rengasamy (2002), and as much A$2.8 billion by Hajkowicz and Young (2005). Of the 'three', sodicity is thought to be the most detrimental to productivity, resulting in the greatest yield gap. In Australian wheat-cropping regions alone, this 'gap' was estimated to be worth A$1.3 billion per annum in lost income (Orton *et al.,* 2018), while close to 20% of Australia's land area is thought to be sodic.

Sodic soils, which are characterised by an excess of sodium (Na^+) ions and classified as those with an exchangeable sodium percentage (ESP) greater than 6% (Northcote and Skene, 1972), are often poorly structured, have a high clay content, high bulk density, and are dispersive. These factors result in poor subsoil structure that can impede drainage, promote waterlogging (low water infiltration), and increase de-nitrification (nutrient imbalance), and soil strength (Orton *et al.*, 2018). These properties also impede the infiltration of water into and within the soil, reduce water and nutrient storage capacity, and ultimately the plant available water (PAW) content of the soil. Subsequently, root growth and rooting depth are impeded, as is crop ability to access and extract deeper stored water and nutrients (Passioura and Angus, 2010). This is particularly problematic in environments characterised by a dry spring, where the reproductive phase often coincides with periods of water stress, and when the conversion of water to grain has the greatest effect both on yield (Kirkegaard *et al.,* 2007), and the likelihood and magnitude of a yield gap (Adcock *et al.,* 2007).

In southern NSW, winter crops commonly have sufficient water supply during their early growth stages either from stored soil water or rainfall. However, the reproductive phase is often affected by water stress or terminal drought and this is thought to be the major cause of variable grain yield (Farooq *et al.*, 2014). The effect of water stress in the reproductive phase is further impacted by shallow root depth induced by subsoil sodicity. Under such conditions, a key to improving crop productivity is to improve root growth in and through sodic subsoils to enable use of deep subsoil water later in the growing season. Water use at this late stage has a 2 to 3 fold greater conversion efficiency into grain yield (Kirkegaard *et al.,* 2007) than seasonal average based conversions efficiencies (e.g. 20 – 25 kg/mm verses 50 – 60 kg/mm).

While there are large advantages to be gained by improving the soil environment of sodic subsoils, the various amelioration approaches (deep ripping, subsoil manuring, applying gypsum, improved nutrition and use of 'primer-crops') have produced variable results (Adcock *et al.,* 2007; Gill *et al.,* 2008). Furthermore, the use of subsoil organic material is also impacted by limited local availability, the high cost of suitable organic ameliorants delivered in-paddock, the sometimes large quantities required, the lack of suitable commercial-scale machinery and the poor predictability of when and where the amelioration will benefit crop productivity (Gill *et al.,* 2008; Sale *et al.*, 2019).

Gypsum application has been the most widespread traditional approach used to correct subsoil sodicity. However, problems have included; surface application when the problem is evident in the subsoil, the large quantities of gypsum required to displace significant amounts of sodium and the somewhat low solubility of gypsum.

This paper reports on the performance of a barley-wheat-canola-wheat rotation on a Sodosol (Isbell, 2002) soil two sites in Rand and Grogan in southern New South Wales in the five (Rand) and four (Grogan) years immediately following incorporation of a range of amendments, and the residual effects of 'subsoil manuring' on crop performance, soil physical properties, and access to PAW stored in the soil profile over subsequent seasons. A range of treatments comprising deep-ripping and subsoil incorporation of organic and inorganic amendments at a depth of 20–40cm were compared to, and contrasted with, surface applications, ripping-only and untreated controls. Amendments that could be easily procured or produced as part of a farming system were used in the trial. It is hypothesised that subsoil incorporation of organic or inorganic amendments will provide significant improvements in grain yield, which are associated with changes in the physical properties of the subsoil that result in improved root growth, and access to, and use of, deep soil water.

Method

Rand amendment site

The trial sites were located at Rand and Grogan in southern New South Wales in paddocks that had been under a continuous cropping (cereal-canola) for more than 50 years. The soil at both sites was a Sodosol with a texture-contrast profile increasing in clay content at depth, and with physical and chemical properties (Table 1.) unfavourable for root growth, including a high bulk density and low hydraulic conductivity.

Table 1. Chemical and physical properties of the soils at different depths at the Rand trial site

Depth (cm)	pH (H_20)	EC (1:5) (µS/cm)	Nitrate N (mg/kg)	Exchangeable cations (cmol/kg)	Exchangeable sodium percentage (%)	Bulk density (g/cm^3)	Volumetric water content (θv)
0–10	6.6	132.1	20.6	16.1	3.8	1.40	0.120
10–20	7.8	104.0	5.8	22.6	7.3	1.52	0.163
20–40	9.0	201.5	4.1	26.7	12.5	1.50	0.196
40–50	9.4	300.5	3.0	27.5	18.1	1.48	0.232
50–60	9.5	401.3	3.0	28.8	21.8	1.53	0.237
60–100	9.4	645.0	2.9	29.7	26.4	1.55	0.218

The trials were established in February 2017 (Rand) and March 2018 (Grogan) as a randomised complete block with a range of treatments (Table 2) and four replicates. Experimental plots were arranged in two blocks (ranges) of 26 plots, separated by a 36m cropped buffer. Individual plots within each block were 2.5m wide (south-north) × 20m long (east-west), separated on their long sides by 2m buffers of uncultivated ground. Plots were ripped to a depth of 40cm, and amendments incorporated into the soil via a custom built 3-D ripping machine (NSW DPI), comprising a 'Jack' GM77-04 5-tyne ripper (Grizzly Engineering Pty Ltd, Swan Hill, VIC, Australia), configured to 500mm tyne spacings, and topped with a custom designed frame supporting two purpose built discharge hoppers (bins) and a 300L liquid cartage tank. The larger, ~1.6 cubic meter-capacity hopper was designed to deliver organic materials and can accommodate approximately 1000 kg of material, roughly equivalent to a standard 'spout top, spout bottom' bulk bag. The organic amendments were obtained in pellet form for ease of application and consisted of dried pea straw pellets (1.13% N, 0.05% P, 1.34% K; extrusion diam. 7–10mm, length 6–35mm), wheat stubble pellets (0.34% N, 0.15% P, 1.59% K; diam. 7–10mm, length 6–35mm), and dried poultry manure pellets marketed as Dynamic Lifter® (3% N, 2% P, 1.7% K; diam. 7–10mm, length 6–35mm). The amendments were applied three months prior to sowing the first season.

In 2017, experimental plots were sown to Barley (cv. LaTrobe⦶) on the 11th of May at a seeding rate of 70 kg/ha (target plant density 100 plants/m^2). Monoammonium phosphate (MAP) was applied at 80 kg/ha as a starter fertiliser at sowing. The crop was sown after spraying with Boxer Gold® (800 g/L prosulfocarb + 120 g/L S-metolachlor), Spray.Seed® (135 g/L paraquat dichloride + 115 g/L diquat dibromide) and Treflan™ (480 g/L trifluralin). The crop was harvested on the 21st of November.

In 2018, wheat (cv. Lancer⦶) was sown on the 15th of May at a seeding rate of 80 kg/ha (target plant density 150 plants/m^2). MAP was applied at 80 kg/ha as a starter fertiliser at the time of sowing. The crop was sown after spraying with Spray.Seed, Sakura® (850 g/kg pyroxasulfone), Logran® (750 g/kg triasulfuron) and Treflan. Urea (46% N) at 110 kg/ha (50.6 kg/ha N) was applied at 106 DAS. The crop was harvested on the 6th of December.

In 2019, Canola (Pioneer® 45Y92CL) was sown on the 10th of April at a seeding rate of 4.4kg/ha (target plant density 40 plants/m^2). MAP was applied at 90 kg/ha (9 kg/ha N, 19.8 kg/ha P) as a starter fertiliser at the time of sowing. The crop was sown after spraying with Roundup® (360 g/L glyphosate, present as the isopropylamine salt in a tank mix with Kamba® 750 (750 g/L dicamba). Urea at 220 kg/ha (101.2 kg/ha N) was applied as a top-dressing at 119 DAS, and Prosaro® (210 g/L prothioconazole + 210 g/L tebuconazole) at 50% bloom as a preventative for Sclerotinia stem rot (132 DAS). The crop was harvested on the 30th of October.

In 2020, wheat (cv. Scepter) was sown on the 16th of May at a seeding rate of 63 kg/ha (target plant density of 120 plants/m^2). Diammonium phosphate (DAP) was applied at 78 kg/ha as a starter fertiliser at the time of sowing. The crop was sown after spraying with Spray.Seed, Roundup, Sakura and Treflan. Urea at 150 kg/ha (69 kg/ha N) was applied as a top-dressing 7 DAS prior to rain. The crop was harvested on the 7th of December.

The long-term average annual rainfall at the site is 553mm with a reasonably uniform average monthly rainfall. In 2017, in-season rainfall (April-November) totalled 329mm, while 244mm and 242mm, respectively, were recorded for the same period in 2018 and 2019. Rainfall in both 2018 and 2019 was approximately 25% less than that recorded for 2017, and approximately 65% of the long-term average seasonal rainfall. The long-term average monthly rainfall, and average monthly maximum and minimum temperatures, daily (bars) rainfall events and monthly rainfall at the Rand experimental site for the period 2017–2021 (Figure 1).

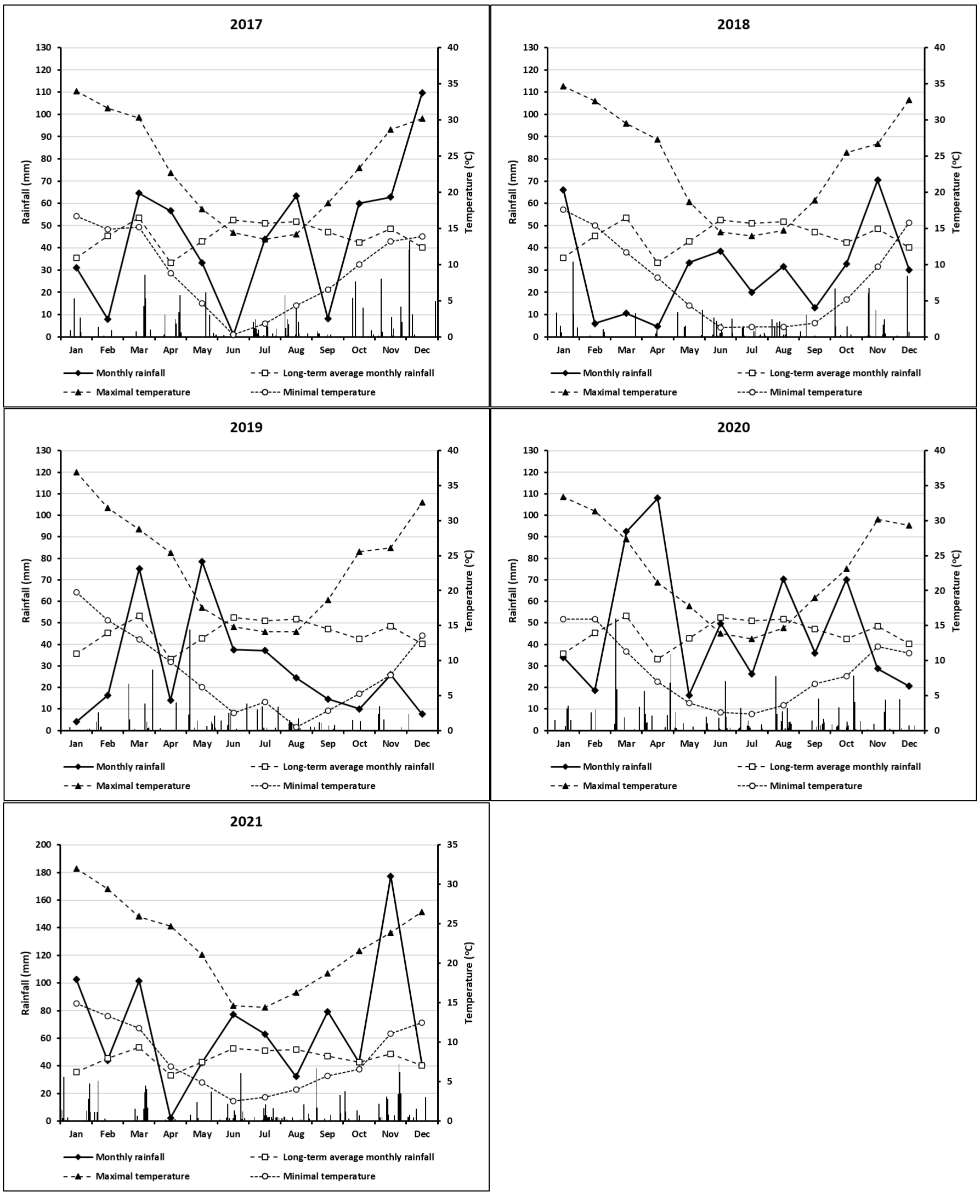

Figure 1. Long-term average monthly rainfall, and average monthly maximum and minimum temperatures, daily (bars) rainfall events and monthly rainfall at the Rand experimental site located at Urangeline East, NSW.

Table 2. Description of the treatments and organic and inorganic amendments used in the trial.

Treatment	Description	Amount of amendment added
1	Control	Direct sowing
2	Deep gypsum	5 t/ha, incorporated to depth of 20-40 cm
3	Deep liquid NPK	Incorporated to depth of 20-40 cm, the amount of NPK added was matched to NPK content of chicken manure
4	Deep chicken manure	8 t/ha, incorporated to depth of 20-40 cm
5	Deep pea straw	15 t/ha, incorporated to depth of 20-40 cm
6	Deep pea straw +gypsum+NPK	12 t/ha, 2.5 t/ha, incorporated to depth of 20-40 cm,
7	Deep pea straw+NPK	15 t/ha, incorporated to depth of 20-40 cm
8	Deep wheat stubble	15 t/ha, incorporated to depth of 20-40 cm
9	Deep wheat stubble +NPK	15 t/ha, incorporated to depth of 20-40 cm
10	Ripping only	To depth of 40cm
11	Surface gypsum	5 t/ha, applied at soil surface
12	Surface chicken manure	8 t/ha, applied at soil surface
13	Surface pea straw	15 t/ha, applied at soil surface

At late flowering soil coring was completed using a tractor-mounted hydraulic soil-coring rig and 45 mm diameter soil cores. The break core method was used to estimate rooting depth and exposed roots were recorded at the following depths 0 - 10, 10 - 20, 20 - 40, 40 - 60, and 60 – 100 cm. Quadrat samples of 2m^2 were taken at physiological maturity to measure plant biomass and grain yield.

Grogan subsoil amelioration experiment

In 2018 an experiment was conducted near the township of Grogan in southern NSW, which included 27 amendments in a row column design with four replicates. The soil profile was slightly acidic in the top 10cm (pH$_{1:5\ water}$ 5.9) and pH dramatically increases with depth (Table 3). The changes in soil sodicity (exchangeable sodium percentage, ESP) followed a similar trend of soil pH with exchangeable sodium percentage (ESP) at 10.5% in the topsoil and increasing up to 40% in the subsoil (Table 3).

Table 3. Site characterisation for the Grogan experimental site. Values are means (n=5).

Soil depths (cm)	EC (µs/cm)	pH (1:5 water)	Colwell-P (µg/g)	CEC (cmol($^+$)/kg)	Exchangeable sodium percentage
0-10	309.40	5.87	58.80	16.66	10.53
10-20	133.00	7.65	7.40	22.06	11.97
20-30	136.90	8.76	2.62	24.53	15.94
30-40	207.66	9.12	2.50	25.55	20.12
40-60	338.94	9.60	1.34	27.17	26.27
60-80	530.40	9.53	1.00	31.63	36.68
80-100	897.20	9.43	1.48	34.07	40.25
100-120	1148.20	9.38	1.50	35.28	40.35

The agronomic management of the trial was similar to Rand site as outlined above. However, the effect of several additional treatments including elemental sulphur, and lucerne hay was investigated.

Results

Rand and Grogan amendment trial

The one-off application of various amendments (Table 2) significantly affected the crop grain yield over 5 consecutive years at the Rand site. For example, in 2021, canola grain yield (relative to control) increased following the deep placement of wheat stubble, wheat stubble + nutrient and manure by 15-12% ($P < 0.001$) (Figure 2). At the Grogan site, canola grain yield (relative to control) increased following the deep placement of manure, lucerne hay and gypsum + pea hay+ nutrient by 45, 42 and 39% respectively ($P < 0.001$) (Figure 2). The variations in yield in response to surface application of amendments or ripping only was not significantly different from the control at both sites.

At the Rand site, a multi-year cumulative analysis of grain yield response (2017-2021) indicated that deep placement of plant-based stubble, gypsum and their combination resulted in significant and consistent improvements in crop yield (Table 4). A preliminary cumulative gross return is also presented in Table 4.

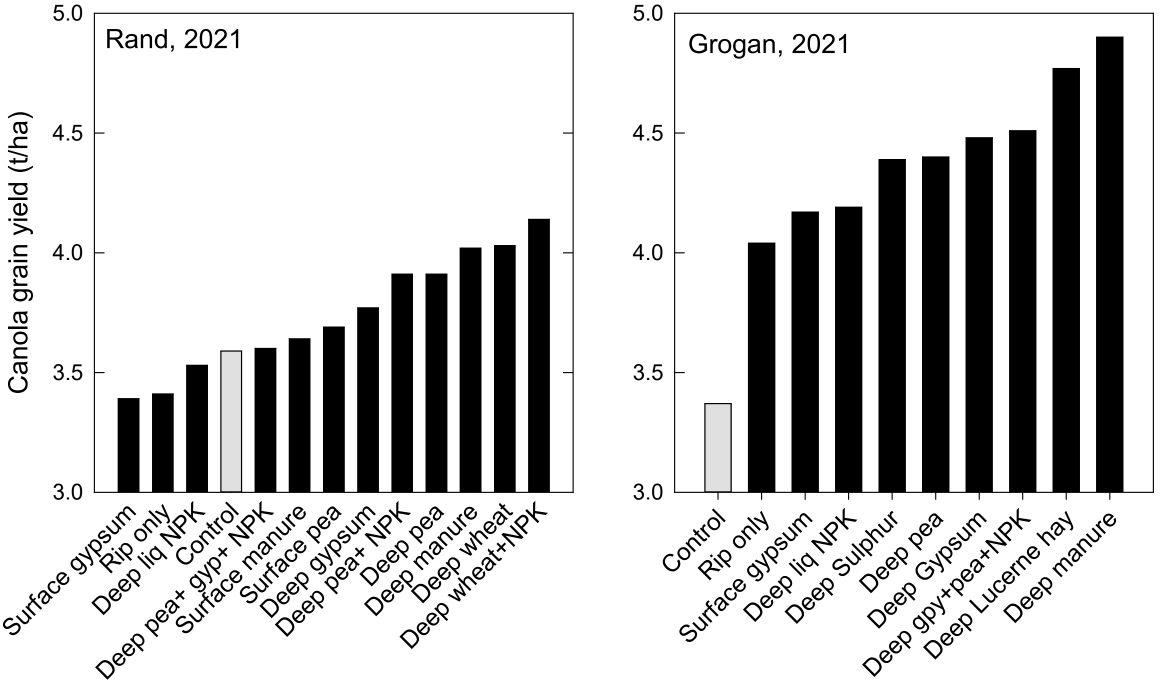

Figure 2. The mean effect of surface or deep-placed amendments on grain yield of canola (cv. Dimond⦶) grown in an alkaline dispersive subsoil at Rand (left) and Grogan (right), SNSW in 2021. Values are mean (n=4). $LSD_{0.05}$ = 0.28 (left) and 0.78 (right).

Table 4. Cumulative grain yield (2017-2020) and cumulative gross return ($) for barley (2017; $220/t), wheat (2018; $250/t), canola (2019; $600/t) and wheat (2020; $250/t), canola (2021; $800/t) at Rand.

Treatment	Yield (t/ha)		$	
Rip only	19.3	a	7465	a
Control	19.3	a	7497	a
Surface gypsum	19.1	ab	7550	ab
Deep liq NPK	20.6	ab	7671	ab
Surface pea	19.7	bc	7769	ab
Surface manure	20.6	bc	7981	bc
Deep pea+gyp+NPK	23.0	cd	8577	cd
Deep wheat	22.3	cd	8614	cd
Deep pea	22.7	cd	8635	d
Deep manure	22.3	d	8645	cd
Deep pea+NPK	22.3	d	8682	d
Deep wheat+NPK	22.6	d	8698	d
Deep gypsum	22.7	d	8700	d

*Results with the same letter after them are not significantly different P < 0.05

Over the course of this study several key measurements of soil and crop parameters were made to investigate the impact of various amendments on soil: plant interactions. Selected data from the Rand trial is reported below.

The number of visible roots in the amended subsoil layer (20 – 40cm depth) were significantly ($P < 0.05$) affected by different amendments (Figure 3). Deep placement of both manure and pea hay increased the number of visible roots by more than 3-fold. Neutron probe readings taken in September also indicate that the highest root counts were associated with the driest soil water profile (Figure 4). Variation in soil pH measured at the amended layer is shown in Table 5. Compared to the control, deep placement of gypsum reduced the soil pH by 0.86 units (8.99 to 8.13) at 20 – 40cm depth. However, pH was not affected by other treatments.

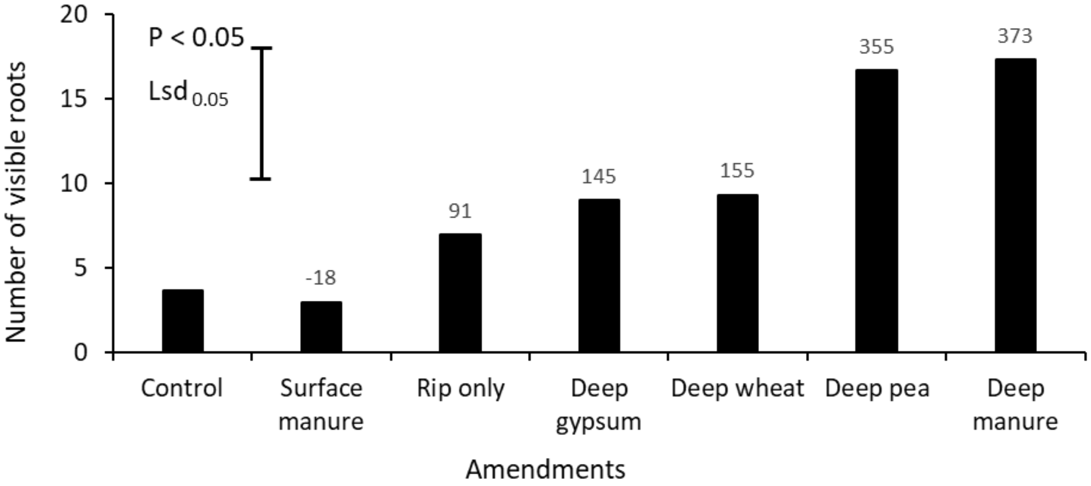

Figure 3. The mean effect of surface or deep-placed amendments on the number of visible roots at 30cm at late flowering of canola (cv. Pioneer 45Y91CL) grown in alkaline dispersive subsoil at Rand, SNSW in 2019. Values on the top of each bar represents the percent change of visible roots compared to control.

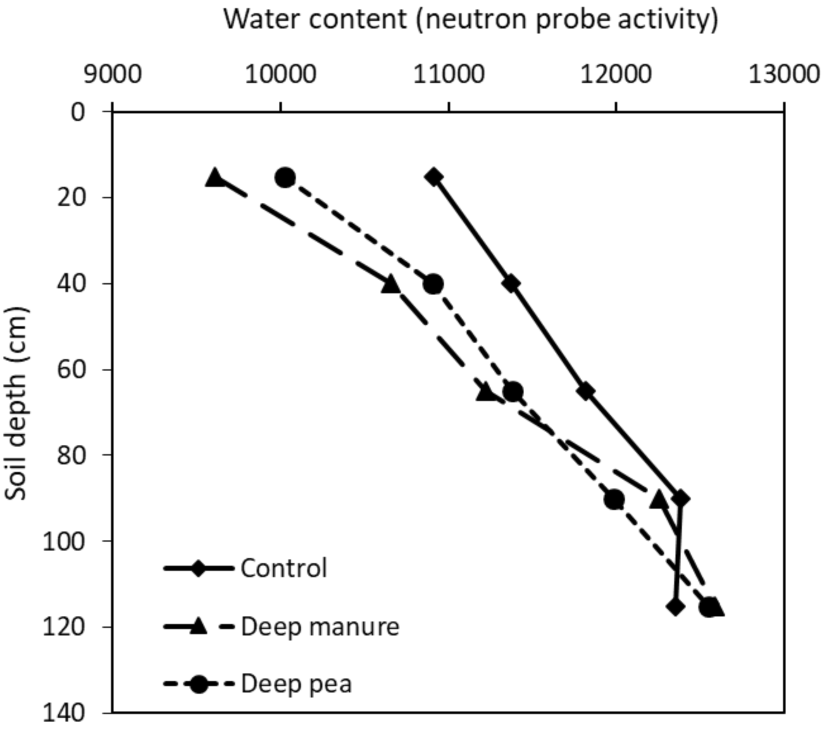

Figure 4. Neutron probe readings taken in September at the Rand amendment site for contrasting treatment comparisons. Results are based on the neutron activity (raw data) where higher values represent higher water content in the soil profile. Values are averages (n = 4).

Table 5. Mean soil pH (20-40 cm) in selected treatments at the Rand site. Samples were collected in May 2020. $LSD_{0.05}$ = 0.27.

Amendment	Predicted mean	Significant difference group
Control	8.99	a
Deep liq NPK	8.96	a
Rip only	8.94	a
Deep wheat+NPK	8.93	ab
Surface gypsum	8.92	ab
Deep pea	8.87	ab
Deep wheat	8.83	ab
Deep manure	8.60	bc
Deep pea+gyp+NPK	8.52	c
Deep gypsum	8.13	d

Discussion

In Alkaline dispersive soils, several properties of subsoils including, high pH, high levels of soluble carbonate species, poorly structured dense clay, and dispersion together with overall poor chemical fertility, represent a hostile environment for crop roots. Here we demonstrate the impact of various amendments on these properties and the potential to re-engineer these hostile subsoils for improved crop performance.

Barley, wheat, canola, wheat and canola were grown in 2017–2021, respectively. Growing season rainfall (April to November total) was average in 2017 (decile 5), and declined in 2018 (decile 1.5), with still drier conditions in 2019 (decile 1.0), when only 45 mm of rain (decile 0) fell during the spring months from September to November. This improved in 2020 and 2021 where the Rand trial received > 401 mm during growing the season. The amendments that consistently resulted in significant yield increases above the control, were the deep-placed combination of pea straw pellets, gypsum and liquid fertilizer nutrients, and the deep-placed gypsum and deep placed pea straw (Table 4). Improvements in subsoil structure were measured in the winter of 2019. The deep crop residue amendments significantly increased macro aggregation, as measured on the rip-line at a depth of 20-40 cm. Similarly, deep gypsum and the deep gypsum/pea straw/nutrient combination markedly increased water infiltration into the soil profile, with higher saturated hydraulic conductivities measured on the rip-line. Our results to date indicate that independent modes of action of various amendments (e.g., crop residue vs gypsum) are required in the amendment mix, in order to ameliorate these subsoils. For example, adding gypsum reduced pH in the amended subsoil to below 8.5 (Table 5). This indicates that significant changes in soil pH can occur with realistic application rates of gypsum in subsoil. Given high alkalinity also increases negative charges on the surfaces of clay particles (Rengasamy *et al.,* 2016), which increases clay dispersion, a reduction in pH following gypsum application also resulted in significant improvement (reduction) in soil dispersion (Tavakkoli *et al.*, 2015). In alkaline sodic soils, high ESP and high pH are always linked together and it is difficult to apportion their effects on the resulting poor soil physicochemical conditions and consequently on crop growth.

The addition of pea straw and nutrients provides substrate for enhanced biological activity resulting in increased macro aggregation and improved subsoil structure. When combined together, organic and inorganic amendments may result in additive effects to improve soil physical and chemical properties (Fang *et al.,* 2020a; Fang *et al.,* 2020b).

In a year of intensive drought like 2019, the grain yield improvements at Rand may be attributed to the additional root growth in the amended subsoil layer (Figure 3), which facilitated the use of extra subsoil water (Tavakkoli *et al.,* 2019 and Figure 4). Under dryland conditions, water captured by roots in the subsoil layer is extremely valuable as its availability coincides with the grain filling period and has a very high conversion efficiency into grain yield (Kirkegaard *et al.,* 2007; Wasson *et al.,* 2012). A major focus of this current research is to understand the amelioration processes of the subsoil application of organic and inorganic amendments. A tentative, but promising, finding from our field and controlled environment trials, is that farm grown products like wheat and pea stubbles when mixed with nutrients improve soil aggregation, root growth, water extraction and grain yield and these treatments are comparable to animal manures and gypsum. If confirmed, this means that grain growers have a potentially large supply of relatively inexpensive organic ameliorants already available in their paddocks, which will increase the application options and viability of correcting subsoil sodicity.

Conclusions

The findings from the current field studies demonstrate promising results of ameliorating alkaline dispersive subsoils in medium rainfall zones of southern NSW. Deep placement of organic and inorganic amendments resulted in significant yield improvement in successive years at Rand and Grogan. This yield improvement was facilitated by a reduction in soil pH and ESP% and increased microbial activity that can lead to improved soil aggregation. Furthermore, deep placement of organic and inorganic amendments increased root growth, which in turn increased soil water use from the deeper clay layers during the critical reproductive stages of crop development, thereby increasing grain yield.

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Soil acidity - its stratification and amelioration with lime

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Key words

acidity, lime, soil pH, stratification, acidification

Take home message

- Historic liming practices are ineffective in addressing the acidification of current farming systems
- Liming to pH targets greater than pH 5.5 and reliming when pH drops back to pH 5.5 maximises the downward movement of the liming effect to address subsurface acidity
- Deep incorporation to a depth of 20 cm was effective in ameliorating soil acidity to a depth of 15 cm
- Sufficient lime needs to be applied to ameliorate acidity within the depth of incorporation to warrant the risks and costs of deep incorporation.

Introduction

Soil acidity is an acknowledged constraint of agricultural production in south-east Australia. To date, research over the last 30-40 years has provided sound knowledge regarding processes associated with soil acidity. This has resulted in lime being applied by growers looking to maintain soil health, sustain productivity and maximise crop and pasture options available to them. However, ‘rules of thumb’ relating to the triggers to initiate liming, the rates of lime applied, and the frequency of applications are grounded to farming practices, production levels, and land and commodity prices of the 1990s.

Using these rules of thumb under current farming practices of no-till farming, high productivity per hectare (including from dual purpose crops), often driven by substantial applications of urea and ammonium-based fertilisers, have been shown to be ineffective in removing acidity from the soil and preventing soil pH decline in the subsurface layers. Figure 1 represents the soil pH profile of the surface 20 cm of an agricultural soil managed using traditional practices of lime application (2.5 t/ha every 8-10 years) compared to an adjacent site that had never been farmed. The lime application has failed to address the acidity formed below the 0-7 cm surface layer.

Stratification

Processes that change soil pH do not occur uniformly within agricultural soil profiles. They occur within different layers of the soil, often only several centimetres thick and as such, result in stratified soil pH profiles having higher pH in the surface few centimetres, due to lime application and return of crop residues, and relatively lower soil pH in the 5-15 cm region due to nitrogen transformations and acid excretion by plants due to nutrient uptake (Figure 1). These lower pH layers are called acidic subsurface layers and have been shown to have significant impacts on plant and soil biological function. This is especially important considering the depth of seed and fertiliser placement when sowing crops and pastures. We are often placing seeds within layers of soil with chemical conditions that are hostile to seedling germination and development of young roots.

Though important, the presence of acidic subsurface layers is often not identified by land managers/advisors due to the standard practice of soil sampling in 10 cm depth intervals. Standard 0-10 cm samples mask the presence of the severe acidity that can be present because the soil layer containing the very low pH is mixed in the sample; the 0-10 cm sample provides an average of the soil pH in that layer. For soils common to south-eastern Australia, it has been shown that sampling in 5 cm depth increments to a depth of 20 cm is an effective method to identify both the location and magnitude of acidity within the surface 20 cm of soil profiles (Condon et al. 2020).

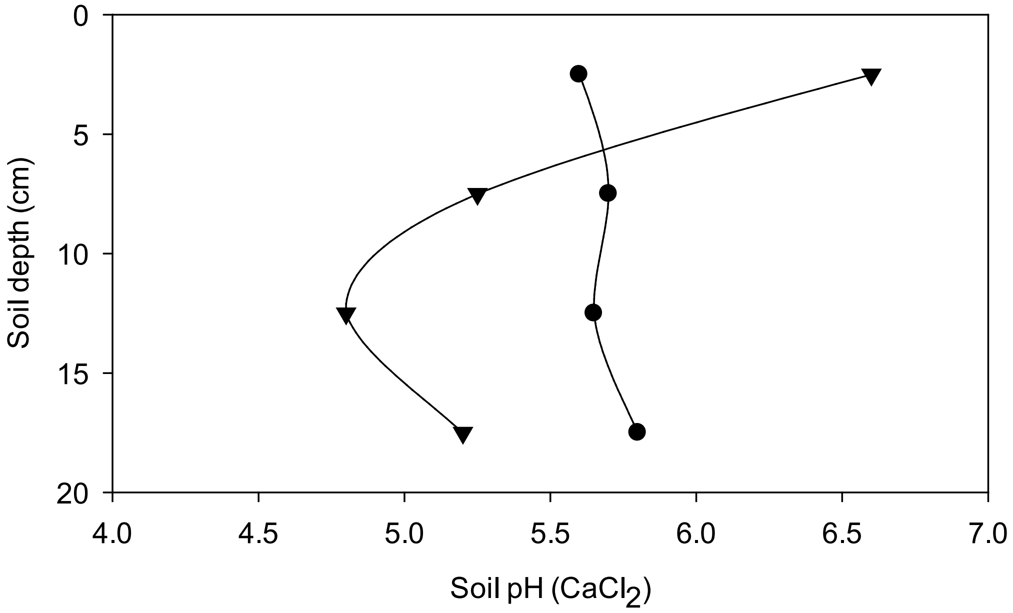

Figure 1. Soil pH_{Ca} profiles taken from the field 40 m apart on the same soil type. Soil pH stratification following approximately 90 years of agriculture (▼) including three applications of lime using traditional practices (2.5 t/ha), compared to under native grass with no agricultural productivity (cemetery, ●), north of Canowindra, NSW.

Amelioration

The lime use recommendations of the 1990s have been found inadequate in modern agriculture, which is more productive, has N fertiliser inputs and is based on no-till cropping systems that do not mix lime and soil together. The consequence of these changes is the formation of acidic subsurface layers, even where there has been a history of lime application (Figure 2) that are not detected by 0-10 cm soil sampling. The pH stratified profiles shown in Figure 2, have 0-10 cm soil test values of pH 4.6 and 5.3, yet both have layers of greater acidity than reported in the soil test. It is worth noting that the latter may result in a grower reporting no response to lime as the soil test value (0-10 cm) indicates lime has been effective, yet the acidic subsurface layer remains to limit plant performance. It is recommended that sampling depth increments of 5 cm be used to a depth of 20 cm to identify the presence, location and severity of acid subsurface layers.

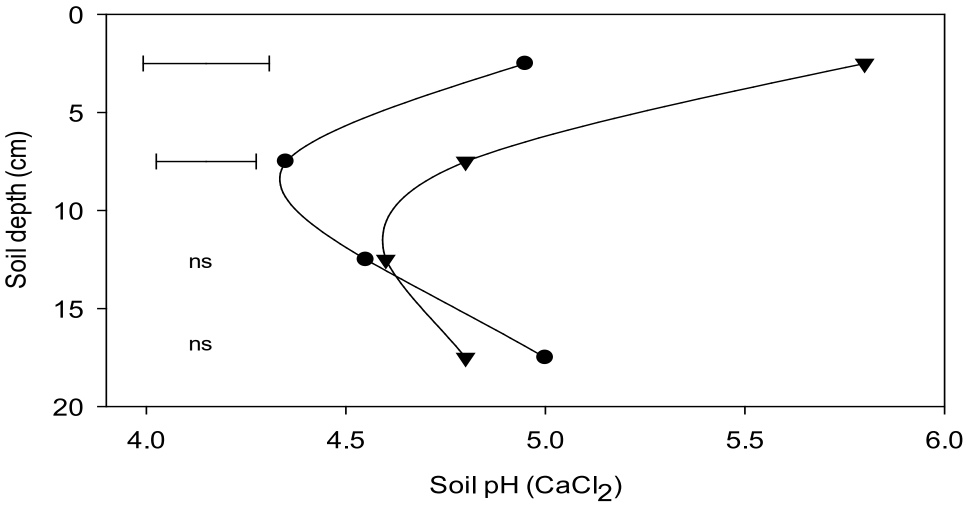

Figure 2. Soil pH_{Ca} stratification following lime application within 5 years (▼, n =33) or more than 5 years (●, n=15) of sampling from locations between Albury and Cowra, NSW. Horizontal bars represent LSD (*P*=0.05), ns = no significant difference. (Adapted from Burns and Norton 2018).

The recommended liming practices generated from research of the 1980s and 1990s aimed to bring the pH to just over 5, to facilitate the minimal quantity of lime required to decrease the plant available aluminium (Al^{3+}) concentration to less than that toxic to plants. This, in combination with higher rates of acidification and lack of soil mixing, results in the alkali of added lime being consumed within the soil surface thereby having no impact on acidity below 10 cm.

Though methods to address subsurface acidity are still being tested, the two simplest approaches are to incorporate lime to the depth of the acidity or apply lime at or near the surface and allow the alkali to move down with time. Long term field trials have demonstrated that maintaining soil at greater than pH 5.5 facilitates the downward movement of alkali from lime (Conyers and Scott 1989 and Li et al. 2019). Shifting to a liming target of greater than 5.5 with a re-liming trigger of pH 5.5 theoretically provides the best long-term outcome for soil pH and associated soil function. The authors have implemented a series of trials that test this under a range of agricultural enterprises, soil type, and rainfall zones. Whilst the higher pH target invokes a concern of greater costs to ameliorate to that level, it is worth remembering that as pH is logarithmic, it takes less lime to move from pH 5 to pH 5.6 than it does to move from 4 to pH 4.6. Therefore, it is cost effective to maintain pH before the acidity drops to a level that causes production losses.

Traditional liming practice applies lime at a rate to ameliorate soil in the 0-10 cm layer and incorporation is known to increase the effectiveness of application due to improved soil to lime contact and mixing through the depth of incorporation. Machinery is now commercially available that can rip and mix soil to a depth of 25 cm. The effectiveness of such machinery to incorporate lime required field experimentation. If the depth of incorporation increases beyond the traditional depth of 10 cm, the rate of lime applied needs to be adjusted to account for the greater soil volume to be ameliorated. Failing to do this will see the lime applied being diluted, resulting in smaller pH changes to the depth of incorporation than expected.

However, not all growers are interested in incorporating lime. Some growers are reluctant to incorporate in their no-till systems, while others may have substantial erosion risk due to slope of land or may be applying lime to existing permanent pastures where cultivation is not appropriate. Under these circumstances, surface application may be the only practical method of lime application. However, surface application will result in much of the applied lime sitting in the surface few centimetres, a depth region that exhibits higher pH than the underlying layers. As lime is sparingly soluble, it requires acid to dissolve, thus surface application to an already relatively high pH soil layer may result in lime sitting unreacted on the soil surface; a source of inefficiency of input dollars. It therefore makes sense that when applying rates of lime calculated to result in higher pH targets (pH >5.5), much of the lime may remain unreacted if surface applied and not incorporated. Greater efficiency of lime applied may occur if small but regular additions of lime are made; topping up surface applied lime as it dissolves. Though costs associated with spreading will be increased, the soil chemical and agronomic benefit of the practice needs to be examined under experimental conditions.

Field trial

A long-term experiment, with short term funding from a National Landcare Program project obtained with support of the Grasslands Society of NSW, was established at Lyndhurst NSW in 2020. The soil is a Red Chromosol (duplex) fine sandy loam with pH_{Ca} ranging from 4.6 in the surface to 4.2 at 20 cm. Exchangeable aluminium percentages were greater than 60% in some layers.

The following treatments were applied in March 2020.

1. Control – untreated soil
2. pH 5.2 surface – lime applied to the surface at rate of 4.7 t/ha which theoretically would raise the pH of the 0-10 cm to pH 5.2. To be surface relimed once pH drops to below pH 4.8 in the 0-10 cm layer; representing historic liming practice.
3. pH 5.2 incorporated – as above but with deep incorporation to a depth of 20cm.
4. pH >5.5 surface – lime applied to the surface at a rate of 5.9 t/ha which should raise the soil pH of the 0-10 cm to pH 5.9. To be surface relimed once pH 0-10 cm equals pH 5.5.
5. pH>5.5 incorporated – as above but with deep incorporation to a depth of 20cm.
6. pH>5.5 in 0-5 cm surface - lime applied to the surface at a rate of 2.8 t/ha which should raise only the soil pH of the 0-5 cm to pH 5.9. To be surface relimed once pH 0-5 cm equals pH 5.5.
7. pH>5.5 in 0-15 cm incorporated- lime applied to the surface at a rate of 7 t/ha which should raise the soil pH of the 0-15 cm to pH 5.9 followed by deep incorporation to a depth of 20cm. To be surface relimed once pH 0-10 cm equals pH 5.5.

Superfine, high neutralising value (>98%) lime was applied. Deep incorporation to 20 cm was done using a Horsch® Tiger cultivator. The trial was sown to dual purpose wheat in 2020 and resown to phalaris, arrow and subterranean clover pasture in 2021. The soil from experimental plots were sampled in 2022 and soil pH and exchangeable aluminium percentage (percentage of the cation exchange capacity occupied by Al^{3+}) is shown in Figure 3.

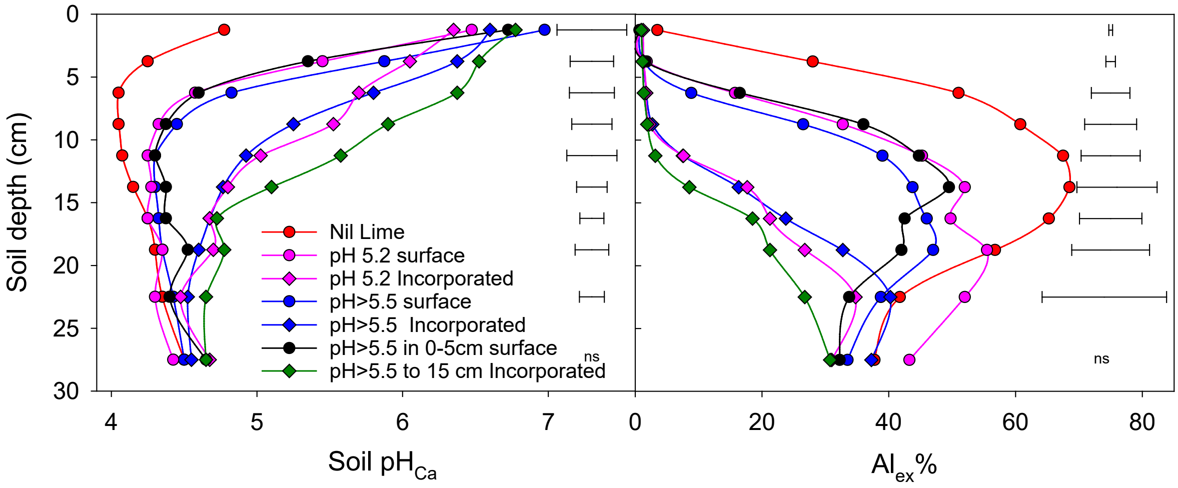

Figure 3. Soil pH_{Ca} profiles (left) and exchangeable aluminium percentage (right) sampled in 2022, two years after lime application at treatment rates to achieve targeted soil pH shown in legend. Lime was either surface applied or deep incorporated on a duplex fine sandy loam at Lyndhurst, NSW. Horizontal bars represent LSD (*P*=0.05), ns = no significant difference.

Surface applications, which by necessity were incorporated by sowing, increased soil pH relative to the control to a depth of 5 cm. However, the Al% remained greater than 40 % below 10 cm for those treatments. The soil pH and Al% of treatments receiving surface applied lime were relatively similar, although the pH of the pH>5.5 surface was significantly greater than the pH 5.2 surface treatments in the 0- 5 cm soil layers. No significant difference in Al% existed between surface applied treatments.

When lime was incorporated to depth, significantly greater soil pH occurred in layers to a depth of 17.5 cm compared to the matching lime treatment when surface applied. There was no significant difference in soil pH for pH 5.2 and pH>5.5 treatments when incorporated. When lime was applied at a rate to ameliorate to 15 cm (7 t/ha), soil pH was significantly greater than all other treatments in the 5-15 cm layers.

The incorporation of lime at all rates examined effectively removed Al^{3+} from solution to a depth of 10 cm (Figure 3) and decreased Al% to less than 30% to a depth of 15 cm. Significant decrease in Al% relative to the control were observed to a depth of 20 cm when lime was incorporated.

Conclusion

In the two years of the experiment, surface application of lime without incorporation has had minor effect below 5 cm, with little difference between rates. This may be due to the elevated surface pH resulting in much of the applied lime remaining unreacted at the surface.

The Horsch Tiger was effective in ameliorating soil acidity to a depth of 15 cm, with improvements in soil chemical measures to 20 cm depth, relative to the control. However, such cultivation is not without peril. The soft cultivated soil is unsuited to grazing before root mats have formed. The porous soil structure created, may lead to a seed bed too wet to be trafficked for sowing or herbicide application after soaking rainfall. Though effective in rapid amelioration of acidity, optimisation of post cultivation management requires thought prior to implementing deep cultivation to incorporate lime within farming rotations. Given these issues, the data indicates that applying lime at a rate to ameliorate the acidity present within the depth of incorporation results in the greatest reward, in terms of pH increase, for the risk and costs associated with deep cultivation.

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Hyperyielding crops lifts canola yield above 6 t/ha

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Key words

canola, hybrid, nutrition, manure, fungicide, plant density

GRDC code

FAR2004-002SAX

Take home messages

- Grain yield reached well over 6 t/ha at Millicent and Wallendbeen in 2021, 1 t/ha above the highest yields observed in 2020
- Yield plateaued from nitrogen application either below or up to 150 kg/ha applied N
- The application of animal manure lifted yield by a further 11-18% above the maximum yield from applied fertiliser N
- Variety choice has a major impact on achieving Hyperyields, with 45Y95 CL being the standout variety in 2021
- Further research will determine the mechanisms behind the strong yield response from animal manure and how nutrition can drive Hyperyields of canola.

Background information from 2020

The canola component of the GRDC and FAR Australia Hyperyielding Crops project commenced in 2020 with sites at Gnarwarre, Victoria; Millicent, South Australia; and Wallendbeen, NSW. The focus has been on determining the management factors including variety choice, nutrition, disease control and plant density required to achieve a canola yield of 5 t/ha. Variety choice and nutrition were the two most important factors driving canola yield in these high yielding environments in 2020, with fungicide and seeding rate less important. Highest yields were at Wallendbeen with 5.6 t/ha of 45Y28 RR with 225 kg/ha N applied. At Gnarwarre, highest yield was 4.8 t/ha of 45Y28 RR with 106 kg/ha N applied plus 5 t/ha pig manure. At Millicent highest yield was 4.6 t/ha of 45Y93 CL. All results from 2020 are available at: https://faraustralia.com.au/wp-content/uploads/2021/04/210325-HYC-Project-2020-Results-Canola-Final.pdf.

2021 Hyperyielding Canola trials

Trials with a similar focus were conducted in 2021 in the same environments as 2020. Yields were higher in 2021 at all sites, with two of the three sites achieving a grain yield of 6 t/ha, well above the target yield of 5 t/ha (Figure 1). This paper outlines the key management strategies to achieve these very high yields at each site.

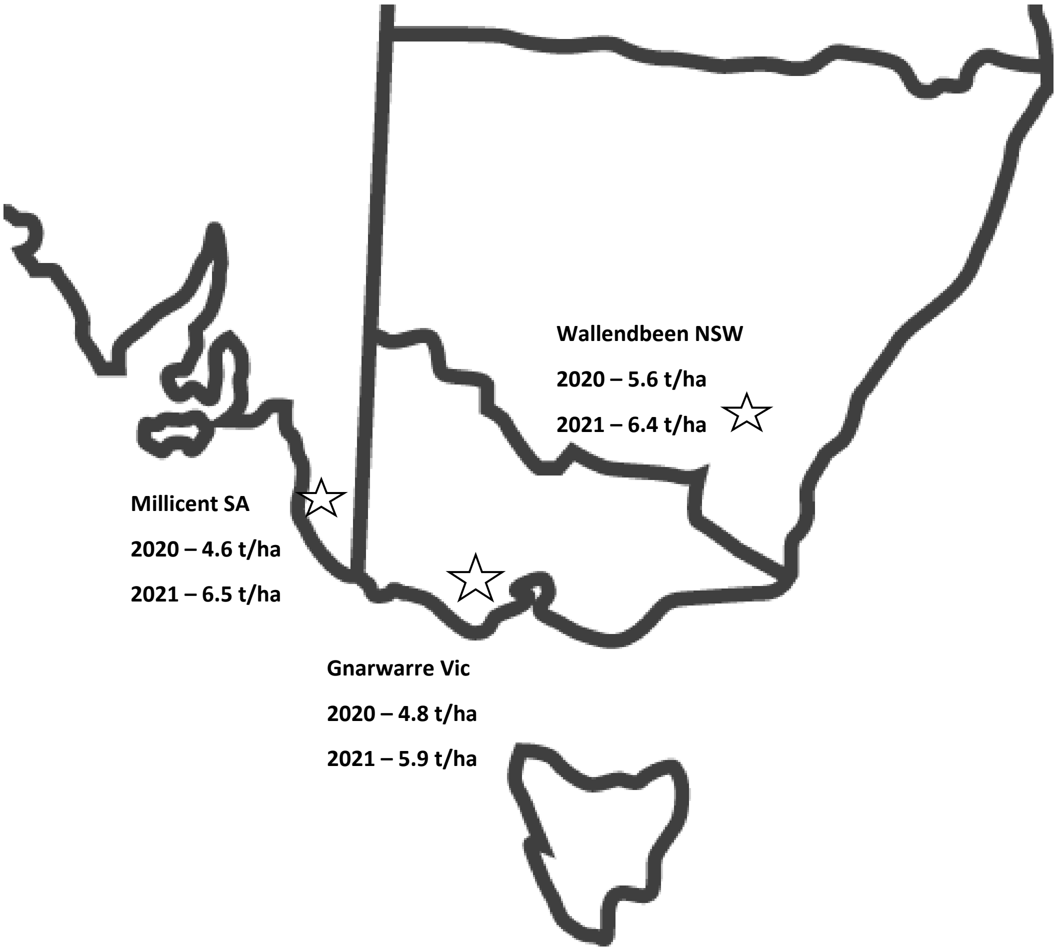

Figure 1. Grain yield of the highest yielding canola treatments at three sites in 2020 and 2021.

Methodology

This paper primarily reports on two key trial series (Table 1). The first series is a Genotype * Environment * Management (GEM) trial, which were split into separate winter and spring trials with three management strategies (Low, Medium and High Input) applied to each variety (blocked by herbicide tolerance) at three locations; Gnarwarre, Millicent, and Wallendbeen (Site descriptions in Table 2). The second trial series was a nutrition trial, again split into separate spring and winter trials with six nutrition treatments, focusing on nitrogen management and the addition of animal manure.

The paper also summarises results of plant density and disease management trials conducted in 2021.

Table 1. Variety entries and treatments in a canola G * E * M trial and canola nutrition trial, conducted at three sites in 2021.

GEM Trial Series			**Nutrition Trial**		
Spring Varieties	*Winter Varieties*	*Treatments*	*Spring Variety*	*Winter Variety*	*Treatments*[#]
ATR Wahoo	Hyola 970CL	Low Input: Seed = Maxim® XL 20% Bloom = Aviator® Xpro 0.8 L/ha N = 150 kg/ha	45Y28 RR	Hyola Feast CL	0 kg/ha N
HyTTec Trifecta					75 kg/ha N
45Y93 CL		Medium Input: Seed = Maxim XL 20% Bloom = Aviator Xpro 0.8 L/ha N = 225 kg/ha			150 kg/ha N
45Y95 CL	Hyola Feast CL				225 kg/ha N
45Y28 RR		High Input: Seed = Saltro® Duo 6-Leaf = Prosaro® 0.45 L/ha 20% Bloom = Aviator Xpro 0.8 L/ha 50% Bloom = Prosaro 0.45 L/ha N = 225 kg/ha			300 kg/ha N
Condor TF					225 kg/ha N + animal manure*

**Manure applied – 6.7 t/ha pig manure at Gnarwarre and Millicent (2.7% N, 1.3%P) and 3 t/ha chicken manure at Wallendbeen (3.3% N and 0.7% P).*

[#] N Applications were split 50% at 6-Leaf stage and 50% at bud visible stage.

Table 2. Site description for three Hyperyielding Canola sites in 2021.

Location	**Region**	**Average rainfall**	**Elevation**	**Soil type**	**Available N at sowing**	**Organic Carbon**	**Colwell P**	**Applied P**	**Applied S**
Gnarwarre	Southern Victoria	600 mm	190 m	Sodic Vertosol	70 kg/ha (0-100 cm)	1.4%	34 mg/kg	22 kg/ha	30 kg/ha
Millicent	South-East SA	710 mm	20 m	Organosol	173 kg/ha (0-10 cm)	9.7%	56 mg/kg	22 kg/ha	30 kg/ha
Wallendbeen	South-West Slopes NSW	680 mm	540 m	Red Ferrosol	340 kg/ha (0-90 cm)	2.0%	63 mg/kg	30 kg/ha	30 kg/ha

Results and discussion

Nutrition trials

In the Spring Nutrition trials, yield from the application of N alone (as urea) plateaued at 150 kg/ha at Gnarwarre and 75 kg/ha at Millicent (Table 3), with no yield increase from applied N at Wallendbeen which had a starting nitrogen of 340 kg/ha in the top 90 cm. In the Winter Nutrition trials, there was no yield response from applied N (urea) at either Gnarwarre or Wallendbeen (Table 4).

Despite high starting fertility levels and saturated N responses, there were still strong responses to applied animal manure over and above high rates of applied N. This response was observed in all spring trials and one winter trial, Gnarwarre. The yield response from manure in the spring trials ranged from 11% at Wallendbeen to 18% at Gnarwarre and in the winter trials from nil to 17.5%. The yield response from nutrition was due to an increase in grain number (per unit area) rather than an increase in grain size.

At Wallendbeen (NSW) there was a response to nitrogen observed by the flowering stage in winter canola with up to 14 t/ha biomass produced (Figure 2). By maturity, lodging followed a similar trend as flowering biomass with very high N input plots being completely lodged. With a shorter duration from sowing to flowering, there was no response to N observed at the flowering stage (average 7 t/ha biomass) in spring canola and minimal lodging of plots. In NSW canola environments, winter canola is more suited to dual purpose farming systems, turning the excess vegetative biomass (up to 7 t/ha more than spring canola) into livestock production. Note there would be major animal health implications with the high nitrogen inputs reported here.

It is exciting to see such strong yield responses from nutrition above the response from applied N (urea) alone, especially to yield levels above 6 t/ha. The challenge for the project team is to better understand the reason for the strong yield response from animal manure and how that can be replicated cost-effectively across the wider grains industry.

Table 3. Effect of nutrition (applied N and animal manure) on 45Y28 RR canola at three Hyperyielding Canola sites in 2021. Shaded cells denote highest yield in trial.

Kg/ha N applied as urea	Gnarwarre Vic	Millicent SA	Wallendbeen NSW
0	4.0	4.9	4.5
75	4.5	5.6	4.4
150	4.9	5.8	4.6
225	5.1	6.1	4.5
300	5.0	5.8	4.5
225 + Manure	5.9	6.5	5.0
l.s.d. (p<0.05)	0.36	0.56	0.32

**Manure applied – 6.7 t/ha pig manure at Gnarwarre and Millicent (2.7% N, 1.3%P) and 3 t/ha chicken manure at Wallendbeen (3.3% N and 0.7% P).*

[#]N Applications were split 50% at 6-Leaf stage and 50% at bud visible stage.

Table 4. Effect of nutrition (applied N and animal manure) on Hyola Feast CL canola at two Hyperyielding Canola sites in 2021. Shaded cells denote highest yields in the trial.

Kg/ha N applied as urea	**Gnarwarre Vic**	**Wallendbeen NSW**
0	3.8	3.8
75	3.9	3.7
150	4.1	3.6
225	4.1	3.8
300	4.0	3.7
225 + Manure	4.7	3.5
l.s.d. (*p*<0.05)	0.51	n.s.

**Manure applied – 6.7 t/ha pig manure at Gnarwarre and Millicent (2.7% N, 1.3%P) and 3 t/ha chicken manure at Wallendbeen (3.3% N and 0.7% P).*

[#] *N Applications were split 50% at 6-Leaf stage and 50% at bud visible stage.*

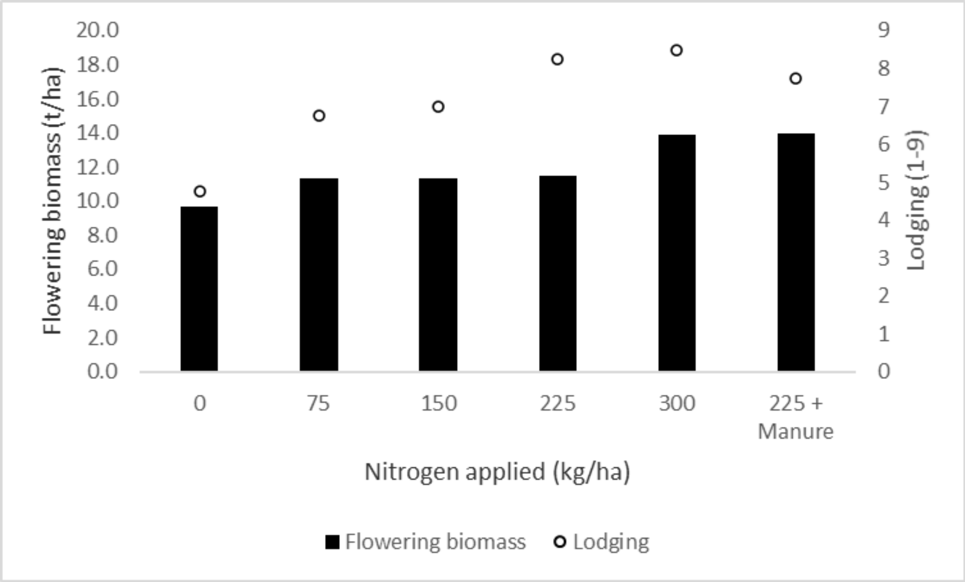

Figure 2. Flowering biomass (t/ha) and lodging (1 = standing, 9 = flat) of Hyola Feast CL winter canola at the Wallendbeen site (NSW) in 2021 in response to increasing rates of nitrogen and animal manure.

**Manure applied – 3 t/ha chicken manure at Wallendbeen (3.3% N and 0.7% P).*

[#] *N Applications were split 50% at 6-Leaf stage and 50% at bud visible stage.*

GEM trials

There were large differences between varieties in the spring GEM trial, with a small response from management at Gnarwarre and Wallendbeen and no management response at Millicent. At Wallendbeen there was an average yield response of 0.3 t/ha in the High Input management versus Medium and Low Input. At Gnarwarre there was 0.3 t/ha higher yield in the High Input management compared to Low Input management.

At Millicent and Wallendbeen, 45Y95 CL was the standout variety with yield of 6.4 t/ha (averaged across management levels) (Table 5). This yield is 28% higher than the target yield of 5 t/ha and highlights what can be achieved with canola when seasons, variety choice and management all align. The addition of manure to improve crop nutrition may raise the bar even higher for canola and this will be tested in the GEM trial in future years.

The high yield of 45Y95 CL at Wallendbeen in 2021 was due to a combination of high biomass (18.6 t/ha) and high harvest index (0.36) (Figure 3). Canola harvest index will always be lower than a cereal crop as the seed is more energy dense. When allowing for the 'glucose equivalents' of the canola at Wallendbeen in 2021, the harvest index would equate to approximately 0.6 in wheat.

45Y28 RR was the highest yielding variety in the GEM trials at Gnarwarre where Clearfield® varieties were not included. However, 45Y95 CL was the highest yielding variety in the adjacent Spring Screen trial.

In the winter GEM trials, Hyola Feast CL yielded higher than Hyola 970CL at Wallendbeen but there was no yield difference between the two at Gnarwarre (Table 6). There was no yield difference between the management levels in the winter GEM trial at either site.

Table 5. Effect of variety choice on grain yield (averaged across three input levels) in Spring G * E * M trial at Gnarwarre, Millicent and Wallendbeen in 2021. Shaded cells denote highest yields in the trial.

	Gnarwarre Vic	**Millicent SA**	**Wallendbeen NSW**
ATR Wahoo ⓓ	3.5	3.3	3.6
HyTTec Trifecta	3.9	4.4	5.2
45Y95 CL	*	6.4	6.4
45Y93 CL	*	5.7	5.6
45Y28 RR	4.5	5.1	4.9
Condor TF	3.9	5.1	5.2
l.s.d. (*p*<0.05)	0.21	0.34	0.36

Table 6. Effect of variety choice on grain yield (averaged across three input levels) in Winter G * E * M trial at Gnarwarre, Millicent and Wallendbeen in 2021. Shaded cells denote highest yields in the trial.

	Gnarwarre Vic	**Wallendbeen NSW**
Hyola Feast CL	4.3	3.8
Hyola 970 CL	4.0	3.4
l.s.d. (*p*<0.05)	n.s.	0.34

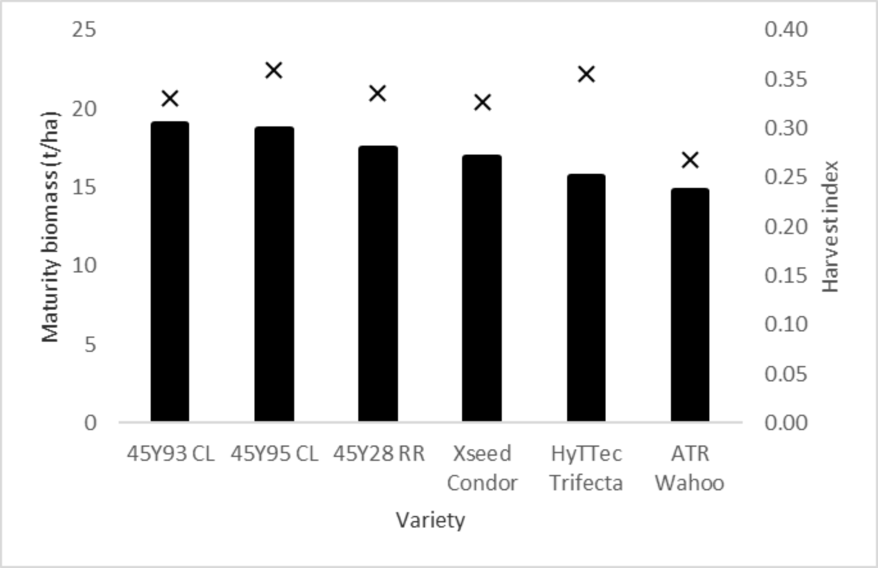

Figure 3. Maturity biomass (t/ha) (solid bars) and harvest index (x) of six canola varieties in GEM trial at Wallendbeen, NSW in 2021.

Canola plant density

Trials have been conducted on winter and spring canola with plant population targets of 15 to 75 plants/m^2. The response to plant density has been minimal despite large visual differences early in the season. Only at Millicent in SA has there been a consistent effect of plant density with a yield penalty for 15 plants/m^2 compared to 30-75 plants/m^2. At Wallendbeen in NSW there has been no difference in yield observed from 15 to 75 plants/m^2. Growers looking to target plant population of ~15 plants/m^2 should pay strict attention to seed size and their expected establishment rates. Large seed combined with high establishment losses may mean that sowing rate (kg/ha) should not be reduced greatly.

Canola disease management

Disease management trials have focussed on varietal resistance and fungicide management. A range of fungicide timings and products have been used but the overall response to fungicide has not been strong.

At Wallendbeen in 2021, Intensive fungicide management (Saltro® on seed + Prosaro® at 6-leaf + Aviator® 20% bloom + Prosaro at 50% bloom, all applied at highest label rates) yielded 0.9 t/ha more than where Nil fungicide was applied to the Resistant/Moderately Resistant 45Y28 RR (Blackleg Group BC) (Figure 4). There was no yield difference between Intensive and Nil fungicide when applied to the Resistant HyTTec® Trifecta (Blackleg Group ABD).

Despite a favourable spring, sclerotinia was only present at low levels at Wallendbeen in 2021 with 1.5% of plants infected in the untreated control. Saltro Duo on seed reduced blackleg crown canker but even where no seed treatment was applied, blackleg severity (% of stem cross section infected with blackleg) was less than 5% for 45Y28 RR and HyTTec Trifecta. The greatest difference between the varieties was with pod blackleg infection, with 1.8% of pod area infected by blackleg in the untreated HyTTec Trifecta versus 6.8% for 45Y28 RR. Intensive fungicide management reduced pod blackleg infection to 2.1% in 45Y28 RR.

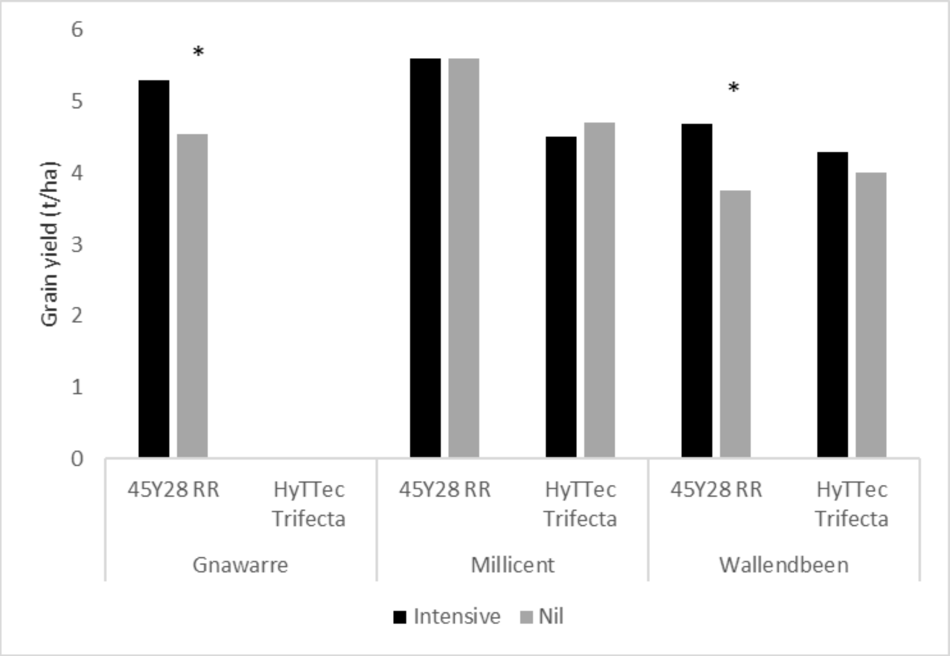

Figure 4. Effect of fungicide program (Intensive versus Nil) on grain yield of 45Y28 RR at Gnarwarre, Millicent and Wallendbeen and on HyTTec Trifecta at Millicent and Wallendbeen in 2021. Intensive fungicide management = Saltro Duo on seed + Prosaro 450 mL/ha at 6-leaf stage + Aviator Xpro 800 mL/ha at 20% bloom + Prosaro 450 mL/ha at 50% bloom.

** Indicates a significant difference at p=0.05.*

Discussion and Conclusion

There were several major stories to emerge from 2021 Hyperyielding Canola trials:

1. Yield levels were above even the most optimistic forecasts for canola – 6 t/ha should be a commercial target for industry and 7 t/ha will be the next frontier for research in these environments.
2. Nutrition is not just about applied nitrogen – strong responses from animal manure showed the importance of nutrition to push yields to new levels. This needs to be further investigated by the project team to determine if the yield response from manure is due to its slow-release nature or from nutrients such as phosphorus and potassium that are applied along with nitrogen in animal manure. Also noteworthy was that despite very high yields observed in 2021, the response to increasing nitrogen rates was not strong. N response usually plateaued at applied rates <150 kg/ha, indicating that much of the crops N requirement came from soil reserves rather than fertiliser inputs.
3. Like 2020, variety choice had a large impact on grain yield outcomes. 45Y95 CL was the standout variety across the three sites in 2021.
4. Fungicide management and plant density generally had less of an effect on grain yield than variety and nutrition and these factors don't appear to be the factors that will open new yield frontiers in canola.

For further detailed results from 2021, including results on cereal crops, please visit https://faraustralia.com.au/wp-content/uploads/2022/04/HYC-2021-Results-FINAL.pdf

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Brown manure as a farm risk strategy – a whole farm perspective

Robert Patterson, Rural Management Strategies Pty Limited

GRDC Grains Research Update paper, published in 2014

Key words

brown manure, farming system, legumes, peas, continuous cropping, profit, risk

Take home messages

- Farmers are faced with highly variable crop yields from one year to the next, with the overall trend in yields down, due primarily to decreasing Growing Season Rainfall and Available Moisture
- The quantity and cost of key crop inputs used in continuous cropping, particularly herbicides and Nitrogen fertiliser, is increasing in spite of decreasing yields
- The production and financial risk profile of continuous cropping farm businesses is increasing, due to crop yields trending down, coupled with costs of production steadily increasing
- A crop production system involving brown manure legumes, can be as profitable as continuous cropping, but even if slightly less profitable, has considerably less production and financial risk due to lower input and operating costs.

Background

Many farmers in southern NSW, particularly younger ones, have switched from a traditional mixed farming system to a more intensive farming system involving no livestock at all. While these decisions may have been rationalised or justified on the basis of dubious economics, or the notion that sheep are nasty for soil structure and incompatible with cropping, the reality is that many of these decisions have been made for reasons of personal choice or lifestyle.

However, it is acknowledged that not many farmers excel at managing both crop and livestock production systems, as compromises do exist and have to be managed on mixed farms. Therefore the adoption of a production system where only crops have to be managed, can be rationalised on the basis that a manager is likely to perform better in an area in which he or she specialises and prefers.

The benefits of crop rotations, especially crop sequences where wheat follows broadleaf crops such as grain legumes or oilseeds is widely known and acknowledged. So also are the benefits of lucerne to livestock production (especially sheep) and subsequent crops.

However, during the relatively dry decade of the recent past, the benefits of lucerne to subsequent crop production have been challenged by many farmers, due to failures of pasture establishment under cereal crops in dry springs, plus poor crop performance following lucerne where recharge of soil moisture has not occurred prior to cropping.

Continuous cropping would appear to be free of these negative impacts of lucerne, but obviously also fails to benefit from the positive aspects of lucerne.

Due to changes in traditional markets for lupins and field peas in southern NSW, there is only a very limited scope for using grain legume cash crops in rotation on any significant scale, which leaves canola as the only viable cash break crop. This has resulted in crop sequences of CWCW or CWW being adopted.

These sequences however, require increasing quantities of artificial Nitrogen, in an attempt to maintain yields and grain protein, while weed control, particularly that of annual ryegrass and wild oats, has become more problematic with increasing incidences of herbicide resistance occurring. Full stubble retention and the adoption of wide row spacing have also presented challenges for controlling grass weeds, through less efficacy of many pre-emergents due to stubble absorption, and less crop competition for weeds, depending on crop type and variety.

The author has serious doubts as to whether these continuous cropping sequences involving only canola and wheat, are sustainable in the medium or long term.

Therefore brown manure legume crops, comprising of field peas and vetch, are being adopted into cropping systems to address the shortcomings of continuous cropping, particularly with regards to Nitrogen input and herbicide resistance.

Rainfall and crop yields

The average annual wheat yields from a typical north eastern Riverina farm in southern NSW, for the period 1986/87 to 2013/14 are presented in Figure 1. The average wheat yield for this period is 3.19 t/ha and the median is 3.37 t/ha, but the trend line slopes down, depicting lower yields over time, coupled with significant variation from year to year. Canola yields for this farm show a similar trend and volatility, with average yields for the same period being 1.46 t/ha (46% of wheat) and median yields being 1.58 t/ha (47% of wheat).

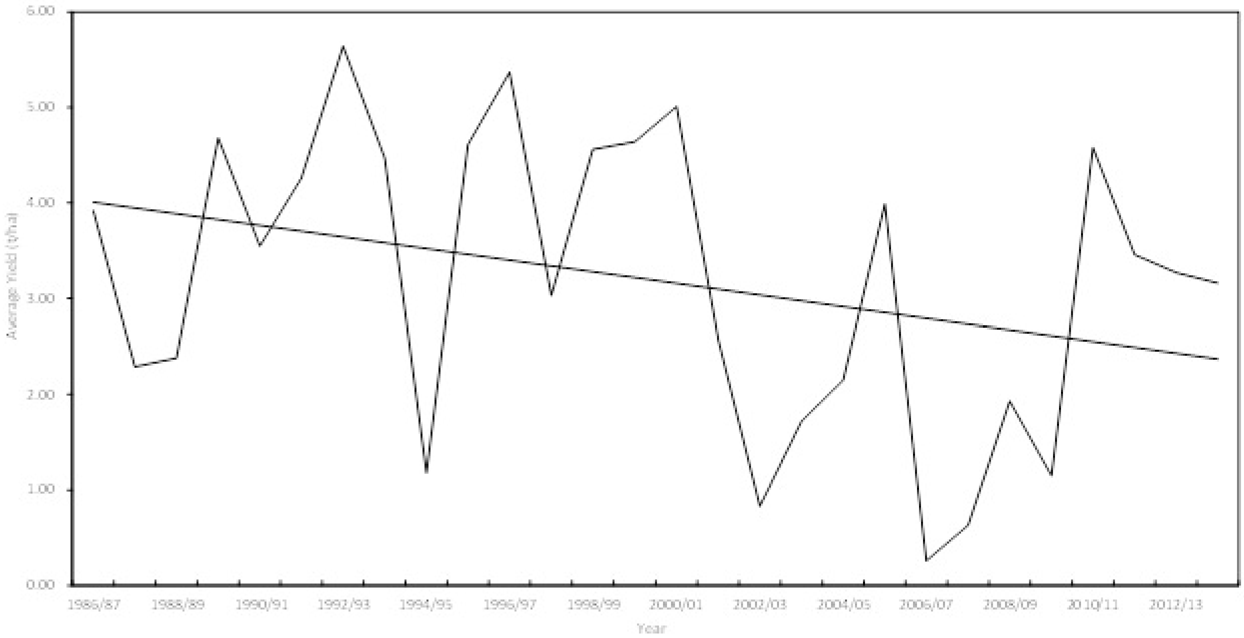

Figure 1. Average wheat yields 1986/87 – 2012/13 (NE Riverina farm).

The volatility and trend in wheat and canola yields is largely explained by decreasing Growing Season Rainfall and Available Moisture (30% November to March rainfall plus April to October rainfall less 110 mm).

The very close relationship between average wheat yields and Available Moisture which averaged 296 mm for the period, is shown in Figure 2.

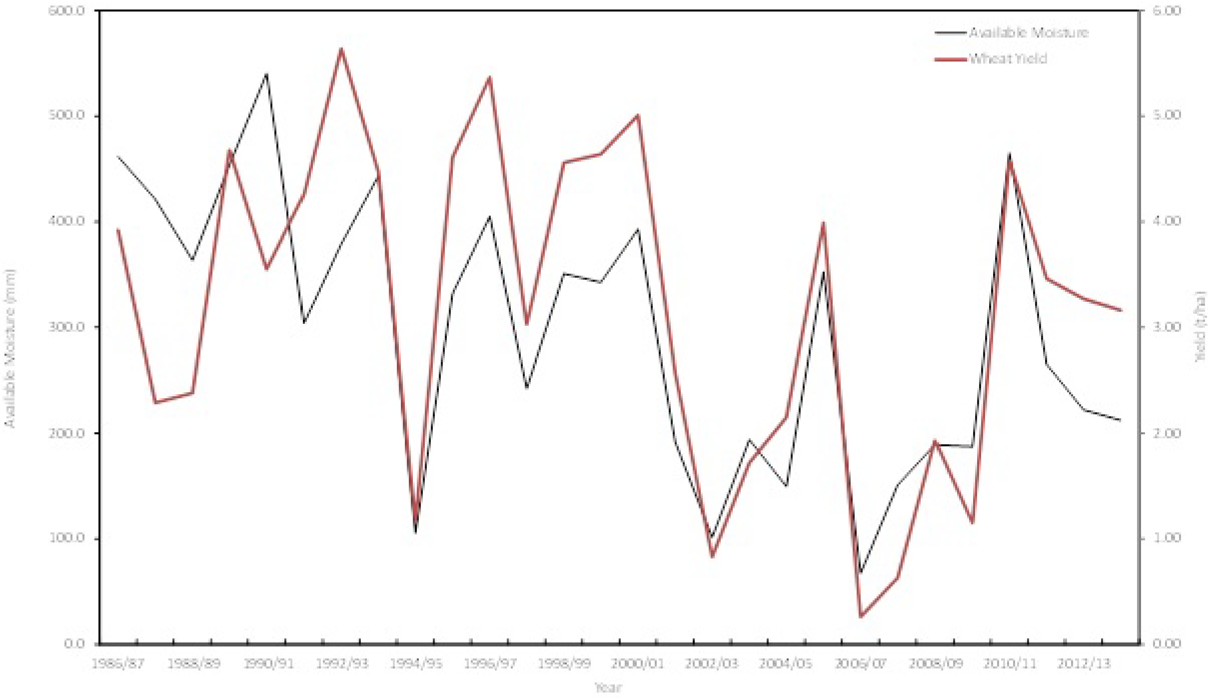

Figure 2. Available moisture versus wheat yield, 1986/87 – 2012/13 (NE Riverina farm).

The downward slope for both Growing Season Rainfall and Available Moisture is very similar, but steeper than the downward slope of the farm’s annual average wheat yields, depicting a slight increase in Water Use Efficiency over this time period. The Water Use Efficiency calculation for wheat based on Available Moisture, expressed as kg/mm is illustrated in Figure 3

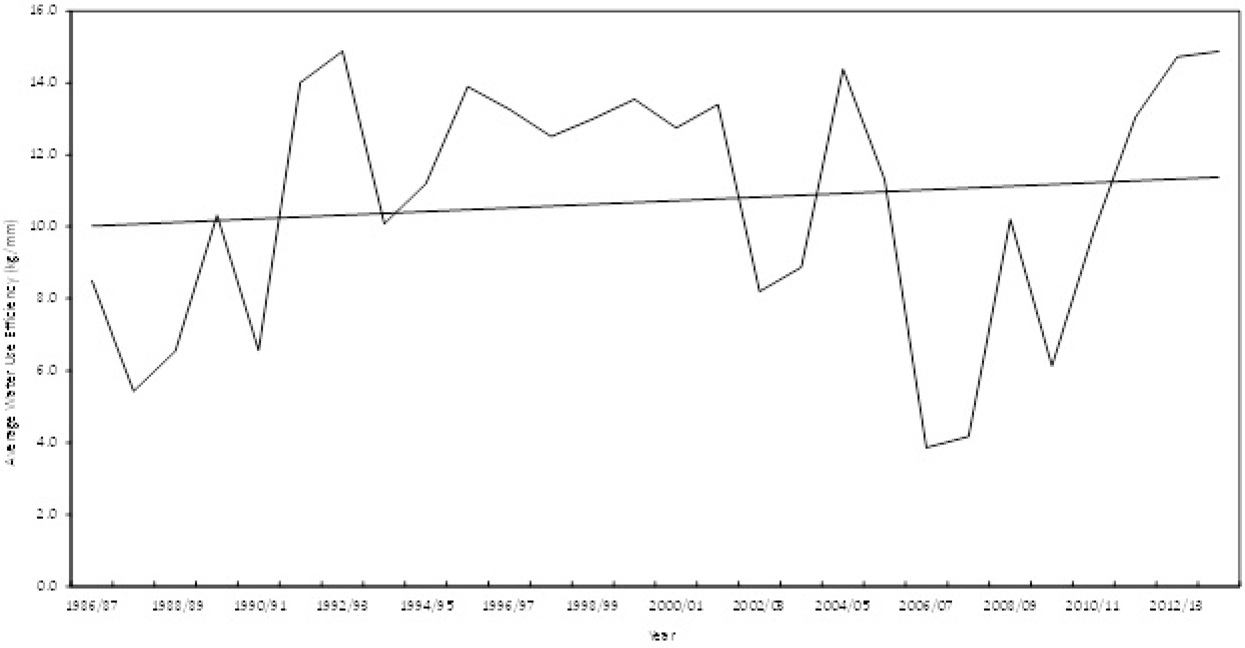

Figure 3. Average WUE 1986/97 – 2012/13 (NE Riverina farm).

Brown manure legume crops

Brown manure cropping has involved growing a grain legume crop with minimal inputs in terms of fertiliser and herbicides, with the aim of achieving maximum dry matter production before the major weed species being targeted, such as annual ryegrass or wild oats, have set viable seed. The grain legume crop is sprayed with a knockdown herbicide before seed set to kill both the crop and weeds, ideally no later than the initiation of pod development of the crop, to also conserve soil moisture. A second knockdown herbicide application is generally made to achieve a "Double Knock". This is in contrast to green manure where both the crop and weeds are killed by cultivation.

Vetch is a common brown manure crop, but the author has favoured early sown field peas, due to their greater competiveness with weeds and potentially greater dry matter production. Higher dry matter production should lead to higher Nitrogen accumulation, while more stubble cover provides shading to reduce evaporation and sunlight available to germinating weeds.

Brown manure legume crops provide three major benefits over long fallowing. These benefits are; competition for weeds (reducing the application of knockdown herbicides during the growing season), accumulation of soil nitrogen and the maintenance of ground cover both during the growing season and over the summer preceding the next crop. This brown manure crop residue should reduce soil surface evaporation and reduce wind erosion, but also provide a better environment for germinating weeds over the summer.

The major disadvantage of brown manure crops compared with long fallowing is the cost of the grain legume seed ($30-$35/ha), plus the cost of sowing, which is low in the overall scheme of things. Fertiliser is not usually applied at sowing unless soil phosphorus levels are low, as grain legumes are relatively non-responsive to phosphorus if sown early. Also, no nutrients are exported from the paddock in that year.

Crop sequences

Grain legume crops such as lupins in southern NSW have traditionally been followed by wheat, which responds well in terms of both yield and grain protein, due to the freedom from root diseases and high soil nitrogen levels. However in dry springs, many of these wheat crops "blow up", due to high early dry matter production depleting soil moisture, resulting in reduced wheat yields, high protein but grain with high screenings.

The author has observed severe take-all in early sown wheat crops (mid to late April) sown on well managed canola, lupin and field pea stubbles, where successive wet winters and springs during the 1990's were favourable for the build-up of the take-all fungus. This occurred especially where liming had taken place recently and crops were direct drilled. Severe crown rot has also been observed in wheat sown after well managed canola crops.

One year's control of wild oats in a break crop, does not appear to give sufficient control to the extent that control measures are unnecessary in the following wheat crop.

Given the desire to establish canola early with stored soil moisture and adequate Nitrogen to optimise yield potential, canola is now being grown after brown manure crops. This enables almost complete prevention of wild oat seed set in two successive years, which depletes the seed bank significantly to the extent that control measures may not be necessary in the following two cereal crops. This has significant cost savings and reduced risk of crop damage from post-emergent wild oat herbicides.

The two year broadleaf crop sequence of brown manure legume followed by canola is also predicted to provide control of crown rot, which a one year break does not. Reduction of take-all levels under high disease pressure weather conditions, should also be adequate to allow early (mid April) sowing of the first wheat crop with little root disease risk. The ability to sow early with confidence (subject to variety), is expected to lead to higher wheat yield potential.

The incidence of yellow leaf spot in wheat crops has also been observed to be substantially less following two sequential broadleaf crops.

A common crop sequence being adopted is brown manure legume, followed by canola, wheat and feed barley. While field peas have generally been the first brown manure crop grown, vetch is being adopted in the second sequence, to minimise disease experienced with only a three year break between pea crops.

Economics

An economic analysis of two farming systems conducted in southern NSW with a 450 mm annual rainfall is presented below. The two farming systems analysed were:

1. Continuous cropping of wheat and canola only.
2. Continuous cropping, but including brown manure field peas grown on 25% of the arable area.

The economic analysis is based on a 1,680 hectare property in Southern NSW, which is 95% arable (1,600 hectares) and run by two family labour units performing most of the operations themselves. The data used is drawn from actual farm results and figures from clients of the author.

The assumptions used for each of the two production systems are presented in Table 1.

Table 1. Assumptions used – 1,600 ha arable (95%) farm

	Continuous crop	**Brown manure peas**
Crop sequence	CWW	PCWB
Crop area	1,600 ha	1,600 ha
Key C - canola W - wheat B - feed barley P - field peas		
Average crop yields		
Canola	1.35 t/ha	1.62 t/ha
Wheat	3.00 t/ha	3.60 t/ha
Feed barley		3.60 t/ha
Average price received (net at local silo)		
Canola	$450/t	$450/t
Wheat	$220/t	$235/t
Feed barley		$170/t
Family labour units	2	2
Family labour allowance	$100,000	$100,000

Farm data from properties which have adopted brown manure peas, have shown 25 – 30% yield increases for both canola and wheat crops grown in the two years following brown manure pea crops. Wheat crops grown either after PC or PW have also shown elevated grain protein levels.

The analysis conservatively assumes a 20% increase in yield above average in the first two crops following brown manure peas. Wheat prices have been adjusted to reflect protein levels.

Table 2 shows the estimated capital required for each of the farming systems. The difference in plant investment is due to a larger header and bins being required for the continuous cropping system, due to the greater area and tonnage to harvest in a given time. The working capital requirement of the continuous cropping system is higher than the brown manure peas system, due to the larger area of cash crop requiring higher inputs in terms of herbicides, fungicides and artificial Nitrogen.

The amount of working capital required is a measure of the degree of risk of the system, as while there is almost a guarantee that costs of continuous cropping will be higher, there is no guarantee that gross income will be higher. This results in the potential for a greater loss to occur in that year if seasonal conditions are unfavourable, leading to the potential for this additional working capital to be capitalised into long term debt.

The brown manure system is considered to be relatively robust and low risk in drier seasons, as there is less potential to spend money on crop inputs, in the desire to achieve elusive higher crop yields.

Table 2. Capital required for business

	Continuous crop	**Brown manure peas**
Land 1,680 ha @ $3,211/ha (4,150 acres @ $1,300/acre)	$5,394,480	$5,394,480
Plant & vehicles	$950,000	$900,000
Working capital	$535,000	$420,000
Total capital required	$6,879,480	$6,714,480

The annual trading results measured by EBIT (earnings before interest and tax) and three key financial ratios are shown in Table 3.

EBIT is a measure of profitability after allowances for plant replacement and family labour.

It is seen that based on the assumptions used, predicted EBIT from continuous cropping is slightly higher than that from the brown manure legume system. There is little difference between the financial ratios, except that while the gross income and EBIT from continuous cropping is higher, it has the lower EBIT Margin, due to its higher costs relative to income. This lower EBIT Margin suggests a higher degree of risk associated with this system.

The results of the comparison are very sensitive to the price of nitrogen fertiliser. A $100/tonne increase in the price of Urea, increases costs in continuous cropping by $19,200 pa compared to $5,200 in the brown manure legume system. This would bring the respective EBITs within $2,000 of each other.

Table 3. Annual trading results and financial ratios ($pa)

	Continuous crop	Brown manure peas
Trading income	$1,028,220	$874,800
Operating costs - variable	$469,656	$339,716
Operating costs - fixed	$271,600	$264,100
Total operating costs	$741,256	$603,816
EBIT (earnings before income & tax)	$286,964	$270,984
Sales to assets (sales/assets)	15%	13%
EBIT margin (EBIT/sales)	28%	31%
Return on assets (EBIT/assets)	4.2%	4.0%

Table 4 presents the annual cash receipts and payments for the two farming systems at average crop yields, based on current fertiliser prices.

It is seen that based on the assumptions used, the annual cash surplus from continuous cropping is slightly higher than that from the brown manure legume system. However to achieve a higher cash surplus of $6,653, the outlay prior to harvest to produce the crops, is $115,000 more for the continuous cropping system.

Table 4. Annual cast receipts and payments assuming average crop yields

	Continuous crop	Brown manure peas
Cash receipts	$1,028,220	$874,800
Cash payments	$853,381	$706,614
Cash surplus	$174,839	$168,186
Working capital	$535,000	$420,000

The annual cash receipts and payments for the two farming systems at one third (33%) of average yields, due to very low spring rainfall and/or late frost after all crop inputs have been used, are shown in Table 5.

Table 5 shows that based on the given assumptions, the annual cash deficit from continuous cropping is substantially greater ($71,930) than that from the brown manure legume system.

While there may be some savings in crop establishment costs in the second year after the adverse weather event depicted in Table 5, the savings are likely to be similar in both systems. Assuming no significant savings, it is seen that the potential working capital requirement in the second year, are around $187,000 more for continuous cropping compared with the brown manure legume system. When interest is added, the difference is close to $200,000, depicting the much higher downside financial risk of continuous cropping in years with dry springs and/or late frosts.

Table 5. Annual cash receipts and payments assuming crop yields 33% of average

	Continuous crop	Brown manure peas
Crop yields		
Canola	0.45 t/ha	0.52 t/ha
Wheat	1.00 t/ha	1.20 t/ha
Feed barley		1.20 t/ha
Average price received (net at local silo)		
Canola	$600/t	$600/t
Wheat	$300/t	$315/t
Feed barley		$230/t
Cash receipts	$464,100	$391,200
Cash payments	$815,368	$670,538
Cash deficit	**- $351,268**	**- $279,338**
Working capital year 1	$535,000	$420,000
Potential working capital year 2	**$886,268**	**$699,338**

Conclusion

Volatile and lower Available Moisture, coupled with an increasing reliance on artificial Nitrogen fertiliser and selective herbicides in continuous cropping systems, has increased the risk profile of those businesses significantly.

Actual farm data from recent years, suggests that a crop production system comprising brown manure legumes, canola, wheat and barley, can be as profitable as continuous cropping, but with less production and financial risk. The brown manure legume system is considered to be more resilient in dry years, plus more sustainable due to the reduced reliance on selective herbicides for weed control and artificial Nitrogen for crop nutrition.

For those producers who prefer not to engage in mixed farming involving livestock, it appears that a brown manure legume system can produce acceptable financial results, with a relatively lower risk profile compared to continuous cropping.

Generally, simple but technically sound systems have less risk and perform better financially, than more complex systems.

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Building soil carbon for your business

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Keywords

carbon sequestration, soil carbon, soil organic matter.

Take home messages

- Many growers are already employing soil sequestration practices as the norm, but only additional activities are valid for claiming a carbon offset
- Soil carbon sequestration in grains systems is low unless a pasture phase is included
- When estimating carbon credits all greenhouse gases must be included i.e. soil carbon sequestration is potentially negated by nitrous oxide and other emissions
- The long term benefits of increasing soil organic matter for soil health are more profitable and low risk compared to the soil carbon market.

Introduction

Soil organic matter is the backbone of any sustainable farming system. In recent times, there has been significant interest in the role that soils can play in helping Australia meet its greenhouse gas reduction targets. Under the federal government's Australian Emissions Reduction Fund (ERF) which financially rewards carbon offsets, there are two legislated methods which involve soil organic matter or more specifically increases in soil organic carbon. These procedures are very specific and require detailed certified measurements of soil organic carbon and bulk density over nominated time periods. A number of international voluntary soil carbon methods also exist, but their validity as offsets in Australia may be questionable.

To engage in these soil carbon offset markets, farmers must first be able to demonstrate they are undertaking management activities which are in addition to their normal practice. For example, a farmer who changes to zero till practices will be rewarded if they have registered the field (i.e. defined a Carbon Estimation Area) and can show a measurable change in soil organic carbon in the top 30 cm or deeper. A farmer who has employed zero till for many years is unlikely to be rewarded unless there is some additional modification to this practice.

Unfortunately, placing a price on soil carbon has skewed the discussion away from what really matters to farmers, which is soil health and productivity. Soil organic matter, of which only half (~58%) is soil organic carbon has multiple benefits, most notably, maintaining nutrient supply and soil structure. Soil organic carbon is usually only about 1 to 5% of the total soil mass, with the higher concentrations normally under long-term grasslands or crop rotations with significant pasture phases.

What is soil organic carbon?

There is some confusion about what constitutes soil organic carbon. Plant residues on the soil surface, roots and buried plant residues (>2 mm) are not accounted for as soil organic carbon. These first need to be broken down into smaller fractions and decomposed to be considered soil organic carbon, which is why the soils are first sieved to two millimetres before an analysis, to remove all larger fractions. Gravel content and inorganic carbon (or carbonates in alkaline soils) must also be taken into account when accurately quantifying soil organic carbon.

Fractions considered to be part of the soil organic carbon (as per a soil analysis) would be Particulate Organic Carbon (POC; 2.0 – 0.05 mm) or labile C, Humus (<0.05 mm) or stable C, with Resistant Organic Carbon (ROC) being historic charcoal from fires or burning of stubbles. In other words, we must not confuse roots with soil organic carbon.

For sustained productivity, increasing the relative amount of POC is beneficial as this is readily decomposable and a supply of nutrients. To have confidence to sell soil carbon, you want a significant amount of carbon in a more recalcitrant (slowly decomposing) form i.e. stable, so that you have confidence that it will still be there in 25 to 100 years. These permanence time frames are required to engage in carbon markets.

Building soil organic matter

The inherent benefits and the role of soil organic matter for productive and profitable agriculture are well documented (Table 1).

Table 1. Biological, physical and chemical co-benefits that high soil organic matter may confer to an agricultural production system.

Biological roles	Physical roles	Chemical roles
- Reservoir of nutrients - Biochemical energy - Increased resilience - Biodiversity	- Water retention - Structural stability - Thermal properties - Erosion	- Cation exchange - pH buffering - Complex cations

(Source: Jeff Baldock)

Building soil organic carbon is basically an input-output equation; the inputs are crop and pasture residues and roots. The outputs are CO_2 from microbes which are actively decomposing and transforming the carbon fractions, using them as energy but in the process releasing nutrients back to the soil to support plant growth. As much as 90% of the carbon input is lost as CO_2. Soils with a higher clay content have a greater capacity to store carbon per unit of inputs. In a good rainfall year, the inputs increase in response to plant growth with a subsequent increase in outputs and an accumulation of carbon. Carbon inputs exceed outputs. In a drought, carbon inputs drop dramatically in response to reduced plant growth, but the outputs remain because the microbes respond to episodic wetting events and soil carbon decreases. Carbon outputs exceed inputs. Fallow years are good example of significant losses in soil carbon.

In Australia, rainfall determines the majority of soil carbon change in a stable management system (see Meyer *et al.,* 2015). Unless there is a significant change in management, e.g. moving out of conventional cultivation into permanent pasture in a high rainfall zone, the majority of the annual change in soil carbon is a function of rainfall, biomass production and its decomposition. Change in soil carbon in mixed cropping system can often be large and unpredictable, particularly from labile, relatively decomposable carbon (Badgery *et al.,* 2020).

Australia has over 20% more rainfall variability than most countries in the world (Love 2005). Banking on selling soil carbon and its permanence is therefore high risk given the frequency of drought. For example, Badgery *et al.,* (2020) reported that after 12 years of increases in soil carbon, this was reversed in the following 3 years in less than favourable climatic conditions.

In contrast, recent research has demonstrated that just two of the co-benefits of high soil organic matter (i.e. nitrogen mineralisation and water retention) confers as much as $150 per hectare per year productivity value in a pasture system in western Victoria, when the carbon trading value under the same scenario is less than $20 per tonne per hectare year (Meyer *et al.,* 2015). This raises the question, should farmers focus on trading soil carbon, or just bank the inherent productivity benefit of having higher soil organic matter, as there is no paperwork no contracts no liabilities, but all the productivity benefits can be banked? In addition, when the farm needs to demonstrate carbon neutral production in the next decade, this soil carbon will be essential to offset the balance of the farmers greenhouse gas emissions.

How much soil carbon can be accumulated?

The current level of organic carbon in soils across the northern grains zone is well below what can be achieved if we consider the impact of 100 years of conventional agriculture (Figure 1).

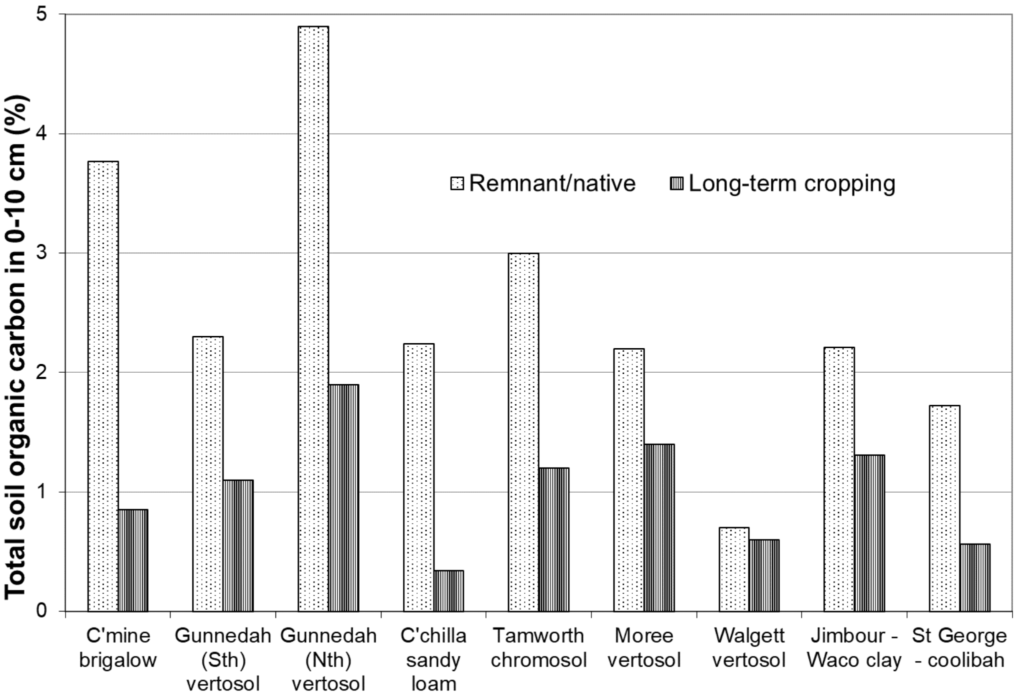

Figure 1. Impact of long-term cropping on soils of the northern grains zone (Lawrence *et al.,* 2017).

The SATWAGL long-term trial at Wagga (Chan *et al.,* 2011) has demonstrated the clear benefits of stubble retention, zero tillage and pasture phases for increasing soil carbon (Table 2). Over a 25-year period, stubble retention compared to burning was 2.2 t C/ha higher, zero tillage compared to conventional cultivation was 3.6 t C/ha higher, and a pasture rotation every second year was between 4.2 and 11.5 t C/ha higher than continuous cropping.

Many of these management practices, as well as reduced fallows, are now commonplace in grains systems of Australia. Soils have potentially reached a new (but low) steady state i.e. little change over time, provided the management does not change. A shift to a pasture-based farming system offers high potential for soil carbon gains (Figure 2) and its benefits, but a major consideration is obviously whether there is enough flexibility on-farm and profitability within the livestock sector to make this transition and to consider the potential for additional emissions from livestock.

Table 2. Change in soil organic carbon (SOC, kg C/ha over 0–0.30m soil depth) and final stock (t C/ha) under different rotation, tillage, and stubble and pasture management in the SATWAGL long-term field experiment (1979–2004) (adapted from Chan *et al.,* 2011)

Treatment	**Tillage**	**Stubble**	**Rotation**	**SOC change (kg C/ha/year)**	**sig**	**Final stock (t C/ha)**
T1	NT	SR	W/L	-52	n.s.	40.5
T2	CC	SR	W/L	-174	*	38.3
T3	NT	SB	W/L	-98	n.s.	39
T4	CC	SB	W/L	-176	*	35.4
T5	CC	SB	W/W	-278	**	33.6
T6	CC	SB	W/W-N	-193	*	34.6
T7	CC	SR	W/C-G	-2	n.s.	41.7
T8	NT	SR	W/C-M	257	*	48
T9	CC	SR	W/C-M	104	n.s.	43.1

NT, No tillage; CC, 3-pass tillage; SR, stubble retained; SB, stubble burnt; W/L, wheat/lupin rotation; W/C, wheat/clover rotation; W/W, wheat/ wheat; N, N fertiliser; G, grazed; M, mown. *$P < 0.05$; ** $P < 0.01$; n.s., not significant

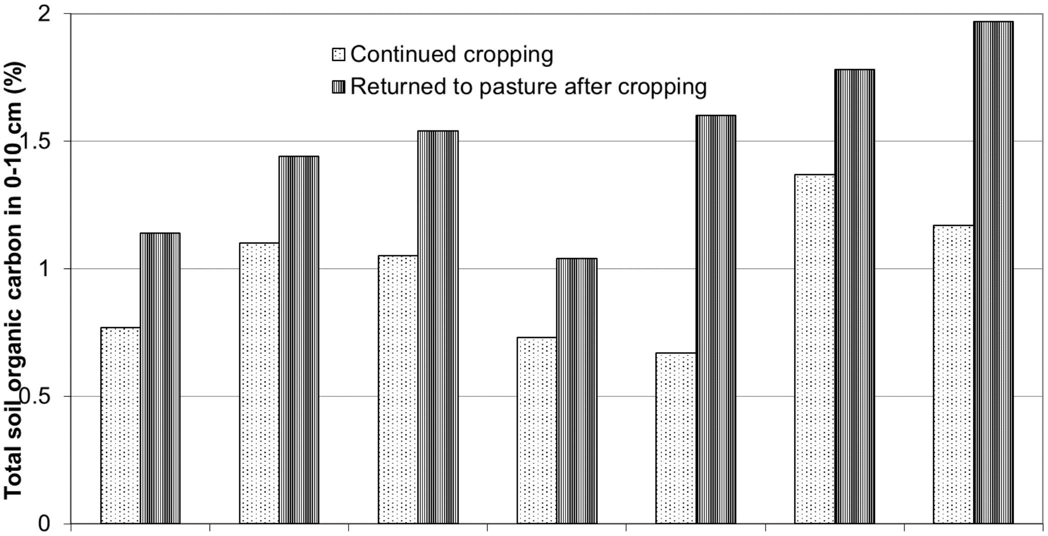

Figure 2. Changes in soil organic carbon levels after shifting from crop to pasture in the northern grains region (Lawrence *et al*., 2017). First value is the total duration of the cropping phase, second value is the duration of the cropping and pasture phases.

Over the past few years there has been an increase in the number of farmers and carbon aggregators making claims of increases in soil carbon that do not align with the published peerreviewed science. Although conservative, the values presented in Table 3 are those estimated by the Australian government official carbon model (FullCAM), showing likely increases in soil carbon in response to management. What is also seemingly ignored in claims of soil carbon increase, is the assumption this can continue in perpetuity, which defies the law of diminishing returns. The more carbon you sequester, the more carbon inputs you then require to maintain this level every year.

Table 3. Modelled soil carbon sequestration potential as stipulated and the Australian government ERF Offset method: Estimating Sequestration of Carbon in Soil Using Default Values, Methodology Determination 2015[1]

	Categories of sequestration potential (t C/ha/year)		
Project management activity	Marginal benefit	Some benefit	More Benefit
Sustainable intensification	0.03	0.16	0.45
Stubble retention	0.02	0.08	0.20
Conversion to pasture	0.06	0.12	0.23

[1] https://www.legislation.gov.au/Details/F2018C00126

Where soil has a low organic matter content, but high clay content and good rainfall (i.e. a high potential to increase soil organic matter), it is possible to achieve rates of soil carbon sequestration that exceed those presented in Table 3. The initial high carbon sequestration rates (i.e. the first 5 to 10 years with rates from 0.7 to 1 t C/ha/year in the top 30 cm when converting cropland to pasture; Meyer *et al.,* 2015; Robertson & Nash, 2013) will result in a new steady state after 10 years that matches the rainfall and management imposed. In contrast, the same conditions but with a high soil organic matter starting point, would only vary in direct relation to annual rainfall and distribution.

Another factor that limits the ability to determine changes in soil C is the large spatial variability that is found within a paddock. A high level of soil sampling is needed to detect differences in soil C between two time points. For example, Singh *et al.* (2013) found that a spatially optimised design, including stratification according to landform and yield mapping, needed at least 48 cores to reduce the standard error of measurement to less than 2 t C/ha at 0-30 cm in a 68 ha paddock. This is major limitation to cost-effectively verifying changes in soil C.

A new approach to managing soil organic matter in Australia

Perhaps there is a need to consider soil organic matter differently in the Australian context, by managing it more specifically for soil types by farming systems and also managing differently in high versus low rainfall periods. Sandy or granitic soils have very limited capacity to build soil organic matter as carbon is less protected to decomposition by microorganisms in these soil types, whereas clay soils generally have far higher potential to sequester carbon when rainfall is sufficient to maintain carbon inputs from stubble, roots or residual pasture biomass.

The key to building soil carbon, is to understand the capacity for the soil to store carbon in your specific environment (climate x soil type) and management system. This capacity varies considerably even within the same district. Therefore, we should not treat the landscape with a single sequestration potential, but target the areas that are low in carbon but high in sequestration potential e.g. the rehabilitation of degraded lands.

We should also be thinking of El Niño versus La Nina years quite differently, in that we have probably built more soil organic matter in eastern Australia during the recent La Nina, than in the previous three dry years put together. Higher rainfall year should focus on strategies that maximise the sequestration of carbon in our soils, and in low rainfall or drought periods, we focus on minimising the losses. Rather than focus on building soil carbon year by year, a longer-term approach would aim for a net increase in carbon over a 10 year period.

Short-term gain may mean long-term pain

Finally, whilst carbon neutrality is being strongly supported by the agricultural supply chain companies, there is an inevitable point where farmers will need to demonstrate progress towards lower emissions farming systems. Any increase in soil organic carbon you bank as a credit, will be negated by in-field emissions e.g. CO_2 from fuel, N_2O from N fertilisers or CH_4 from grazing livestock. Selling soil or tree carbon means that when the asset **value** leaves your property, you are left with the liability of maintaining what is now someone else’s asset for the next 25 to 100 years (short term gain, long term pain). If the soil carbon is sold internationally, it also leaves the industry and the country, making any industry or national carbon sequestration targets increasingly difficult to achieve . Once the soil carbon is sold, the new buyer will be using it against their carbon footprint, which means that the farm will never again be able to use that soil carbon against their future liability, making their carbon neutral target increasingly impossible to achieve. The low risk option is to bank the inherent productivity benefit of improved soil health and don’t sell your soil carbon, as you will need this asset for the day when you might need to table it against the balance of your own greenhouse gas emissions to meet supply chain demands.

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Cranking up crop yields and livestock production using summer sown pasture legumes – revisiting fundamental soil and agronomy with new technologies to increase production and rotation flexibility

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Take home message

- Summer sowing of hardseeded legumes is a robust and effective way to establish pastures well adapted to climatic variability and acidic soils
- Once a seedbank is established, hardseeded legumes can add flexibility to pasture-crop rotation systems enabling growers to capitalise on crop and livestock market opportunities
- Hardseeded legumes can support high yields in following grain crops even when they were grown in a poor season. Considerable savings in nitrogen fertiliser are possible
- Growers should focus on what they should grow, considering soil, climatic and pasture-crop rotation systems used in order to maximise the potential of hardseeded legumes in their farming systems.

Introduction

Maintaining crop areas and profitability is facing considerable pressure as a result of rising input costs, particularly fertilisers, and competition from currently lucrative livestock enterprises. Increasingly, this is leading growers to explore opportunities to better integrate crop and livestock production in a way that allows for more fluid transition between enterprises in response to market opportunities, input cost pressures and climatic conditions. A component of building flexibility in to mixed farming systems is via consideration of the pasture component of the farming unit.

Pastures in mixed farming systems of eastern Australia have generally been used as phases of 3-10 years in a cropping rotation. While such pastures systems can provide stability in terms of productivity, they are also relatively inflexible in terms of allowing for rapid transition of total farming land area between crop and livestock production enterprises. Additionally, these pastures often require relatively lengthy periods to adequately establish (i.e. lenient grazing in the first 12 months) and require resowing after each cropping phase. For traditional pastures, sowing also coincides with peak labour demand, with ideal sowing time generally coinciding with the winter crop sowing window. Labour competition frequently results in pasture sowing occurring after the winter cropping program is completed, which can lead to poor pasture growth and seed production with impacts on long term persistence and performance.

However, astute pasture legume breeding programs and development of intuitive pasture establishment techniques such as summer sowing, have resulted in the development of highly productive and flexible legume-based pastures. Such pastures can be integrated into farming systems to increase productivity of crop and livestock systems. Legume species used in these pastures have also proven to be very tolerant of highly variable seasonal conditions, including extreme drought.

What is summer sowing and what legume species is it applicable to?

Summer sowing was developed by Dr Brad Nutt and colleagues at Murdoch University and the Department of Primary Industries and Regional Development in Western Australia (see Nutt et al. 2021). Summer sowing eventuated after the same team had previously developed range of robust pasture legume species including bladder clover, biserrula and gland clover, along with the first cultivars of hardseeded French serradella and new cultivars of arrowleaf clover and yellow serradella. All of these species produce their seed aerially, as opposed to subterranean clover which buries a proportion of its seed. Aerial seed production meant that it was possible to harvest seed of the legumes using conventional headers. This alone was a significant achievement as it allowed seed to be harvested quickly, efficiently and at relatively low cost.

When the aerial seeded legumes are harvested with a header, very minimal damage is caused to the seed coat (or the pod in the case of serradella), meaning that the seed retains a very high hard seed level. Such seed could be sent for further processing (i.e. scarification) and then subsequently sown in mid to late autumn like a traditional pasture sowing. However, early experiments showed that if the unprocessed seed was sown in mid to late summer, then a proportion of it would soften due to fluctuations in temperature and moisture and be capable of germinating on opening autumn rainfall. This meant that pasture sowing could be completed well ahead of the winter crop sowing program. The legume species suited to summer sowing also had attributes such as deep root systems and/or capacity for improved control of transpiration losses, which meant they could survive periods of high temperature and/or moisture stress that would normally result in high mortality of early sown traditional pasture legumes such as subterranean clover and annual medics. Additionally, as the pasture emerged early while temperatures were warm, more biomass could be produced than for conventionally sown pastures.

The early experiments in Western Australia found that bladder clover and hardseeded cultivars of French serradella were reliable for summer sowing in that environment. Later experiments found that arrowleaf clover, biserrula and gland clover in addition to bladder clover, hardseeded French serradella cultivars and some cultivars of yellow serradella were options for summer sowing in the central and southern regions of NSW. Higher soil moisture throughout summer and its interaction with temperature fluctuations appears to have increased hard seed breakdown rates in NSW (Nutt *et al.,* 2021).

How effective is summer sowing?

To date, in NSW, we have completed 18 replicated field trials (2012-2021) comparing summer sowing to conventional sowing across areas receiving long-term average annual rainfall of 380- 650 mm. Average annual rainfall over that period has ranged from 70% below to 50% above average across sites, with growing season rainfall varying by a similar magnitude. Across year and seasonal conditions, summer sowing has resulted in production of 4-10 t dry matter (DM)/ha, considerably higher than that achieved when pastures were conventionally sown (Table 1). Under drought conditions summer sowing maintained a similar level of production to the overall average and showed capacity for elasticity in response to improved conditions in wetter than average years.

Table 1. Total herbage production for annual legumes established via summer sowing (t DM/ha) as unprocessed seed in February or via conventional sowing of scarified seed in late May averaged over all years, in drought years or in higher than average rainfall years for 18 experimental sites between 2012 and 2021 in central and southern NSW. The herbage production for subterranean clover established via conventional sowing is also shown.

	Overall average (t DM/ha)	Drought year (t DM/ha)	Wet year (t DM/ha)
Summer sowing[1]	4-10 (av 4.8)	4-6 (av 4.1)	4-20 (av 8.6)
Conventional sowing[1]	0.3-4 (av 0.9)	0.3-1.8 (av 0.6)	2-5.5 (av 2.4)
Subterranean clover	0.8	0.3	2.0

[1] Species included were arrowleaf clover, biserrula, bladder clover, gland clover, French serradella and yellow serradella

With the exception of arrowleaf clover, all hardseeded legumes when established via summer sowing in extreme drought (2019), produced at least 80% of average herbage yield for all years (Figure 1). Capacity to maintain high levels of productivity in drought provides useful feed for livestock as well as building soil nitrogen for following crops. All species except bladder clover were also highly responsive to improvements in seasonal conditions producing 20-30% more herbage than the average across all years.

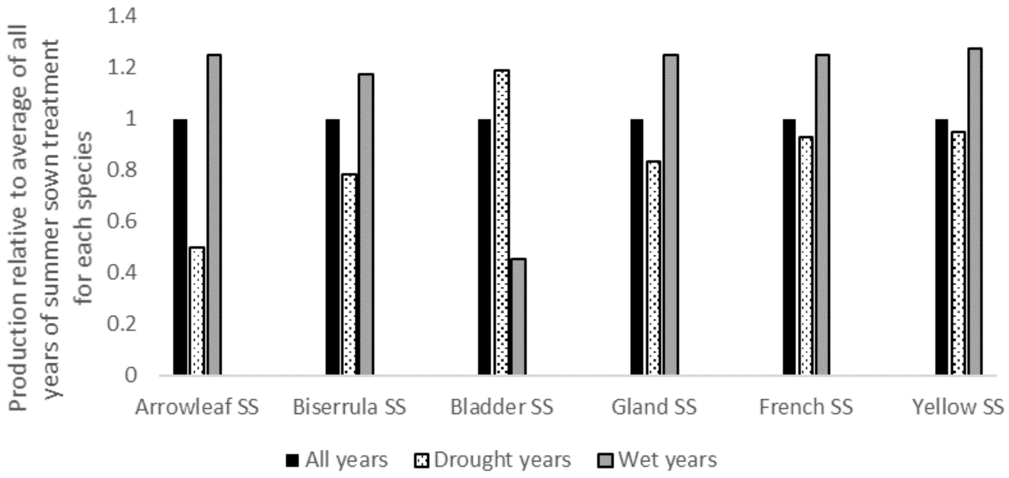

Figure 1. The herbage production of a range of hardseeded annual pasture legumes established via summer sowing relative to the overall average herbage production within each species averaged over 18 sites in NSW in the period 2012-2021.

N supply for following crops

The capacity of hardseeded legumes to support following crop production has been under evaluation at a number of sites in NSW. Near Ungarie in 2019, a number of annual legumes were grown under severe drought conditions in a replicated experiment with wheat included as a control. In 2020, the site was sown to wheat with the plots split for nitrogen treatment. Nitrogen treatments were either nil nitrogen, nitrogen applied at sowing only (as MAP) or nitrogen applied at sowing plus topdressing with urea at GS31.

Despite the severe drought of 2019, all hardseeded legumes provided sufficient nitrogen to support grain yields in 2020 of >3.8 t/ha without addition of nitrogen (Figure 2). Application of nitrogen at sowing or at sowing and then at GS31 did not increase the grain yield above that achieved by the nitrogen provided by the legumes alone. In contrast, both the continuous cereal and subterranean clover treatments showed significant response to addition of nitrogen at sowing with a further significant increase if nitrogen was also applied again at GS31. Further, the continuous cereal and subterranean clover treatments, application of nitrogen at sowing and at GS31 was required to produce an equivalent grain yield to the hardseeded legumes where no nitrogen was applied. Results for grain protein followed a similar pattern with wheat grown after hardseeded legumes achieving 12-14% protein without addition of any nitrogen compared to 8-9% wheat grown in the continuous cereal rotation or after subterranean clover. Application of nitrogen as sowing and GS31 was required to lift grain protein to 11% in the continuous cereal rotation.

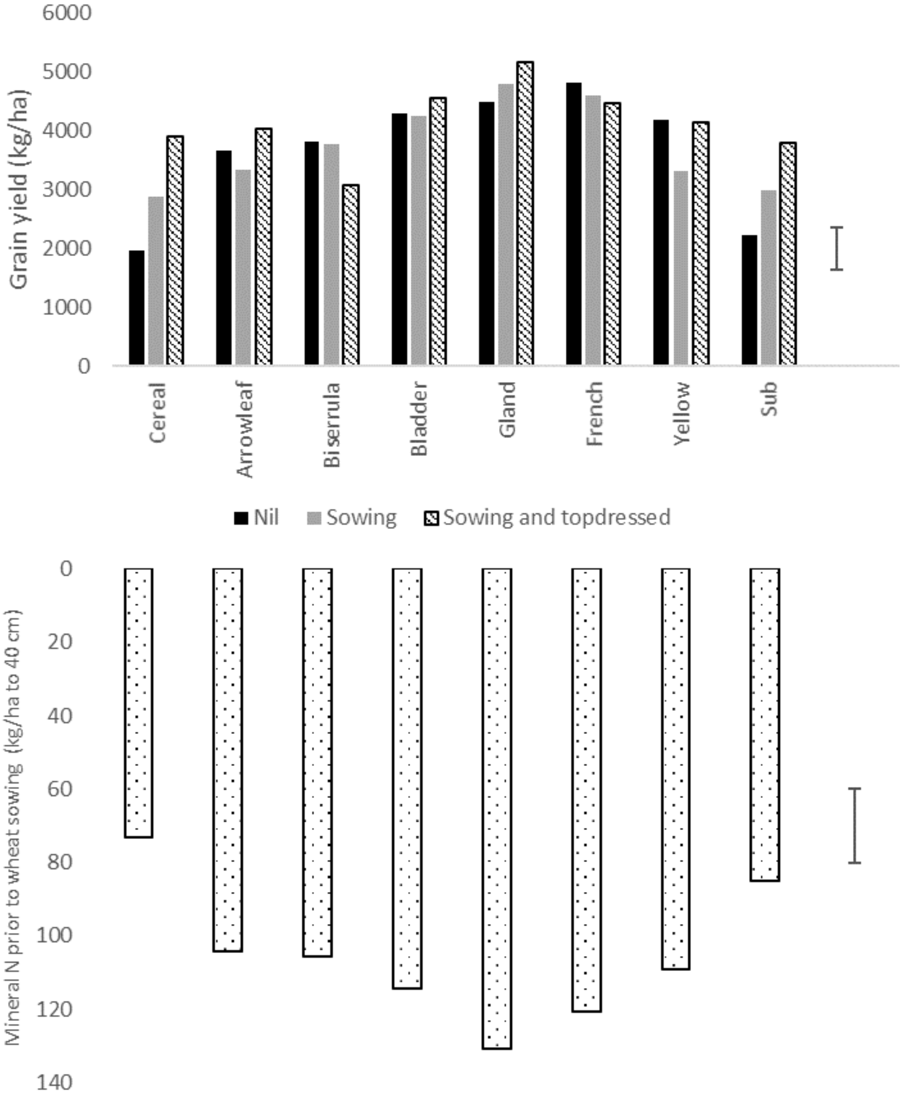

Figure 2. The grain yield of wheat (kg/ha) where no nitrogen, nitrogen at sowing only or nitrogen at sowing and at GS31 was applied in 2020 grown after a range of hardseeded annual legumes, wheat or subterranean clover in 2019. Soil mineral nitrogen prior to wheat sowing in 2020 is also shown.

Feed quality for livestock

Previous research has shown that at the same stage of growth, the feed quality of hardseeded legumes is similar to that of traditional legumes such as subterranean clover (Hackney *et al.*, 2021a). Therefore, when utilised directly via grazing, it would be expected that similar liveweight gains would be achieved if intake is not restricted by herbage availability.

However, capacity for increased production from hardseeded legumes due to better tolerance of variable growing conditions or because of suitability to summer sowing, means that there is potential for greater levels of livestock production to be achieved. Such increases in livestock production may be achieved through utilising the forage produced directly by grazing (i.e. increasing stocking rate) or via strategic fodder conservation when seasonal conditions allow.

In terms of fodder conservation, it is important to consider the timing of cutting. The quantity of herbage available and its quality can change rapidly throughout spring, which has a significant impact on the potential liveweight gain that might be achieved later in feeding the conserved fodder. At a site near Condobolin in 2021, the quantity of herbage available for fodder conservation from hardseeded legumes established via summer sowing was monitored over the growing season (Figure 3). If we consider the probable times for making silage (15 September) and hay (16 October), it can be seen that the quantity of herbage available at each time was reasonably stable, but the stem, leaf and reproductive plant material ratio varied considerably. We are still awaiting plant quality analysis for these data. However, based on our previous research, we know that in mid-September at the late vegetative-early reproductive stage of growth, the digestibility and protein of the herbage of hardseeded legumes would range between 65-69% and 21-29%, respectively. By mid-October, given the plants stage of growth, digestibility would be in the order of 59-62% and protein 13-20% (Hackney *et al.*, 2021a). From a livestock production perspective, delaying harvest from mid-September to mid-October, the likely decline in feed quality would see the potential liveweight gain of weaner steers decline from 2.5 kg/hd/d to 1.6 kg/hd/d (Grazfeed version 32). In this scenario, the potential liveweight gain declines from 1.1-3.1 t/harvested ha as silage to 0.75-2.3 t/harvested ha for hay, depending on legume species. In some situations there may be an increase in herbage availability between probable silage and hay cutting times, however, the inevitable decline in plant quality over that time almost always means that there will be a reduction in potential liveweight gain on a per head basis (Note: these calculations include factoring in of 20% loss due to residual herbage below cutting height and losses during the fodder conservation process).

Whether the increase in herbage availability makes up for the decline in feed quality will determine what the absolute livestock production per harvested hectare will be. Clearly, however, summer sowing of suitable species offers scope for increasing livestock production either directly via grazing or indirectly via conservation as compared to the conventional sowing of traditional legume species such as subterranean clover or annual medics (Figure 3).

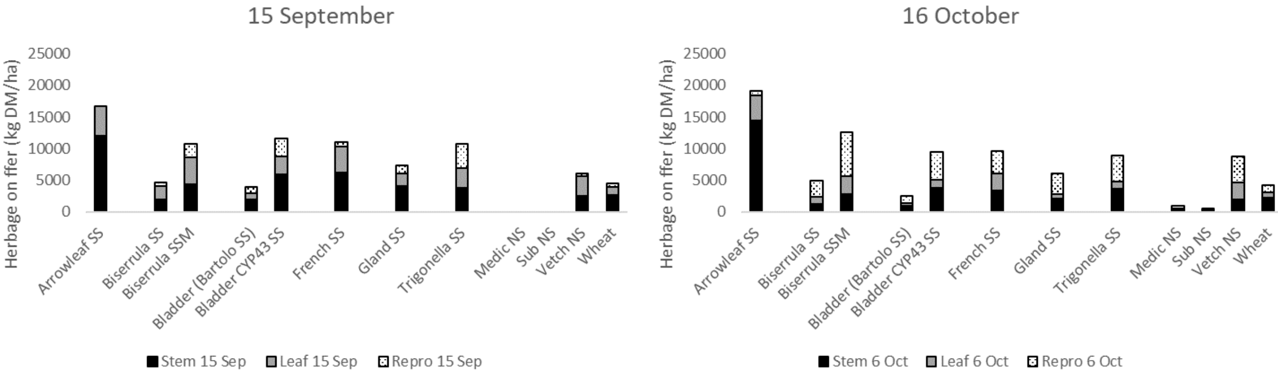

Figure 3. Herbage on offer (kg DM/ha) of stem, leaf or reproductive plant components for a range of hardseeded legumes established via summer sowing (SS) or for annual medic, subterranean clover and vetch established via conventional sowing and wheat at probable silage (15 September) or hay (16 October) cutting times at Condobolin in 2021.

Considerations when using hardseeded legumes in rotations and specific considerations for summer sowing

Hardseeded annual legumes can be highly successful when used in rotation with crops. However, there are certain fundamental management requirements that must be satisfied in order to ensure success in growing them. Many of these principles are common to traditional legumes but some are specific to the hardseeded legumes.

Paddock preparation

All plants have four fundamental requirements for growth; space, light, moisture and nutrients. Paddock preparation is key in setting a foundation for satisfying these requirements when sowing any new pasture. Running down the weed seedbank in the years leading up to sowing a new pasture is critical to establishment success. Competition from weeds is the leading cause of establishment failure in newly sown pastures. A minimum of two, but preferably three years of absolute weed control leading up to pasture sowing are essential to minimise weed competition in newly established pastures. For many weed species providing there is no topping up of the seedbank (e.g. wind borne seed, seed from weed escapes, seed transported by water, machinery or livestock), populations within the weed seed bank can be drastically reduced in a two to three year period (Figure 4). However, it is important to consider the absolute number of weed seeds that main remain in the seedbank rather than just the percentage. For example, a 3% survival of a weed seed after three years with an initial seedbank population of 300 seeds/m^2 gives a vastly different competition scenario to 3% survival from an initial seedbank population of 10 000 seeds/m^2. Populations of the same weed can also exhibit differences in how quickly seed will decline in number within the seedbank with locality. Local climate and soil conditions (e.g. temperature, temperature variation, moisture) can influence factors such as germination, dormancy and emergence of weed seeds. Similarly, management can influence population dynamics of a weed population. For example, development of herbicide resistance can result in changes in seed behaviour of resistant weed populations within the seedbank or regular use of specific herbicides may see plants develop escape mechanisms such as later emergence. Such factors can result in changes in the weed competition risk profile when sowing new pastures. The key point is to plan well ahead when considering sowing any new pasture to minimise potential weed competition.

Some weeds such as wild radish and spiny emex can persist at low levels in the seedbank over an extended period of time and for species such as these, survival of the seed is aided if the seed is buried at depth. The population density of these species can rapidly rebound from low levels due to their ability to produce large quantities of seed per plant. However, significant reductions in seedbank populations can still be achieved over a three-year period. As with any weed, strategies for selective control once a pasture is established must be considered in advance to prevent weeds rapidly increasing in density. Carefully considering herbicide tolerances of pasture species to be sown is an important in the planning process to maximise options for selective weed control. Similarly, thought should be given to other tactical options that can be used to control weed seed set leading up and following pasture sowing. This may include use of tactical grazing, spray-grazing or strategic fodder conservation. Research in Victoria demonstrated an 80% reduction in the wild radish seedbank population through instigating silage cutting in one year (Henne and Sale 2014).

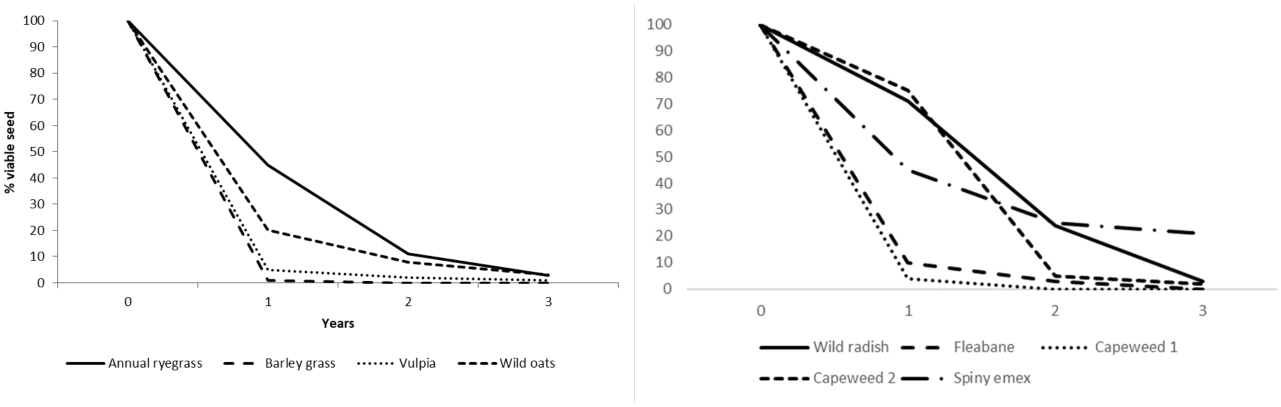

Figure 4. The percentage of seed in the soil seedbank remaining viable over a three year period for a range of grass and broadleaf weed species. Source: Cheam (1987), Dowling (1996), Peltzer et al. (2002), Dunbabbin and Cocks (1999), Green et al. (2010).

Herbicide residues

Ensure, when sowing new pastures, that all plant back requirements have been met prior to sowing. Carefully check the herbicide label. Herbicides can have time, rainfall and/or specific soil moisture requirements for breakdown. Additionally, some herbicides present different risks for residues associated with soil pH or texture. The rate of application also needs to be considered for some herbicides. It is critical to have accurate records of what herbicides have been used in previous crops and to make sure all requirements for safe plant back have been met. Remember, if you are undertaking summer sowing, this will occur some 3-4 months earlier than traditional pasture sowing meaning that plant back requirements need to have been satisfied at the time of sowing so that seed, inoculant and early germinating pastures are not exposed to residues.

It is also critical to be mindful of herbicides used in the maintenance of summer fallow following harvest of the previous years crop. It is not uncommon to see poor establishment in newly sown pastures due to a forgotten herbicide used in the summer fallow. A recent survey (n=155 farming businesses) found that more than half had used at least one herbicide in the fallow that would present a risk for pasture legumes they intended to sow that year, either via summer or conventional sowing (Hackney et al. 2021b)

Species selection

When choosing which hardseeded legume(s) to grow, it is important to determine if what you want to grow aligns with what you should grow. What you should grow is determined by your climate, soils and the type of pasture-crop rotation system you intend to run.

Most of the hardseeded legumes will grow well in soils with good drainage where soil pHCa is in the range of 5.0-7.0 (Table 2). Species such as serradella and biserrula have good tolerance to more acidic soils. All species in Table 2 have good tolerance to drought conditions. However, arrowleaf clover tends to produce seed later in the season than other hardseeded legume species and so under severe drought conditions, its seed production may be compromised.

Residual hard seed levels are an important consideration in species selection for inclusion in crop rotations. Residual hard seed is a measure of how much of the seed produced in a given season that remains hard by the following autumn. Higher levels of residual hard seed mean that the legume will be more persistent in the seed bank over time and has the capacity to withstand a longer cropping interval and regenerate without the need for resowing.

Generally, cultivars of legume species with residual hard seed of 40-60% are well suited to 1:1 rotations (that is alternating years of pasture and crop). Occasional two-year crop intervals may also work well with such cultivars once a couple of years of legume seed set have occurred. For cultivars of legume species that have higher hard seed levels (>70%), cropping phases of 2-4 years are feasible.

Table 2. Preferred soil pH_{Ca} for hardseeded annual legumes and their rhizobia, suitable soil texture and soil drainage characteristics, drought tolerance and residual hard seed percentage in the autumn following seed set.

	pH_{Ca} (Plant)	**pH_{Ca} (Rhizobia)**	**Soil texture**	**Soil drainage**	**Drought tolerance**	**Residual hard seed[2] (%)**
Arrowleaf clover	4.8-8.0	5.5-7.5	Sandy loam to medium clay	Good drainage	Good	40-60
Biserrula	4.2-7.5	4.8-7.0	Sandy loam to loam	Good drainage	Excellent	70-90
Bladder clover	5.0-8.0	5.5-7.5	Sandy loam to loam	Good drainage	Very good	40-60
Gland clover	4.8-8.0	5.5-7.5	Sandy loam to clay	Good to poorly drained	Very good	40-60
French serradella[1]	4.0-7.0	4.5-7.0	Sand to loam	Good drainage	Very good to excellent	40-60
Yellow serradella	4.0-7.0	4.5-7.0	Sand to loam	Good drainage	Very good to excellent	40-80

[1] This information refers to the hardseeded French serradella cultivars Fran2o, Margurita and Erica.

[2] The hard seed remaining in the autumn following seed set

Which cultivars of the hardseeded legume species are suitable for summer sowing?

There are a limited number of commercially available cultivars of most of the hardseeded legume species. As an example, there is only one cultivar each of gland clover and bladder clover and these have proven to be successful for use in summer sowing. For both French and yellow serradella, a number of cultivars are available. For French serradella, the cultivars Fran$_2$o, Margurita and Erica are suitable for summer sowing. For yellow serradella, we have had success with Avila and a soon to be released cultivar. It should be noted that Avila is not well suited to areas receiving less than 500 mm average annual rainfall.

For biserrula, we have had good success in sowing unprocessed seed for summer sowing. However, in cases where summer is extremely dry, hard seed breakdown can be restricted and therefore plant density may be lower than desirable. In the past two years we have been experimenting with seed that has been lightly scarified (25% germination). Use of partially processed biserrula seed in summer sowing has resulted in a significant increase in plant density and biomass production (Figure 5).

It is critical to check local trial results in determining which species/cultivars are suited to summer sowing in your area. As stated earlier in this paper, initial field trials in WA suggested bladder clover and the hardseeded French serradella cultivars were suitable for summer sowing in their hot, summer-dry conditions. However, in NSW, where many areas receive more summer rain and/or retain higher levels of soil moisture due to the higher clay content of soils, use of other species/cultivars are possible. Remember to carefully assess your particular situation with regard to summer rainfall, soil and temperature conditions and seek advice if you are unsure.

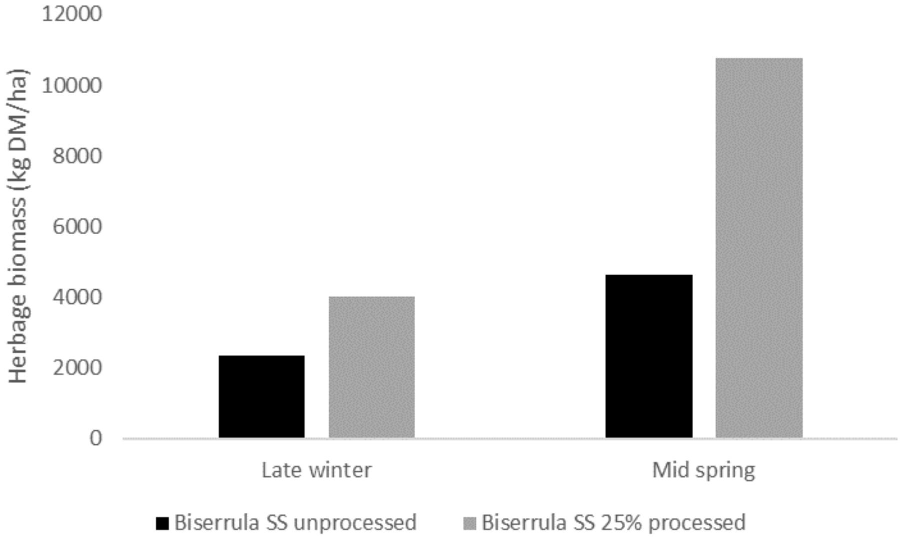

Figure 5. Herbage biomass (kg DM/ha) of summer sown biserrula where seed was either unprocessed or where a mix of 75% unprocessed and 25% scarified seed was sown.

Sowing time

For summer sowing, unprocessed seed is used. For the clover species and biserrula, this means seed that has not been scarified, while for serradella, pod segments are used. Adequate time is required for a proportion of the hard seed to break down for germination. Summer sowing is generally best undertaken from mid January to late February. However, successful establishment has occurred where sowing has occurred as early as December or as late as mid March. However, it is important to note that sowing beyond late February may result in reduced hard seed breakdown and lower plant density.

Sowing rate

Summer sowing requires a source of unprocessed seed. Generally, growers will have a nursery paddock from which they harvest seed and then use this to sow other areas of the farm. Use of nurseries can be a useful way to evaluate which species might work best for your farm. We frequently advise growers who have not previously grown hardseeded legumes to grow nursery blocks of 5-20 ha of a range of species (using purchased scarified seed sown in autumn). Growers can then harvest species that work best for them and use this unprocessed seed in summer sowing operations.

When summer sowing the hardseeded clovers or biserrula, the minimum suggested sowing rate is 12 kg unprocessed seed/ha. For serradella pod segments, a minimum rate of 20 kg/ha is used.

Inoculants

It is critical to ensure the correct inoculant group is used for each legume sown. Additionally, sowing in summer presents additional challenges of high temperature and often limited soil moisture, both of which can adversely impact rhizobia survival. Low moisture clay granular inoculant has proven to be an effective form of inoculant delivery in our summer sown field trials since 2012.

Fertiliser at sowing

Adequate nutrition is critical for both the legume plant and for rhizobia. Recent surveys have shown that phosphorus deficiency prevalence is relatively low (<30%) compared to sulphur deficiency (>75%) in soils of central and southern NSW (Hackney et al. 2021b). However, most growers (70%) use MAP or DAP when sowing new pastures. Ensure that soils are analysed from paddocks to be sown to new pastures and that appropriate fertilisers are used to address deficiencies that may be present.

Management following the establishment year

Our field trials have shown that hardseeded legumes produce 4-10 t DM/ha within the growing season. This represents potential nitrogen fixation of 80-250 kg N/ha (Table 1). We often find that growers want to allow legume pastures to regenerate in the second year. However, growers need to consider the value of nitrogen for supporting production of following crops. As shown in Figure 2, the use of hardseeded legumes in rotation with crops can significantly reduce the expenditure required on N-fertiliser to support crop production. Further, large quantities of unutilised nitrogen present an opportunity for weed proliferation.

Flexible rotations

Once a seedbank of hardseeded legumes is established, there is opportunity to alter how pasture-crop rotations are managed in response to seasonal conditions and commodity prices. With an on-demand seedbank in place, growers have the opportunity to flex and change their pasture to crop ratios and hence livestock to crop ratios within short timeframes. As an example, if seasonal conditions are predicted to be poor and high risk for cropping, then paddocks with a seedbank of hardseeded legumes can be allowed to regenerate and the herbage utilised for livestock and/or to build soil nitrogen for subsequent crops. Alternatively, if returns from cropping are high, then paddocks can be put to crop knowing that there is sufficient seed in the seedbank to allow for regeneration after the crop.

The crop phase length that can be imposed without needing to resow depends on residual hard seed levels of the legumes. For species with very high residual hard seed levels such as biserrula and some cultivars of yellow serradella, it is possible to crop over paddocks where there has been high initial seed set for 3-5 years and have strong regeneration of the legume. For species such as arrowleaf clover, bladder clover, gland clover and hardseeded cultivars of French serradella, rotations of one year crop, one year pasture are suggested, although once the legume has set seed a number of times, the seedbank will support occasional two-year cropping phases without needing to be resown.

Ultimately, the length of the crop phase imposed over the legumes will involve balancing out nitrogen supply provided by the legumes relative to requirements of the crop as well as considering the relative value of cropping and livestock to the overall farming system within and between years.

Conclusions

Over the last decade, summer sowing of hardseeded legumes has proven to be an effective means of establishing highly productive pastures. Summer sowing has been robust in the face of seasonal variation including extreme drought providing feed for livestock and nitrogen for subsequent crops. From a cropping perspective, hardseeded legumes have supported high levels of grain production in the year following their growth without requiring additional N-fertiliser; a significant cost and risk mitigation strategy that can be incorporated into contemporary farming systems. The ability of hardseeded legumes to maintain productivity in drought conditions, yet exhibit elasticity in response to improved seasonal conditions and provide additional options for use such as fodder conservation can only be beneficial in achievement of crop and livestock production goals. Perhaps though, one of the greatest advantages of hardseeded legumes is the capacity for growers to flex and change their crop and pasture ratios over short time periods once a seedbank is established in response to seasonal and commodity price conditions.

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Discussion notes

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