Crops sensors — just part of the big picture

WRITTEN BY

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Recent trials carried out in Lubeck, Victoria have shown that crop sensors can be used to determine potential nitrogen uptake in-crop, but sensor results still need to be weighed up carefully with current soil moisture conditions and predictions.

KEY POINTS

- **Crop sensors can be used successfully to determine nitrogen requirements of crops at various growth stages.**
- **Nitrogen application decisions are still best made using a variety of decision-support tools, including current and predicted soil moisture levels, crop requirements and yield potential estimations combined with current fertiliser and grain prices.**

A recent Grains Research & Development Corporation (GRDC) funded project, aimed to determine whether crop reflectance at particular wavelengths of light could be used during stem elongation to determine the need for applied nitrogen.

Derrimut wheat was established in large plot trial (individual plot 6 metres x 30m) using a 12m Simplicity + Janke (narrow tyne) seeder with 22.5 cm (9”) row spacings, following a lentil crop grown during 2007.

The wheat crop was fertilised with granular urea (46 per cent nitrogen) at five different rates (0, 25, 50, 75 and 100 kg N/ha) applied at three different timings (see Table 1).

The trial was subject to a comprehensive assessment programme including crop structure assessments, dry matter (DM) and nitrogen content analysis, green area index (GAI), assessment with a hand-held Greenseeker, *Yield Prophet* monitoring, yield and quality analysis.

In order to determine whether there was a relationship between plant nitrogen uptake and crop reflectance (measured with the Greenseeker), above-ground dry matter was assessed at key growth stages during spring to determine dry matter and % nitrogen content.

Understanding crop sensor technology

Crop reflectance sensors, such as the Crop Circle and GreenSeeker, measure light reflectance from the crop canopy at different wavelengths of light. Reflectance, in the red and infrared wavelengths is strongly influenced by the biomass and chloropyhll content. The greater the chlorophyll content of the crop, the less red light is reflected. With greater biomass content there is an increase in near infrared (NIR) reflectance.

These wavelengths are used to calculate normalised difference vegetative index (NDVI) for the crop, which is a simple index of canopy greenness.

$$\text{NDVI} = \frac{\text{reflectance at the red} - \text{near infrared wavelength}}{\text{reflectance at red} + \text{near infrared wavelength}}$$

TABLE 1 Nitrogen timing and rainfall subsequent to application (mm)

Nitrogen timing	Description	Date of application	Rainfall following
1. 100% pre sowing	Single dose — pre sowing	May 14, 2008	23mm May 18
2. 100% GS30	Single dose — at start of stem elongation	July 30, 2008	3.5mm July 31 6mm August 2
3. 50% GS30 f.b. 50% GS38	Split dose applied at start of stem elongation (GS30) and flag leaf (50% emerged, GS38)	July 30, 2008 September 12, 2008	1.5mm September 16 5mm September 25

For most agricultural crop canopies, readings are between 0 and 1. The higher the reading, the greater canopy greenness.

The GAI is a measure of the green surface area of the crop canopy and in this trial it was measured manually. GAI is expressed in m^2 of green canopy occupying $1m^2$ of soil. For example, a GAI of 6 means there is $6m^2$ of green surface on $1m^2$ of soil. Only one side of the leaves is taken into account when calculating GAI.

Trial results

This site was assessed to have 253kgN/ha in the 0–100 centimetre m profile when assessed on the April 28, 2008 with more than 60% of the available nitrogen in the top 40cm.

Crop structure assessments and visual appearance were strongly linked to the fertile nature of the paddock.

Tiller numbers averaged more than 700tillers/m^2 with head counts averaging 560heads/m^2 (average across all treatments). There was no difference in tiller number recorded at the start of stem elongation between 0 and 100kgN/ha applied at sowing.

The same was true with head counts recorded just before harvest.

The differences in tiller loss due to nitrogen rate and timing were small. With lower soil nitrogen reserves in previous seasons, nitrogen at sowing has lead to both higher tiller numbers and higher tiller loss between stem elongation and maturity.

Yield Prophet was used to estimate crop yield performance and potential need for nitrigen. *Yield Prophet* is an online crop production model designed to provide grain growers with real-time information about the crop, providing integrated production risk and monitoring decision support relevant to farm management.

Indications from *Yield Prophet* showed that despite the high yield potential of the site recorded during July and August (at the start of stem elongation *Yield Prophet* gave 80% probability of achieving 5t/ha, see Figure 1), applied nitrogen would not be needed to reach maximum yield. The situation had not changed significantly at the end of August GS32-33 (see Figure 2).

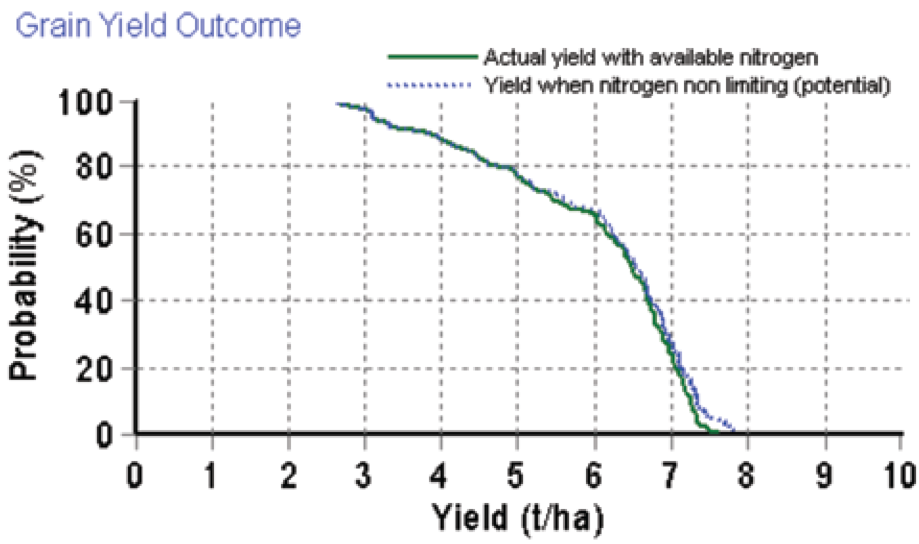

FIGURE 1 ***Yield Prophet* grain yield probabilities taken from July 31 Report (GS30) on Lubeck wheat sown May 14, 2008, cv Annuello**

While yield estimates were on the high side, the predictions surrounding the use of applied nitrogen were accurate.

One possible explanation for yields being on the high side was that since the phenology for Derrimut was not available, the report was based on Annuello. *Yield Prophet* predictions were about 8-10 days later at GS30 and GS31 than the growth stages recorded with Derrimut in the field (GS30 was predicted for about August 8 whereas Derrimut in the field was at GS30 on July 31). However, the probability curve does include the grain yield outcome achieved in the field.

Crop reflectance and nitrogen uptake

Above-ground dry matter assessments at two at key growth stages during spring to established the relationship between nitrogen uptake by the plant and NDVI (see Figure 3).

The trial was also assessed with the Greenseeker in order to quantify differences in 'greenness' between treatments (see Figure 4). This assessment showed no significant difference in NDVI until GS38 when higher nitrogen rates gave significantly higher NDVI compared with the control. It was not until flag leaf that the Greenseeker could detect differences in NDVI, which also corresponded to differences in plant uptake of nitrogen.

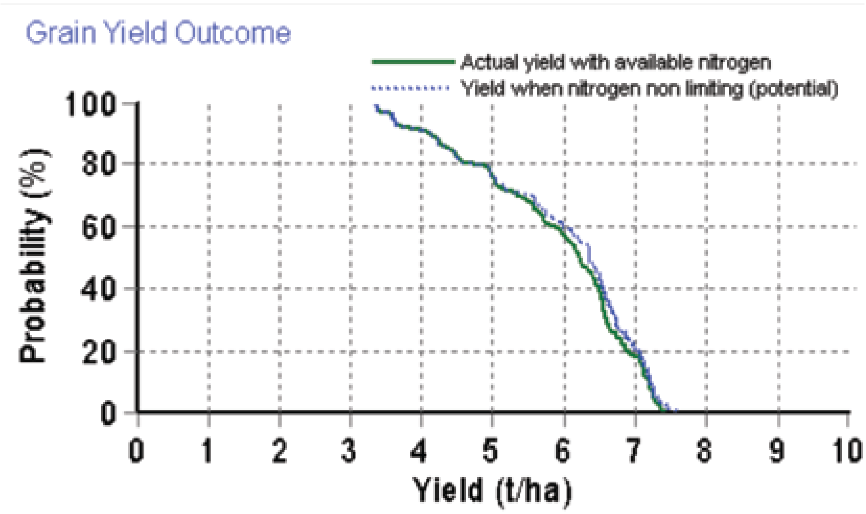

FIGURE 2 ***Yield Prophet*** **grain yield probabilities taken from August 29 Report (GS32-33) on Lubeck wheat sown May 14, 2008, cv Annuello**

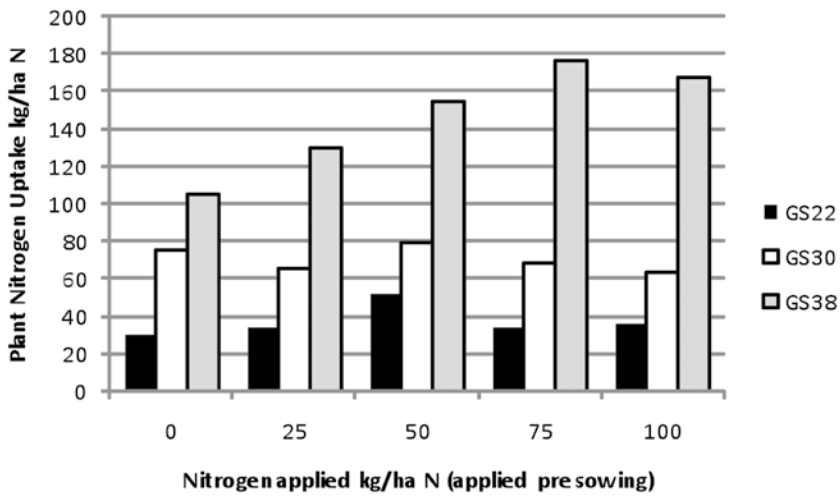

FIGURE 3 Nitrogen uptake in above-ground biomass at GS22 (main stem and two tiller), GS30 (pseudo stem erect) and GS38 (50% flag leaves emerged on the main stem) for different rates of pre-sown nitrogen (0, 25, 50, 75 and 100 kg N/ha) in wheat — cv Derrimut

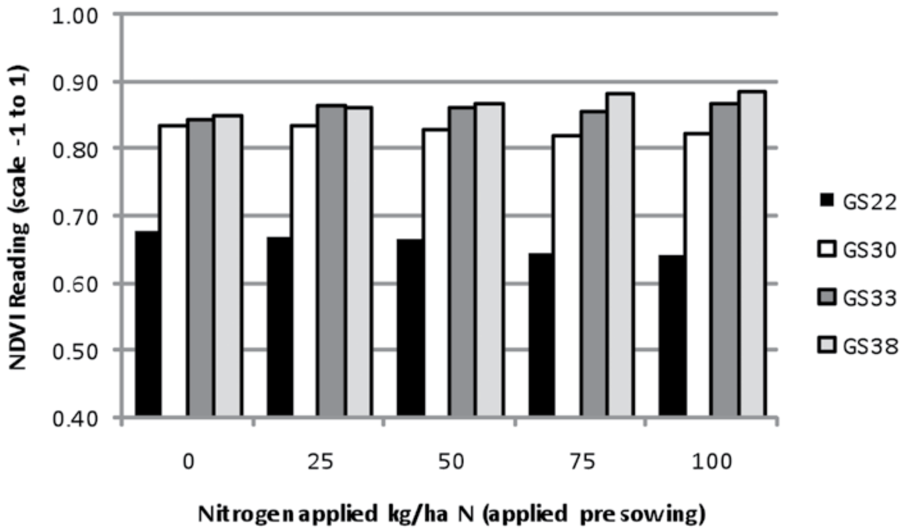

FIGURE 4 NDVI readings taken with the Greenseeker at GS22 (main stem and two tiller), GS30, (pseudo stem erect) and GS38 (50% flag leaves emerged on the main stem) for different rates of pre-sown nitrogen (0, 25, 50, 75 and 100 kgN/ha) in wheat — cv Derrimut

When NDVI readings from the different growth stages were plotted against plant nitrogen uptake there was a strong correlation, indicating that crop reflectance up to flag leaf could be linked to nitrogen uptake (see Figure 5). However, differences in nitrogen uptake due to different growth stages were greater than differences generated by different nitrogen rates in this fertile paddock situation.

Though the absolute differences in crop reflectance were small (see Figure 6), there was significantly higher NDVI associated with nitrogen application when assessed from GS38–87 (compared with the nil-nitrogen control), which was not apparent at GS30 and 33.

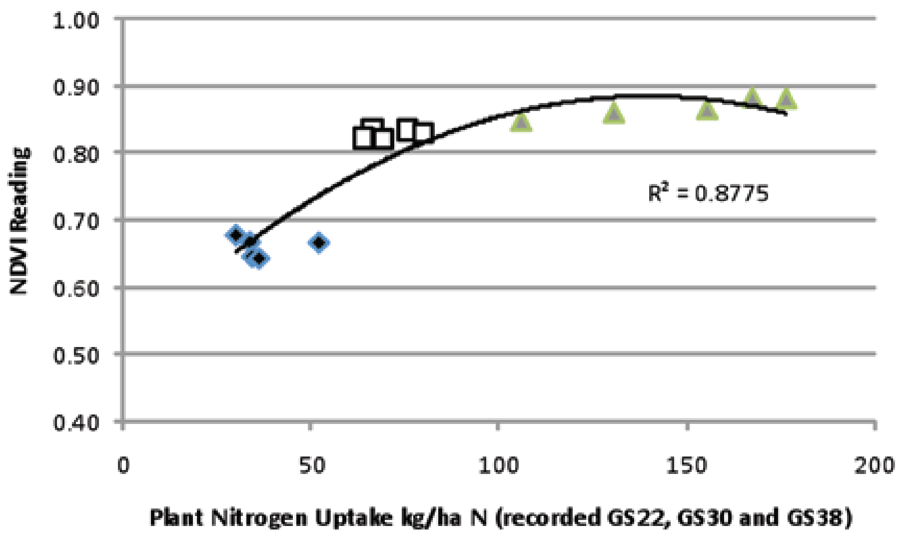

FIGURE 5 NDVI readings taken with the Greenseeker at GS22 (main stem and two tiller), GS30 (pseudo stem erect) and GS38 (50% flag leaves emerged on the main stem) and the relationship with plant nitrogen uptake (in above-ground biomass) in wheat — cv Derrimut

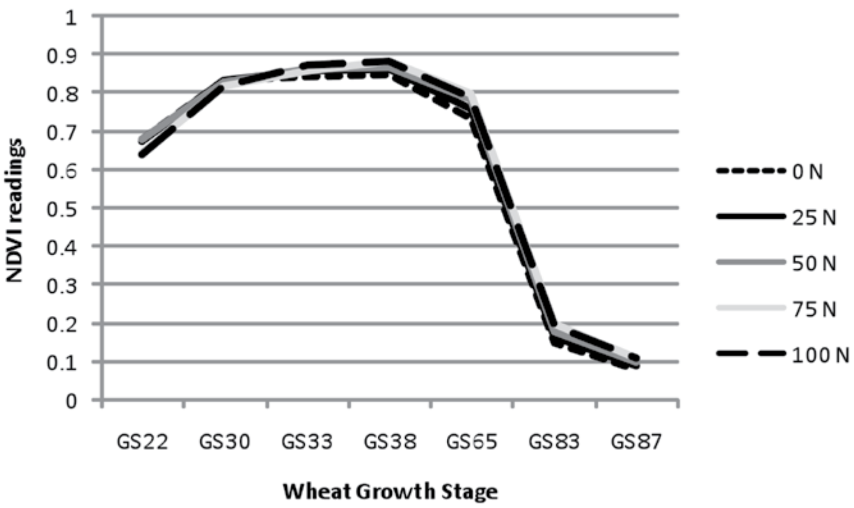

FIGURE 6 NDVI readings taken from GS22 (tillering) through to GS87 (late grain fill) based on crops treated with five rates of nitrogen at sowing – cv Derrimut

At GS65 the difference in NDVI between different levels of upfront nitrogen was ground truthed by examining the GAI of the crops fertilised at sowing with 0, 50 and 100kgN/ha level. This revealed that GAI in these treatments increased from 5.7 to 5.92 to 6.65 (m^2 of green canopy on one square metre of soil) with increased nitrogen application.

Water stress

At GS65 the crop was clearly water stressed based on *Yield Prophet* predictions (22mm below the stress threshold) having crossed the stress threshold at ear emergence GS55-59 (see Figure 7).

The predicted water stress during grain fill mirrors the sharp drop in NDVI observed between GS65 and GS83 (see Figure 6).

Grain yield and protein

There was a significant trend for increasing amounts of applied nitrogen to reduce yield, irrespective of nitrogen timing.

In association with the decreasing yield there was an increase in grain protein (see Figures 8 and 9).

The later nitrogen split was higher yielding than earlier applications, however evidence from weather records and grain protein (see Figure 10) suggested the later application of the split (GS30/38) was not taken up, hence did not reduce yield to the same extent.

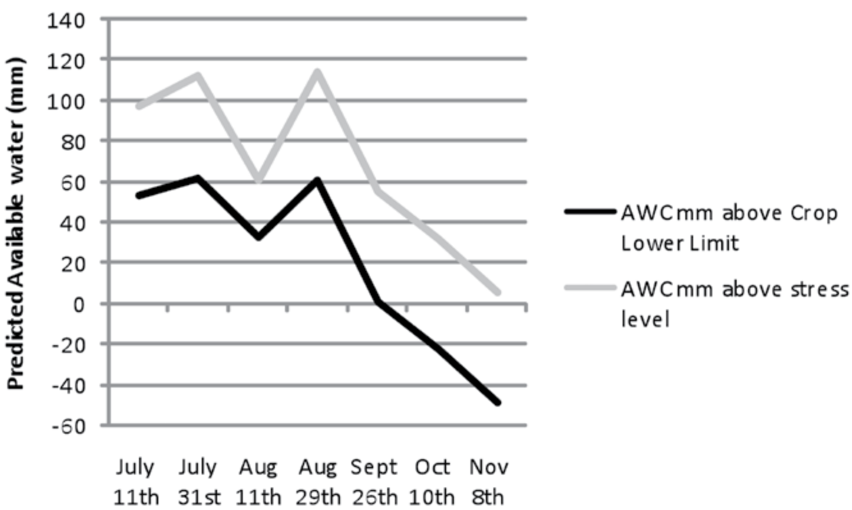

FIGURE 7 *Yield Prophet* predictions of soil water content (mm) in relation to stress threshold (for wheat) and crop lower limit based on *Yield Prophet* reports from July 11 to November 8 — Lubeck, Wimmera Grey Clay.

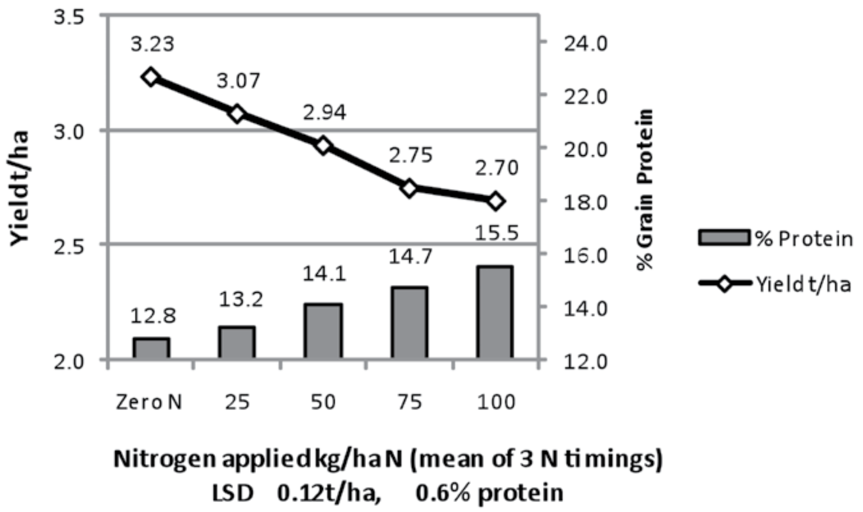

FIGURE 8 Influence of nitrogen rate on yield (t/ha) and % protein of Derrimut wheat grown at Lubeck (average across three nitrogen applications)

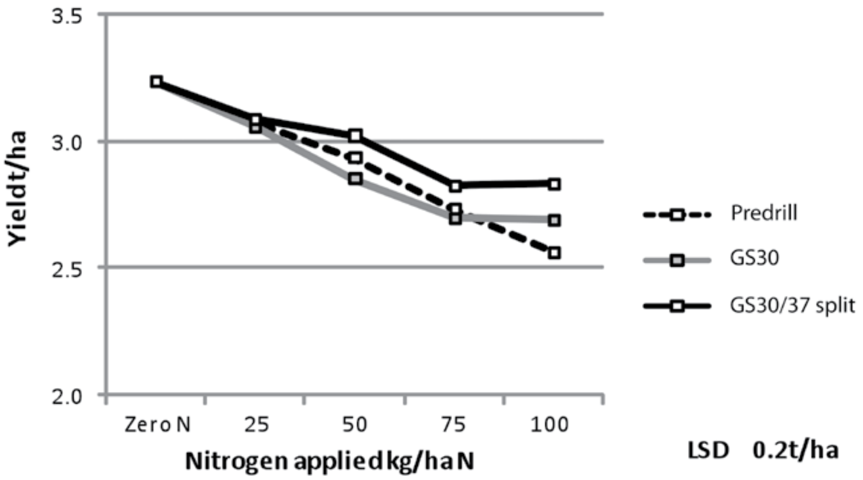

FIGURE 9 Influence of nitrogen timing and rate on yield (t/ha) of Derrimut wheat grown at Lubeck

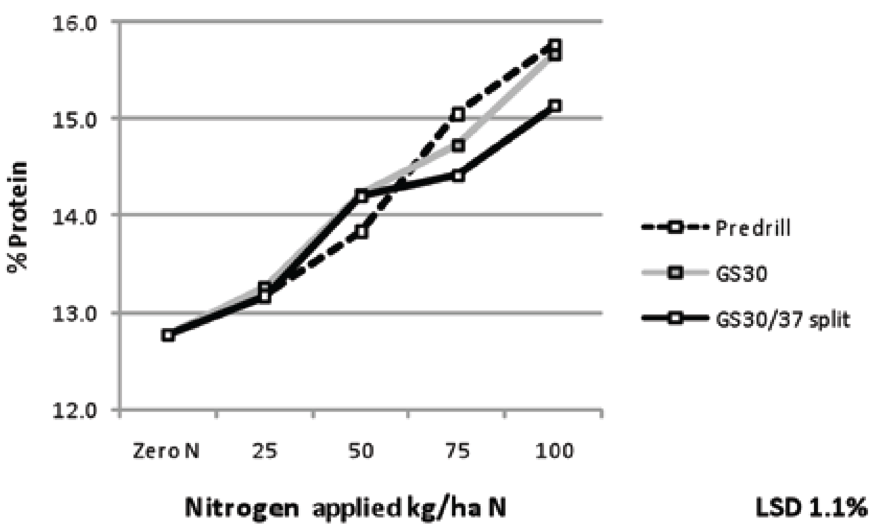

FIGURE 10 Influence of nitrogen timing and rate on grain protein (%) of Derrimut wheat grown at Lubeck

Crop gross margins

Reduced yield from additional nitrogen led to a reduction in gross income after urea cost was taken into account (see Table 2).

This effect was more pronounced during 2008 due to high fertiliser prices. Though nitrogen fertiliser increased grain protein content from H2 grade to H1, this $4/t advantage was small relative to the overall fertiliser cost and its negative yield impact.

The average margin of the split nitrogen timings was higher than the pre-sowing and GS30 applications, principally due to lack of uptake of the second nitrogen dose.

Interpreting the results

Nitrogen content of the plant (kgN/ha) was correlated to NDVI readings from the Greenseeker when assessed from tillering to flag leaf emergence.

Different rates of nitrogen at sowing created nitrogen-rich strips for comparison of canopy greenness and NDVI later during spring. Based on the comparison of these different levels with the nil-nitrogen plots it was possible to conclude that the crop canopy was not nitrogen deficient at tillering and early stem elongation (based on no difference in canopy greenness as detected by Greenseeker readings in NDVI).

Up to GS30 the Greenseeker was useful for confirming that nitrogen uptake in above-ground biomass was the same irrespective of the amount of nitrogen applied at sowing —nitrogen fertiliser was not required.

At flag leaf emergence there was clear evidence from NDVI readings and plant nitrogen uptake that the nil-nitrogen treatment was giving lower readings than where nitrogen had been applied at sowing.

The differences in NDVI were small but statistically significant. It was assumed that nitrogen-rich crops possessed the desirable level of greenness and plant nitrogen content. It might be argued that nitrogen should have been applied at this later timing. During last season's Lubeck trial, nitrogen applied at GS33 created the highest yields.

In fact, the higher NDVI, plant nitrogen content and resultant GAI of these nitrogen-rich crops served to reduce yield compared with the untreated control. Application of nitrogen at GS38 as part of a split resulted in no advantage over the untreated crops, principally due to lack of rainfall for uptake at this later growth stage.

TABLE 2 Gross income ($/ha) for Derrimut wheat based on yield and protein after nitrogen costs (not including application cost)*

Nitrogen timing	N rate (kgN/ha)	Yield (t/ha)	Protein (%)	Gross income ($/ha)	Gross income — urea cost ($/ha)*
1. Single dose Pre-sowing	0N	3.23	12.8	779	779
	25N	3.08	13.2	753	702
	50N	2.94	13.8	720	617
	75N	2.73	15.1	669	514
	100N	2.57	15.8	628	422
2. 100% GS30 Single dose at start of stem elongation	25N	3.06	13.3	750	698
	50N	2.85	14.2	699	596
	75N	2.70	14.7	661	506
	100N	2.69	15.7	659	453
3. 50% GS30 f.b. 50% GS37 Split dose applied at start of stem elongation and flag leaf just visible	25N	3.09	13.2	756	705
	50N	3.02	14.2	741	638
	75N	2.83	14.4	692	538
	100N	2.83	15.1	694	488

*Based on AWB cash price for H1 of $245/t ($273/t — $28/t freight) and H2 at $241/t ($269/t — $28) delivered January 7th 2009. All treatments except zero N were H1 quality.
Cost of nitrogen as urea (46% N) — $950/t or $2.07/kg N.
Note: Application cost has not been included and growers should apply their own costs to these results. Clearly nitrogen timings based on a split application have higher costs than single applications, but have the advantage of spreading risk.
The following figures are put forward as a guide: pre drilling application costs $31/ha, top dressing $8/ha and at sowing using a triple bin less than $5/ha.

But, in a commercial situation if a change in NDVI was being used as the trigger to apply nitrogen, it is unlikely that any urea would have been applied due to the low stored soil water content and lack of rainfall for nitrogen uptake. This scenario was played out on the host farm where required nitrogen rates were split, with half applied at GS30-31 and the second dose planned to be applied at GS33-39. With low stored water and no rainfall during the critical period, the second dose of nitrogen was not applied. This illustrates that crop reflectance on its own cannot be used as trigger for nitrogen application, unless it can also measure moisture stress.

Greener crops set up as benchmarks to indicate when soil nitrogen was exhausted were successful at demonstrating the high soil nitrogen reserve up to flag leaf emergence GS38, at which time a lower NDVI of the nil-nitrogen plots correlated to lower levels of nitrogen in the plant. Using nitrogen at these later stem elongation timings was unsuccessful during 2008 since there was little rainfall subsequent to application.

During 2007, when GS33 represented the optimum application timing, there was both early November rainfall and 7.5mm following application at GS33. In addition with a soil nitrogen reserve of 113kgN/ha *Yield Prophet* predicted a 70% probability of obtaining a response to nitrogen in that season.

OVERVIEW

Summing up the results

This work serves to illustrate the value of knowing your soil nitrogen reserves with regard to nitrogen application, particularly where applications are being made at sowing.

In order to take advantage of crop reflectance technology, such as the Greenseeker, it will still be necessary to link outputs with soil water levels in order to secure the greatest value from this technology.

However the trial has served to illustrate that NDVI reading can be linked to nitrogen already present in the plant at key timings for spring applications.

The work, which is taking place at two other sites in Australia, will be repeated in a less fertile scenario next season.

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Insect management — strategic control and what's next

Photo: Kondinin Group

Redlegged earth mites: A combination of control options will give the most stable, long-term pest control.

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Long-term prophylactic use of broad-spectrum pesticides for insect pest control is unsustainable. The grains industry has highlighted the need to move towards strategic and selective control options that better target the pests of concern. Integrated pest management (IPM), in its simplest form, is a control strategy in which a variety of biological, chemical and cultural control practices are combined to give stable long-term pest control.

KEY POINTS

- **A change in mindset on how to tackle pests coupled with the development of a new set of decision-making tools is critical for sustainable insect management.**
- **Economic thresholds are flexible; not static.**
- **Monitoring programmes and record keeping for pests and beneficial insects is required over a substantial timescale.**
- **Long-term investment into ecosystem services can provide economic benefits.**

As growers progress with the desire to do something different, and change the way they tackle pests, agribusiness will need to undertake and actively engage in a 'transformative' learning process. Advisers and consultants must gain confidence in, and adopt, a new set of tools in the decision-making process, which encompasses a whole systems approach for sustainable insect management.

IPM principles are now well documented. However, when and how to intervene remain the key questions in the minds of most growers and advisers.

In order to move away from chemical-based control strategies, the use and worth of 'economic thresholds' as the front line for decision-making needs to be re-visited.

Getting a grip on thresholds

An economic threshold (ET) can be defined as the critical pest density causing damage equal in value to the cost of control (pesticide and application).

The ET is a quantitative measure and usually specified as the number of pests found per unit area of crop, using a specified (standard) sampling technique.

Yield loss and grain quality reduction are usually the critical factors (threshold types) governing control decisions.

In general, the viability of a generic number for an ET to take out the 'guess work' of when to intervene is not a static number. Thresholds are, at best, flexible guidelines that require constant revision and up-to-date knowledge based on system changes. These can include, but are not limited to, changing management practises (for example, minimum-till), environmental constraints, new varieties, new pest incursions and/or multiple pest species, new market standards and variations in market value.

In addition, the economic importance of a particular pest species will vary with crop type and developmental stage.

While ETs are a key component of IPM that provide a rational basis to the decision-making process, it is important to understand the flexible nature of thresholds (i.e. how they are developed and the factors that can cause them to vary). This helps builds confidence around the use of ETs as a 'supportive' management tool and how to adjust them accordingly to differing regions and cropping situations.

Unfortunately the lack of entomological broadacre research in the southern grain belt during the past couple of decades has seen many ETs become outdated and somewhat irrelevant to current economic costs and management practises.

'Softer' chemicals

Although chemical control is still an important part of an IPM strategy, there needs to be a shift from using broad-spectrum pesticides to more selective alternatives when available. Broad-spectrum chemicals invariably kill non-target organisms.

The use of more selective or 'soft' pesticides (for example, pirimicarb, Bt sprays) is an effective management tool that facilitates — rather than disrupts — the natural biological control that already exists (see Figure 1). By specifically targeting plant-feeding invertebrates, they allow beneficial species to remain in the system to help suppress pest numbers.

Seed dressings (for example, Gaucho®, Cosmos®) also can be an alternative control option and will delay applications of foliar sprays giving beneficial insects time to build up (see Figure 2).

The decision to apply seed dressings requires some consideration of the potential pest pressures before sowing, as many different dressings are available. Seed germinating baits are a quick and effective monitoring method to assess levels of potential soil-dwelling pests that attack seeds and seedlings.

Enhancing ecosystem services

There is a growing awareness of the use of ecosystem services for long-term sustainability of agro-ecosystems and the ability of these services to generate economic and ecological benefits.

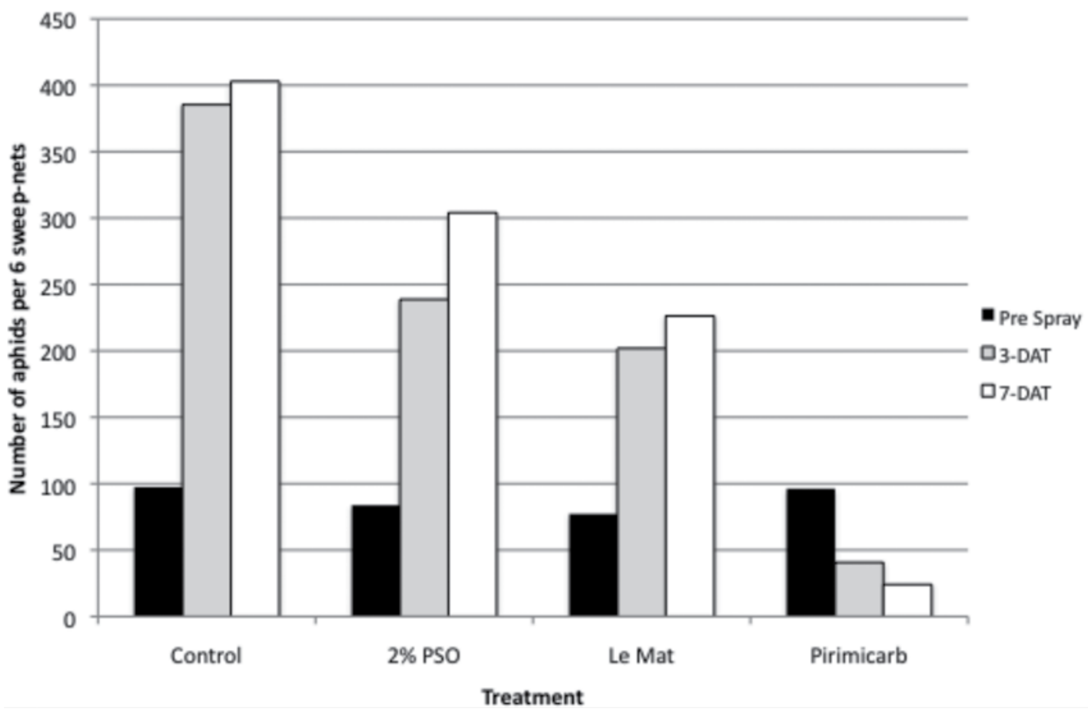
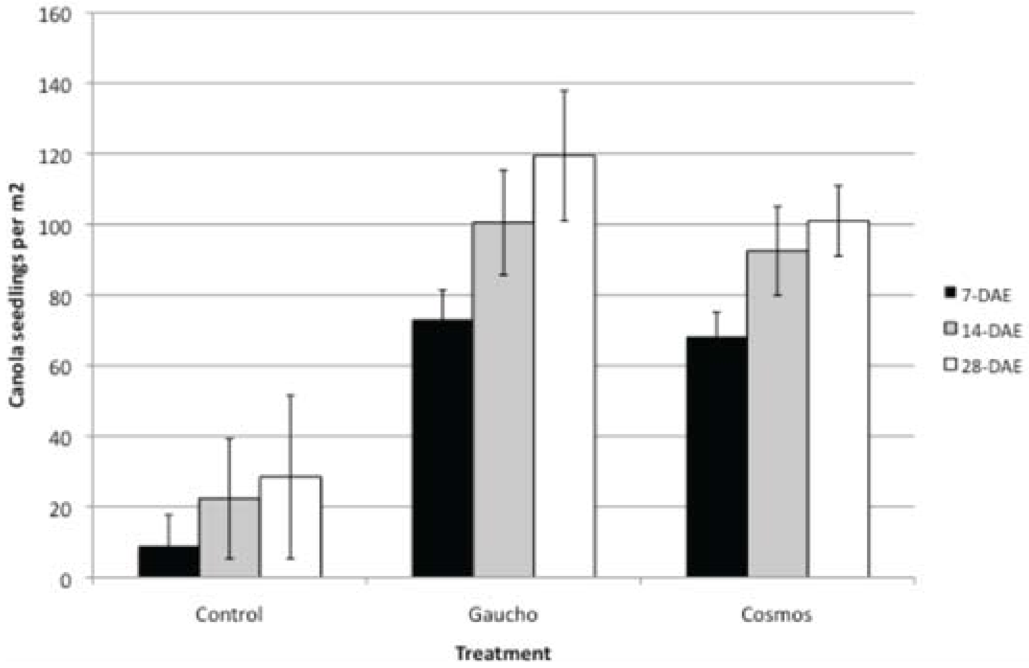


FIGURE 1 Preliminary field trials assessing the effect of 'soft' chemical options as a means of controlling cabbage aphids in canola at Elmore, Victoria in 2008

Control = unsprayed canola. 2% PSO = 2% (v/v) Canopy® spray oil. DAT = days after treatment application.

A



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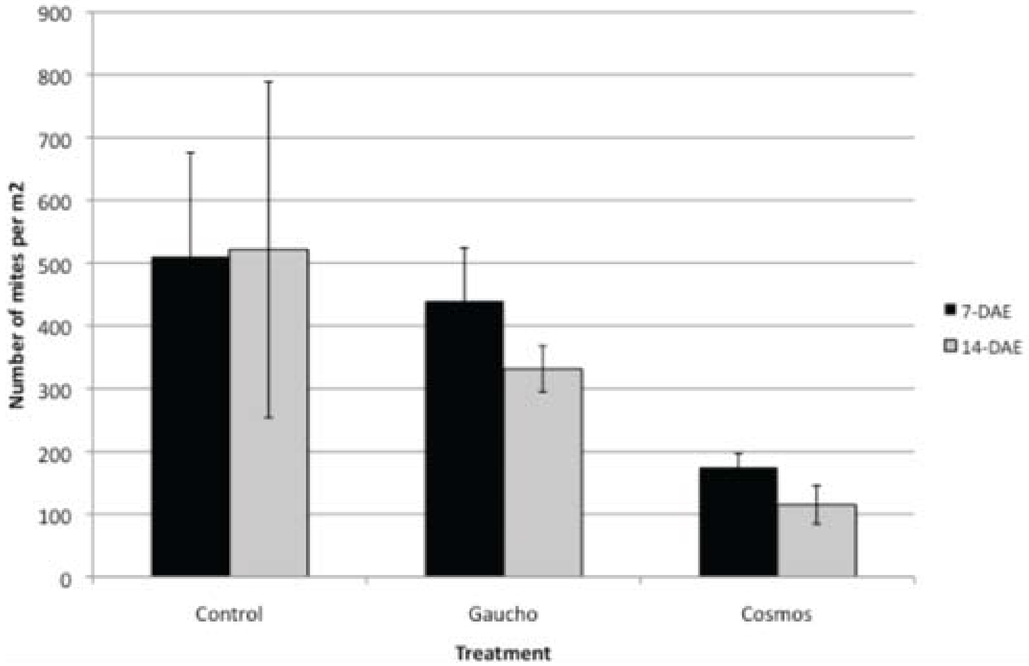

FIGURE 2 Preliminary field trials assessing the effect of seed treatments as a means of protecting emerging canola at Ballarat, Victoria during 2008

A) Average number of seedlings per metre square at 7 days, 14 days and 28 days after crop emergence.
B) Average number of redlegged earth mites per metre square at 7 days and 14 days after crop emergence.
Control = untreated seed. Error bars = standard error of the mean.

Landscape ecology can be manipulated in such a way that promotes natural enemies and aids IPM strategies. The use of windbreaks in providing a reservoir for key functional invertebrates and their impact on pest species is a relatively new area being examined. Research has demonstrated that pest numbers (for example, redlegged earth mites, blue oat mites and lucerne flea) in adjacent paddocks can be reduced by predators and other beneficials residing in windbreaks.

The windbreak composition/ecology is important, with long grasses and shrubs offering complexity, which in turn provides more niches for important beneficial invertebrates such as spiders, predatory mites, parasitoids and pollinators (see Figure 3).

In this way, relatively simple measures, such as management of windbreak understorey can be used to maximise the use of naturally occurring biological control.

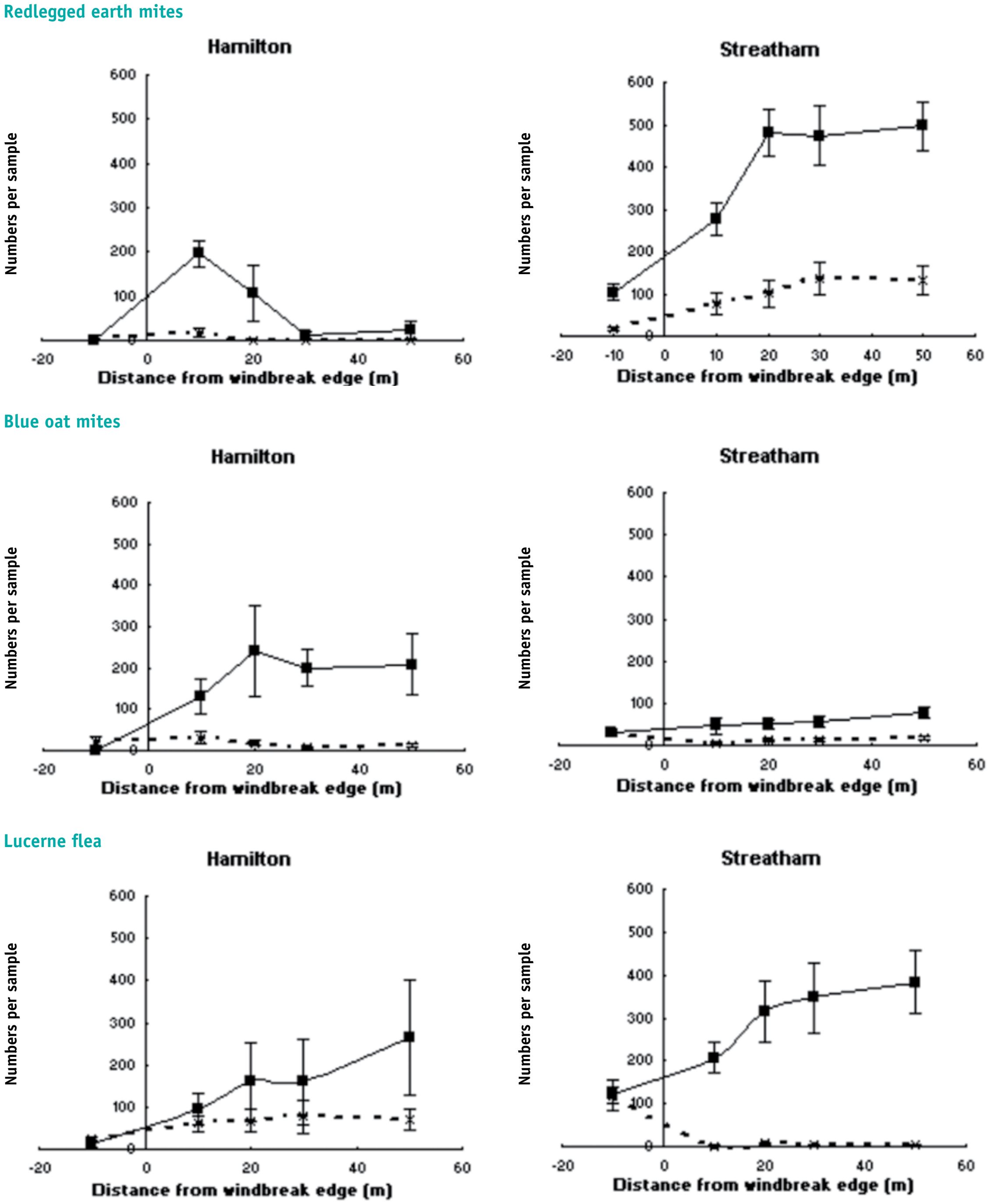

FIGURE 3 Number of pest species in windbreaks and in adjoining pasture

Transect points are marked as negative when extending into the windbreak and positive into the adjacent pasture.
Closed squares and solid lines = simple shelterbelts. Crosses and dashed lines = complex shelterbelts.
Error bars are standard errors for transect points. Data from Tsitsilas *et al.*, 2006 *AJEA* 46: 1379–1388.

Emerging insect pests

Changing management practices and climate change are having an impact on the type of pests being found in the Australian grain belt. A comparison of pest outbreak reports from southern Australia has revealed changes in pest outbreak patterns during the past 10–20 years (see Figure 4). These changes can be attributed to both management and climatic factors.

In some cases the introduction of minimum and no-till systems has been accompanied by increased pesticide use, accelerating selection pressures for resistance in pest species. Other management strategies that can affect the incidence of certain pests include irrigation, paddock rotation strategies and cropping intensity.

Many of the changes observed in pest species during the past few decades could have been driven by increases in chemical use, particularly the use of synthetic pyrethroids. Pests such as blue oat mites, Balaustium mites and lucerne flea have a relatively high tolerance level to synthetic pyrethroids routinely used in the grains industry. In the future, even more significant changes in the distribution and status of some pests are likely as conditions become drier, migration patterns of pests change and insect pests and their natural enemies respond differently to climate change.

PestFacts and other extension services

The adoption (communication and extension) team at GRDC's National Invertebrate Pest Initiative (NIPI) has been funded until 2010, which will see the continuation of *PestFacts* services and diagnostic support. The *PestFacts* service draws on the field observations of consultants, growers and industry specialists across the southern grain belt region, with an online observational reporting proforma, which has been developed to assist with reporting and to track pest occurrences, distribution and insect pressures over time.

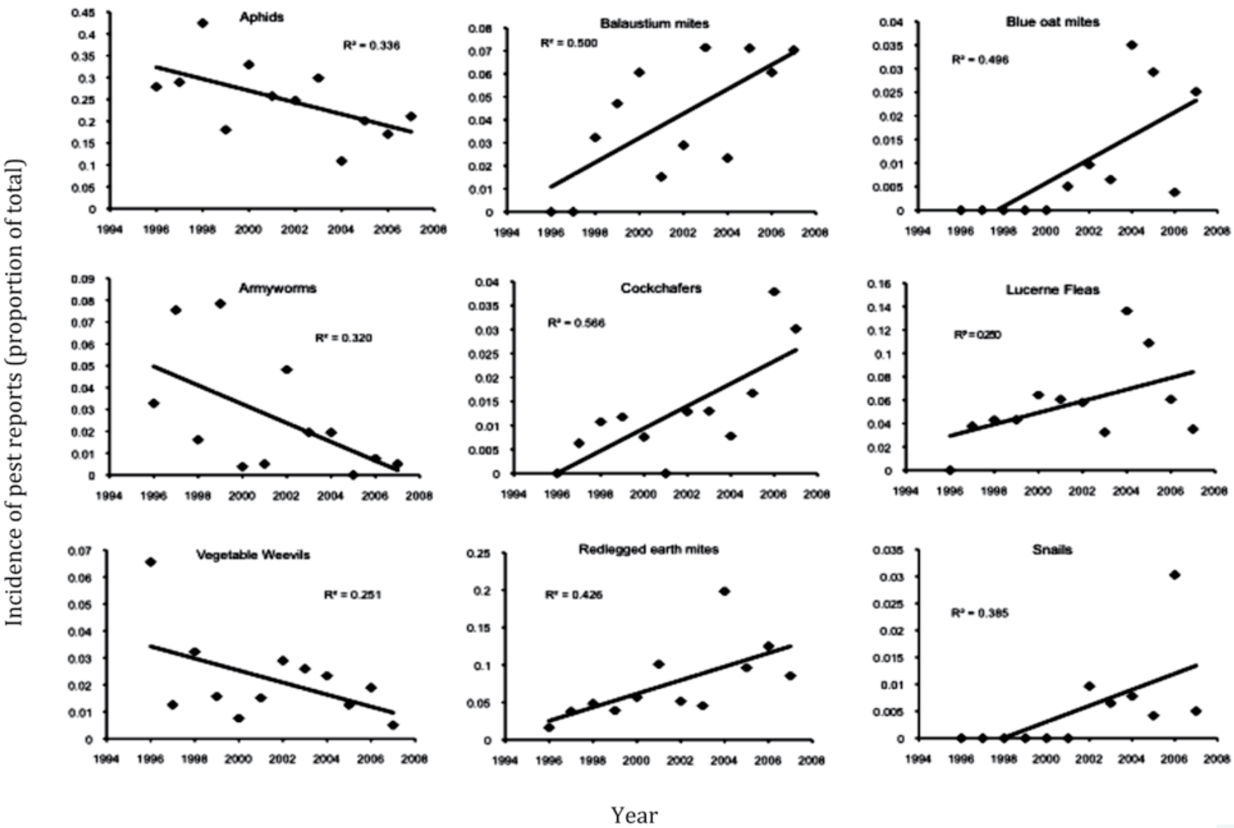

FIGURE 4 The incidence of outbreaks of some important pest species that have changed in relative importance between 1996 — 2007

Data from Hoffmann *et al.*, 2008 *AJEA* 48: 1481–1493.

TABLE 1 Invertebrate pest reports during 2008 in south-eastern Australia

	Species	Total	May	Jun	Jul	Aug	Sep	Oct
Seedling establishment pests								
Mites and Lucerne Flea	Redlegged earth mite	8	6	1				1
	Blue oat mite	14	5		5	1	1	2
	Lucerne flea	4		4				
	Bryobia mite	6	2	4				
	Balaustium mite	4	1		2	1	1	
Caterpillars	Pasture day moth	3			1	2		
	Cutworms	2					2	
	Pasture tunnel moth	1		1				
	Pasture webworm	3				3		
Beetles	Pasture cockchafer	7	2	5				
	Grey-banded leaf weevil	3		1		2		
	Mandalotus weevil	7		7				
	Small lucerne weevil	1		1				
	Vegetable weevil	3		1	1			1
	African black beetle	3		3				
Other	Slaters	2	2					
Grain formation pests								
Aphids	Cereal aphid	1					1	
	Cabbage aphid	13				2	1	10
	Green peach aphid	3						3
	Cowpea aphid	2					1	1
	Corn aphid	1					1	
	Spotted alfalfa aphid	1		1				
	Turnip aphid	1						1
	Bluegreen aphid	3						3
Caterpillars	Native budworm*	3					1	2
	Armyworms	1					1	
	Lesser budworm	1						1
	Brown pasture lopper	3				1	2	
	Lucerne leafroller	2	1	1				
Other	Rutherglen bug	7		7				
	Australian plague locust	3	1					2

* estimates of Native budworm are likely to be underestimated as pheromone trapping data provided from DPI Victoria was incorporated into the *PestFacts* services.

The information generated by *PestFacts* can also be used to gain an idea of the occurrence and location of pest problems. This provides an opportunity for awareness, discussion and ongoing evaluation of changing pest importance. Table 1 shows the invertebrate pest reports received by *PestFacts* South-Eastern for Victoria and New South Wales during 2008.

Through feedback from the diagnostic services and the insect identification workshops that have been carried out during the past, a training manual is currently being developed to complement current identification workshops for the southern and western grain-belt regions.

Useful references

PestFacts South-Eastern
www.cesarconsultants.com.au/services/agriculture.html

Crop insects: *The Ute Guide* (Southern Grain belt edition)
www.grdc.com.au/director/events/bookshop?pageNumber=2&category=204

Special issue in *Australia Journal of Experimental Agriculture*: Invertebrate pests of grain crops and integrated management: current practice and prospects for the future
www.publish.csiro.au/nid/73/issue/4062.htm

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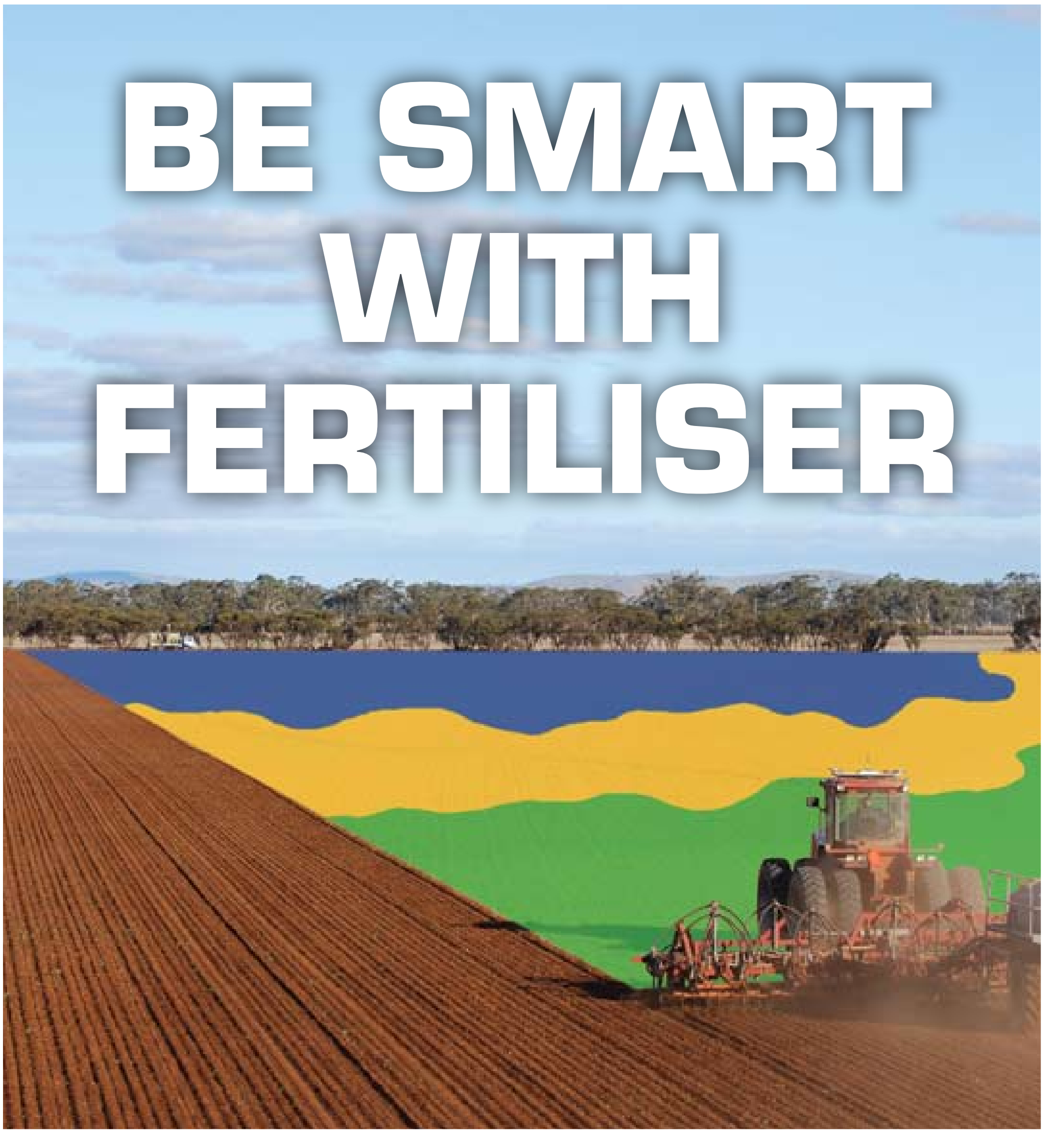

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Pasture cropping proves profitable under perfect conditions

Photos: NSW DPI

Squaring up: Even crop appearance in a no-tillage plot in a high perennial paddock. INSET: Uneven crop appearance in a pasture cropping plot in a high perennial paddock due to patchy nitrogen.

KEY POINTS

- Pasture cropping under suitable conditions and with careful management can increase overall annual productivity and maximise whole-farm resource use.
- Crop yields similar to conventional cropping are possible, provided soil fertility, weed control and soil moisture are adequate.
- During the cropping phase pasture production may be reduced, depending on pasture type, but can return to production levels similar to straight pasture after the cropping phase.

WRITTEN BY
Geoff Millar NSW DPI
Warwick Badgery NSW DPI

Rumour has it that pasture cropping can successfully exploit the different growth phases of summer-active perennial pastures and winter-active grain crops — without significantly limiting crop yields. Results from recent New South Wales Department of Primary Industries, (NSW DPI) research trials suggest that grain yields from pasture cropping can indeed match those obtained by conventional methods, but depend on adequate soil fertility and moisture and effective weed control.

Pasture cropping is an innovative farming system where cereal crops are sown directly into summer-active perennial pastures.

Generally, crops are sown into native perennial pastures, such as red grass (*Bothriochloa macra*) when these species become dormant — after the first autumn frost. The system exploits the differential growth phases of the annual crop and the perennial grasses.

Delayed sowing, or a selective herbicide such as paraquat/diquat, can reduce competition at the start of the cropping phase when these species are grown together.

Also, shading from the crop delays the growth of the summer-growing perennial grasses until the crop senesces and the canopy opens. In this way, the system can be managed to have minimal direct competition during the cropping phase. But, perennial grasses growing through summer can prevent the accumulation of nutrients and soil moisture, reducing crop performance in many cropping regions.

Pasture cropping can improve year-round resource use, and if resources are adequate, increase overall annual productivity compared with conventional annual cropping or pasture alone. In addition, costs are limited as fallowing is not required and fertiliser input can be matched to available soil moisture at sowing.

In a pasture cropping system, the key to improved profitability is efficient use of the additional forage to compensate for any reduced crop yield that occurs.

Testing the theory

Two recent field experiments, carried out by the NSW DPI at Wellington Research Services Centre from 2005–2007, aimed to:

- determine the success of pasture cropping compared with no-till cropping and pasture treatments; and
- determine the effect of fertiliser level and in-crop weed control on the production and resource use of a pasture cropping system.

Two trial areas were set up — a high perennial (HP) pasture dominated by red grass, and a degraded lucerne (DL) pasture dominated by lucerne and annual grasses (wild oats, barley grass and annual ryegrass).

It is important to note the research has been carried out at the extremes of pasture condition as pasture cropping is usually practised in paddocks with lower plant density than in the red grass pasture studied in this trial.

Both trials had core treatments: continuous pasture with no fertiliser or herbicide (PA), a no-tillage crop with a glyphosate-treated summer fallow (NT), and pasture crop which was treated with paraquat/diquat before sowing (PC).

All crops were sown with 60 kilograms per hectare of Ventura wheat in a single pass to minimise soil disturbance.

Pasture cropping had 0, 50 or 100 kg/ha and no-till 100 kg/ha of DAP fertiliser at sowing. Plot size was 0.09ha per plot, with three replicates per trial.

Under the microscope

Both trials investigated the effects of nitrogen fertiliser, while the degraded lucerne experiment also looked at post-emergent annual grass control.

Measurements included plant composition and biomass, groundcover, perennial grass recruitment, crop yields, soil fertility and soil moisture.

Rainfall was above average during 2005 due to substantial rain during the second half of the year, but the late 'break' delayed sowing until late June of that year.

In contrast, 2006 was an extremely dry year with only 302 millimetres of rain, 71mm of which fell during the crop growing period (sown mid June) and crops were grazed instead of harvested.

During 2007, rainfall was above average from April to June (sown late May), but substantially below average for the remainder of the cropping phase.

Proof is in the pasture

In the high perennial paddock, red grass was effectively removed in the no-till treatment by mid 2006. During the cropping phase, red grass was reduced in pasture cropping compared with continuous pasture, but it returned to similar levels to that in continuous pasture in the noncropping phase, except during the dry conditions of summer 2006/2007.

In the degraded lucerne paddock, lucerne biomass was maintained at low levels in no-till and was significantly lower in pasture cropping compared with continuous pasture only during July 2007.

Groundcover was maintained on continuous pasture at more than 80 percent throughout the experiment, while it was significantly less on no-till and pasture cropping (average 40%). During late 2007, groundcover was significantly greater on pasture cropping compared with no-till.

There was no difference in the number or basal area (cross-sectional area) of red grass plants during 2005 (before sowing) in any treatment (see Table 1). Even though red grass plants were completely removed from no-till by 2006 they were retained at similar levels in both the pasture and pasture cropping treatments. There was a decreasing number of older plants but an increasing number of seedlings in the pasture cropping treatment. The basal area of adult plants was significantly lower in pasture cropping compared with continuous pasture during 2006, but there was no difference by 2007.

Overall, there was no significant recruitment of perennial plants in pasture cropping compared with pasture

Grain yield effects

Average crop yields were significantly lower in the high perennial paddock than the degraded lucerne during 2005, but the converse was true during 2006 (in terms of crop biomass), and not significantly different between the two paddocks during 2007 (see Table 2).

Yields were greater in the high perennial paddock for no-till across all three years.

There was very little difference in crop yields between pasture cropping and no-till during 2005 and 2007 in the degraded lucerne paddock, but during 2006 crop biomass was doubled for no-till.

In both paddocks there was little effect of DAP level at sowing on pasture cropping yields, except during 2005, where nil DAP significantly reduced crop yield in degraded lucerne.

TABLE 1 Groundcover of pasture during autumn*

Autumn	Treatment	Adult plants	Seedlings (plants/m^2)	Total	Adult basal area (cm^2 plant)
2005	PA	–	–	30	36.6
	PC	–	–	28	35.2
	NT	–	–	20	45.1
	lsd**	–	–	ns	ns
2006	PA	27	4	31	47.2
	PC	22	6	28	19.3
	NT	0	0	0	0
	lsd	7.58	4.77	9.83	15.61
2007	PA	22	6	28	30.9
	PC	15	11	26	19.7
	NT	0	0	0	0
	lsd	18.20	6.41	12.83	14.59

* Average adult red grass plants and seedlings and adult plant basal area measured during autumn annually on the high perennial paddock.
** Least significant difference is a test of statistical significance. For example, during 2007 seedlings with a lsd of 6.41, PC is significantly greater than NT (11 v 0), while PC is not different to PA (11 v 6), nor is PA different to NT (6 v 0).

Source: Department of Primary Industries, New South Wales

TABLE 2 Grain yields and crop biomass

Treatment	DAP kg /ha	2005 grain (t/ha)		2006 crop biomass (t/ha)		2007 grain (t/ha)	
		HP	DL	HP	DL	HP	DL
Mean		1.4**	2.0**	1.0***	0.4***	1.9	2.2
NT	100	1.7	2.3	1.6	0.8	2.7	1.9
PC	0	–	1.7	–	0.3	–	2.1
PC	50	1.1	2.1	0.6	0.4	1.4	2.2
PC	100	–	2.2	0.7	0.3	1.5	2.3
	lsd	0.1	0.3	0.2	0.2	0.5	nsd

Note: Yields and biomass measured in NT and PC with different fertiliser, in both HP and DL paddocks. All plots treated with post emergent herbicide.
* Indicates significant differences in average yields per paddock each year.

Source: Department of Primary Industries, New South Wales

Crop yields in the lucerne were more affected by annual grass weeds than by fertiliser application (see Table 3), with nil post-emergent plots yielding 30% less than treated plots.

In all years the nil DAP and nil herbicide treatment produced the lowest yields (see Table 4), but by including annual grass weed control on the nil DAP treatment near maximum yields were produced across all years.

Soil fertility

Available soil nitrate was found to be an important factor that varied significantly between paddocks and systems (Table 5).

Nitrate can vary greatly throughout the year depending on the stage of plant growth and season. It is generally depleted through the winter growing season and accumulates during summer, with highest levels occurring before autumn growth. During 2006 after the experiment had been running for a full season there was an increase of nitrate from pasture to pasture cropping to no-till at the start of the cropping season.

Due to the drought during 2006, which limited plant utilisation, this gradient was not as evident during 2007.

TABLE 3 Effects of DAP fertiliser and post-emergent herbicide on grain yields and crop biomass

Year	DAP kg /ha				Herbicide		
	0	50	100	lsd	nil	plus	F prob
2005	1.36	1.90	1.90	0.18	1.39	2.03	*P<0.001*
2006	0.25	0.37	0.25	nsd	0.22	0.37	*P<0.01*
2007	1.43	1.98	2.05	nsd	1.44	2.21	*P<0.01*

Note: Yield and biomass measured in PC plots in DL pasture.

Source: Department of Primary Industries, New South Wales

TABLE 4 Effects of DAP fertiliser, with nil or plus post-emergent herbicide

DAP kg/ha	Herbicide	2005 Grain (t/ha)	2006 Crop biomass (t/ha)	2007 Grain (t/ha)
0	nil	1.0 a	0.16 a	0.8 a
0	plus	1.7 b	0.35 c	2.1 b
50	nil	1.7 b	0.32 bc	1.8 b
50	plus	2.1 c	0.42 c	2.2 b
100	nil	1.5 b	0.17 ab	1.8 b
100	plus	2.2 c	0.34 c	2.3 b
		P<0.001	*P<0.05*	*P<0.05*

Note: Grain yields and crop biomass measured in PC plots in DL pasture. Values within each year followed by the same letter are not significantly different.
Source: Department of Primary Industries, New South Wales

TABLE 5 Soil nitrate (milligram/kilogram) in the top 10cm measured before sowing

Treatment	2005		2006		2007	
	HP	DL	HP	DL	HP	DL
Mean	9.8***	36.0***	17.9*	41.0*	38.6**	75.7**
NT	10.9	31.0	35.0	60.7	52.0	100.7
PC	9.5	34.3	10.5	39.0	40.0	69.0
PA	8.8	42.7	8.2	23.3	23.7	57.3

Note: Significant differences between paddock means in each year are indicated by ****(P<0.001)*, ***(P<0.01)* or **(P<0.05)*.
Source: Department of Primary Industries, New South Wales

On average the degraded lucerne pasture had significantly more nitrate than the high perennial paddock and was not as limiting on crop yield.

However, in the high perennial paddock there was a strong relationship between grain yield and nitrogen measured as soil nitrate 0–10 centimetres and added as DAP during 2005 and to a lesser extent in 2007.

Furthermore, in the perennial paddock during 2007, soil nitrate, measured soon after sowing, was significantly higher in no-till than pasture cropping at depths of 0–10cm and 40–80cm. More soil nitrate at depth in conventional cropping in dry finished seasons produces greater crop yields, and explains why additional fertiliser in pasture cropping systems did not increase yield even though the crop was severely nitrogen limited.

Soil moisture

While there were no consistent treatment effects on drying of the soil profile down to 1.8 metres, the profile was generally drier in lucerne than in the perennial paddock (maximum soil water deficit of 120mm compared with 100mm). But, there was limited summer rainfall throughout the experiment to store moisture in fallowed conventional cropping systems.

Acknowledgements

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The trial was funded by the Central West/Lachlan Grain & Graze programme. Grain & Graze is a national programme investigating 'mixed farming systems' and is a collaborative partnership between the Grains Research & Development Corporation (GRDC), Meat & Livestock Australia (MLA), Australian Wool Innovation Limited (AWI) and Land & Water Australia. The Central West/Lachlan is one of nine regions across the traditional sheep/wheat zones of southern Australia. For more visit the website at www.grainandgraze.com.au.

More information

A case study covering the benefits of pasture cropping for one farmer in NSW can be found on www.farming.com.au by searching using the phrase 'pasture cropping'.

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OVERVIEW

Summing up the results

The results of these trials suggested pasture cropping would affect perennial grass production during the cropping phase, but producers could expect grass production levels from pasture cropped land returned to that for pastures during the non-cropping phase.

Lucerne production in the trial was generally unaffected by pasture cropping. Red grass seedling recruitment could help offset the reduction in perennial plant coverage caused by the sowing process in pasture cropping. But, the results showed no significant increase in recruitment due to pasture cropping compared with pasture alone.

The potential to maintain or regenerate pastures without removing them from production is a significant benefit. The pasture cropping system can reduce the risks associated with ground preparation and pasture establishment associated with conventional crop–pasture rotations.

It needs to be noted that the Wellington and Gulgong region in NSW, where pasture cropping was developed, has a seasonal rainfall that can sustain summer pasture and winter crop growth. Soil moisture may have determined differences in crop production between years but differences in yield between no-till and pasture cropping systems in the perennial paddock appeared to be explained by differences in soil nitrogen. In this paddock yield was higher in no-till than pasture cropping during 2007, even when similar fertiliser levels were applied, apparently due to lower nitrogen through the whole soil profile in the pasture cropping treatment.

As for any cropping programme, effective weed control and fertiliser are essential for successful crop yields.

Lucerne: Lucerne production was largely unaffected by pasture cropping in a recent NSW DPI trial.

Photo: Kondinin Group

New chemistry aids in the battle against annual ryegrass

WRITTEN BY
Craig A Ruchs Syngenta Crop Protection

As resistance in annual ryegrass increases and control options narrow, new chemistry and an alternative mode of action (MOA) could see growers armed with a new herbicide weapon to control the weed in wheat and barley crops this season. Recent research demonstrates the ability of Boxer Gold to improve the control of ARG seedlings when used in tank mixtures with a registered rate of non-selective herbicides. An alternate MOA means this herbicide can be used as part of an integrated weed management strategy for the management of herbicide-resistant ARG biotypes. A wider window for incorporation (seven days), rotational flexibility and compatibility of Boxer Gold with a range of knockdown herbicide and insecticide tank mix partners further adds to the flexibility of this herbicide relative to current pre-emergent alternatives.

KEY POINTS

- **A new chemical formulation and mode of action is set to provide growers with new pre-emergent options to control annual ryegrass (ARG) in wheat and barley.**
- **Improved knockdown control of seedling ARG provides reduced weed competition, greater water and nutrient-use efficiency and improved crop establishment.**
- **Enhanced knockdown weed control occurs when targeting ARG seedlings in mixtures with Spray.Seed® or glyphosate.**
- **Weed growth stage and rainfall within 7 days of application will influence final weed control.**

Boxer Gold is a soil-applied pre-emergent herbicide registered for the control of annual ryegrass (ARG) and toad rush (*Juncus bufonius*) in wheat and barley. Boxer Gold contains 800 grams per litre of prosulfocarb (Group J) and 120g/L S-metolachlor (Group K) formulated as a non-staining emulsifiable concentrate.

The co-formulation of prosulfocarb and S-metolachlor provides growers with new chemistry and an alternative mode of action (MOA) for the control of ARG in wheat and barley. The product offers many unique benefits over existing soil-applied herbicides registered for use in wheat and barley.

One of these benefits relates to the three modes of uptake of the herbicide in susceptible weed species. While the primary route of uptake of Boxer Gold is via the mesocotyl of emerging weed seeds, significant root and foliar uptake of the herbicide is also possible. The foliar uptake of Boxer Gold is well known and has been recently studied in relation to improvements in knockdown weed control when applied in tank mixtures with Spray.Seed® or glyphosate.

Field trials

The foliar activity of Boxer Gold was evaluated in a number of replicated field trials across southern Australia during 2007 and 2008, in particular targeting the control of seedling ARG plants at growth stage the one- to three-leaf stage (Z11 to Z13).

This series of trials assessed the efficacy of Boxer Gold alone, in tank mixtures with non-selective herbicides and in comparison with common Group G herbicide spikes*.

All herbicides were applied using a pressurised hand-boom delivering a water rate of 50-100 L/ha. Trials were set up in a RCBD as small plots and consisted of 3-4 replicates.

Herbicide treatments were applied to seedlings under normal field conditions, with no mechanical incorporation of herbicide taking place.

Initial weed density was established using a random sampling method and objective assessment of plant numbers within a 0.3 m^2 quadrat, with 20 counts carried out across each site.

Efficacy of weed control was assessed through subjective assessment of weed brownout or plant death compared with control plots at seven, 14, 21 and 42 days after herbicide treatment. Photos of weed control were also taken in some trials.

Convincing results

Boxer Gold tended to provide an improvement in the knockdown control of seedling ARG when used in a tank mixture with a registered rate of non-selective herbicide. Mixtures with Spray.Seed® or glyphosate increased ARG control by up to 16% compared to either of the non-selective herbicides applied alone (see Figures 1 and 2).

A comparison between Boxer Gold and common Group G herbicide spikes including carfentrazone-ethyl, oxyfluorfen and butafenacil (contained in Logran® B-Power®) also showed that Boxer Gold provided control of ARG at least equivalent to oxyfluorfen and Logran B-Power (see Figure 3).

As some root uptake of Boxer Gold is also possible, movement of herbicide from the soil surface into the root zone of emerged seedling weeds is likely to enhance final weed kill. Sufficient rainfall within seven days of application is likely to enable maximum root uptake and final weed control.

Similarly, the performance of Boxer Gold would be expected to be greater where mechanical incorporation of herbicide is practised, as recommended on the product label for maximum residual weed control, as well as providing a degree of mechanical weed kill.

In addition to providing excellent pre-emergent control of ARG the demonstrated improved knockdown control of seedling ARG provides reduced weed competition, greater water and nutrient-use efficiency and improved crop establishment.

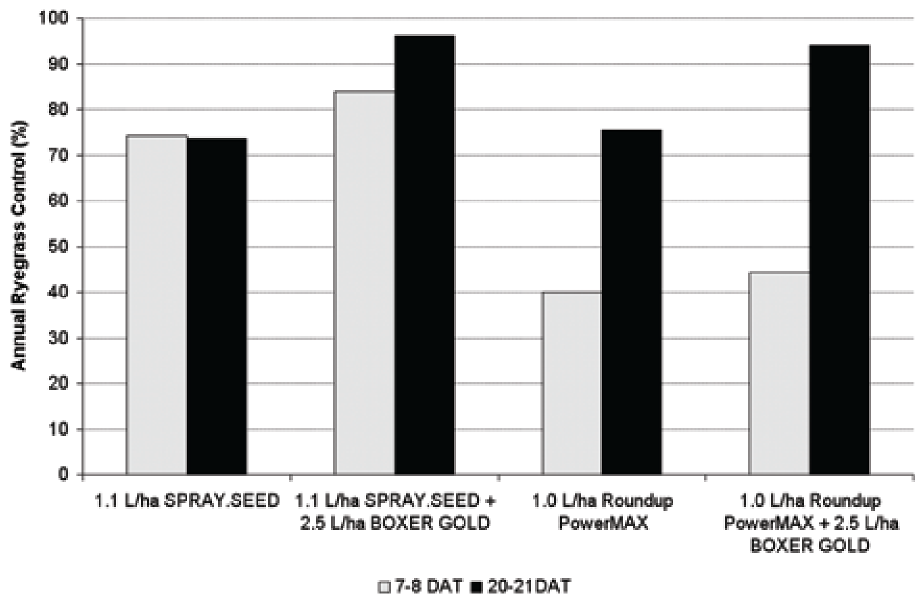
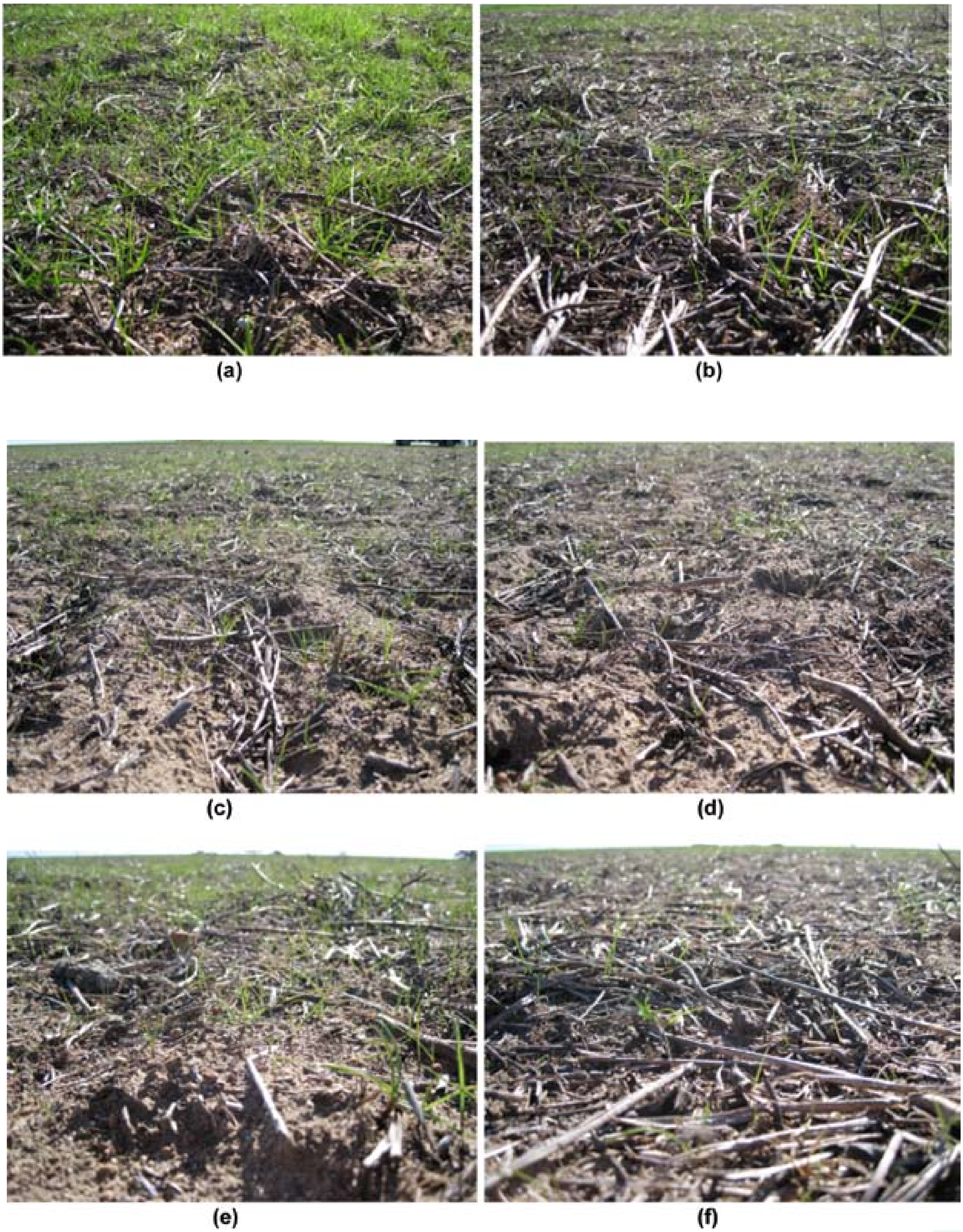


FIGURE 1 Knockdown activity of Boxer Gold when applied in tank mixtures with Roundup PowerMAX* or Spray.Seed®*

Data is average of four replicated field trials carried out across southern Australia from 2007-2008. Results 7-8 days after treatment (DAT) and 20-21 DAT. Lsd ($P < 0.05$) = 29.8 (7-8 DAT) and 29.6 (20-21 DAT).

Source: Syngenta Crop Protection and Landmark Product Development



Photos: Syngenta

FIGURE 2 Knockdown activity of Boxer Gold in the control of Annual Ryegrass (Z11 to Z13) when applied in tank mixtures with glyphosate or Spray.Seed®, Grass Valley WA 2008

(a) Untreated **(b)** Boxer Gold 2.5 L/ha **(c)** Roundup PowerMax 1.0 L/ha **(d)** Roundup PowerMAX 1.0 L/ha + Boxer Gold 2.5 L/ha **(e)** Spray.Seed 1.1 L/ha and **(f)** Spray.Seed 1.1 L/ha + Boxer Gold 2.5 L/ha. Photos taken 19 days after application.

Source: Courtesy of Craig Ruchs, Syngenta Crop Protection

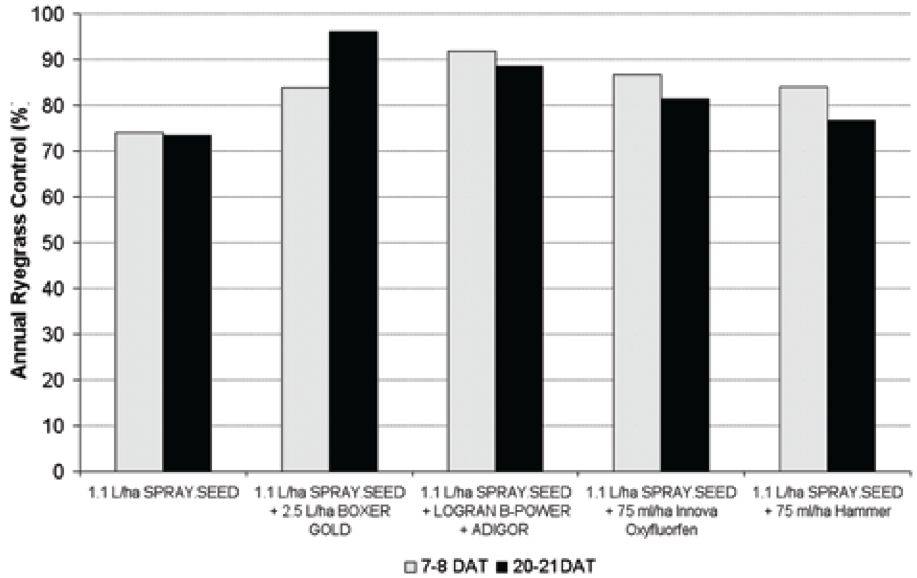


Figure 3 Comparison of Boxer Gold versus common Group G knockdown spikes

Data is average of four replicated field trials carried out across southern Australia from 2007-2008. Results 7-8 days after treatment (DAT) and 20-21 DAT. Lsd ($P < 0.05$) = 29.8 (7-8 DAT) and 29.6 (20-21 DAT).

Source: Syngenta Crop Protection and Landmark Product Development.

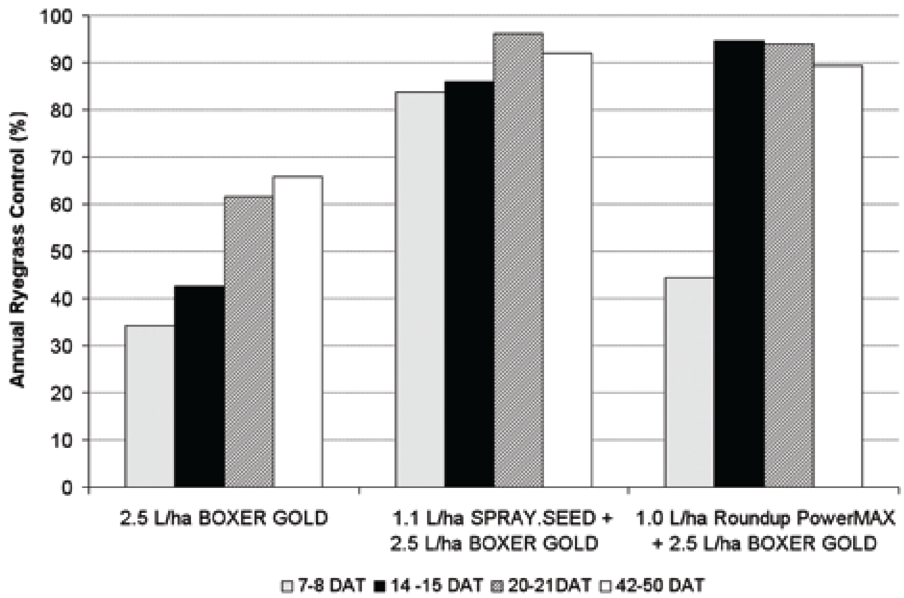


FIGURE 4 Speed of activity using Boxer Gold in tank mixtures with Spray.Seed or glyphosate for the control of Annual Ryegrass (Z11to Z13), Southern Australia 2008

Data is average of four replicated field trials carried across southern Australia from 2007-2008.
Results 7-8 days after treatment (DAT), 14-15 DAT, 20-21 DAT and 42-50 DAT. Lsd ($P < 0.05$) = 29.8 (7-8 DAT), 24.5 (14-15 DAT), 29.6 (20-21 DAT) and 21.8 (42-50 DAT).

Source: Syngenta Crop Protection and Landmark Product Development.

Boxer Gold in action

The characteristic symptoms resulting from foliar application of Boxer Gold on seedling ARG are leaf twisting and distortion, often combined with plants turning a darker green in colour. Typically, symptoms are slow to develop. Time until complete plant death depends on the chosen non-selective herbicide partner and is fastest when used with Spray.Seed (see Figure 4).

As the rainfast requirement for Boxer Gold is short, this makes tank mixtures with Spray.Seed ideally suited for knockdown weed control of seedling grass and broadleaf weeds. While rainfall within one hour of application of Boxer Gold can reduce foliar uptake, subsequent root uptake and final weed control is likely to be improved.

Most Spray.Seed is absorbed within 10 minutes and is considered rainfast within 30 minutes of application. A tank mix of Boxer Gold and Spray.Seed is an effective combination, offering security in uncertain weather conditions.

Further work is required to evaluate performance in the control of broadleaf weed species.

Acknowledgements

The author would like to acknowledge the Landmark Product Development group for contribution of some of the replicated data presented and J. Sabeeney for peer review of this paper.

**This information does not endorse the use of Boxer Gold post crop emergence nor does it support the use of Boxer Gold as a direct substitute for a non-selective herbicide.*

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OVERVIEW

Maximising efficacy

The level of additional knockdown weed control achieved using Boxer Gold is likely to be influenced by two key factors;

- Weed growth stage — target one-leaf to two-leaf ARG seedlings. Current research suggests that the foliar activity of Boxer Gold on ARG is greatest on one-leaf to two-leaf plants and the efficacy of the herbicide in enhancing knockdown control of weeds beyond this growth stage at application is likely to be significantly reduced.
- Rainfall within seven days of application is likely to maximise herbicide performance. As some root uptake of Boxer Gold is also possible, movement of herbicide from the soil surface into the root zone of emerged seedling weeds is likely to greatly enhance final weed kill. Sufficient rainfall within seven days of application will enable maximum root uptake and final weed control.

Additional factors

The speed of weed kill will depend upon choosing a non-selective tank-mix partner. Avoid heavy infestations of emerged weeds at application. Always use a registered rate of non-selective herbicide and keep in mind that the additional activity from Boxer Gold does not warrant a reduction in glyphosate or Spray.Seed® rate.

Loss minimisation reduces volatility — it doesn't increase profit

Photo: Kondinin Group

Plan for success: A business strategy that aims for profit maximisation has the greatest potential to protect ling-term business profitability.

WRITTEN BY
John Francis Holmes Sackett

The past few years of drought is leading some farm business managers to implement a loss minimisation approach with the aim of reducing risk. But while this approach will see managers experience less volatility in returns, over the long-term this strategy will lead to a greater reduction in profits than in losses — even during the worst seasons.

KEY POINTS

- **Growers are better placed with a business strategy that aims for a good year every year, even if the resulting season proves otherwise.**
- **There is far greater variability in returns with the profit maximisation strategy relative to the loss avoidance strategy but most of the variability is in additional profits rather than larger losses.**

On the back of several severe droughts in much of south-eastern Australia, thoughts are turning to next season and the best management strategies to employ. The consecutive years with little to no cash flow will be a major business issue facing many grain producers — some will have no choice but to draw down on equity to provide working capital, once again.

Not surprisingly, given the human psychological constitution, after successive severe short-term business losses there is a tendency to disregard objectivity and allow emotions to rule decision making. This is an understandable but dangerous position for a business manager to find themselves in and it is at this point when an independent opinion can be the most valuable.

Minimising risk — an avoidance tactic

The decision to reduce the level of inputs for the next crop, for the sole purpose of 'minimising risk', is a case in point. This 'loss avoidance' approach is a typical situation where either emotion has taken over, there is a lack of understanding of the consequences of the decision or cash is genuinely limiting to the point that any foregone profits from taking this position have to be ignored because another loss would result in bank foreclosure.

Any reduction in inputs primarily relates to phosphorus and nitrogen fertiliser, as there is little scope for reducing other inputs without significantly reducing crop yield potential. Phosphorus inputs account for about 30% of the enterprise expenses and 15% of the combined enterprise and overhead expenses.

The dilemma is that phosphorus is highly immobile in the soil so it must be applied at sowing. Responses to phosphorus fertiliser applied after sowing are uneconomical. Decisions about the phosphorus application rates need to be made during autumn, when there is no useful information about how the season will finish.

The question being posed is: "Is it time to change the strategic direction of the business to a loss minimisation approach rather than a profit maximisation approach?".

Determining the answer

An analysis of wheat crop performance during a decade in a medium-low rainfall area has been carried out to investigate the comparative costs, yields, returns and variability in returns of a strategy set up to minimise losses with a strategy set up to maximise profits. The analysis has been compared over a decile 1 and median decade seasons (deciles are based on historical plant available water) to investigate whether the outcome of the analysis changes depending on the run of seasons.

Decades have been assessed on a rolling 10-year average basis and a decile 1 decade has been chosen for comparison with a median decade in an attempt to mimic the impact of climate change. The inference is that if climate change is here to stay it will result in seasonal conditions consistent with a decile 1 decade.

The strategy set up to minimise losses applies sufficient phosphorus (6 kilograms per hectare) to achieve target yields of 1.5 tonnes/ha while the strategy set up to maximise profits applies sufficient phosphorus (10kg/ha) to achieve target yields of 2.5t/ha.

Phosphorus is applied at a rate of 4kg/t of target yield. Yield during the decade is capped at 40% above the target yield to reflect the fact that in good seasons yield exceeds the theoretical phosphorus limited potential. This means the loss minimisation strategy is capped at 2.t/ha and the profit maximisation system is capped at 3.5t/ha.

The decision being assessed is the long-term strategic direction of the business rather than a tactical phosphorus decision for the coming year.

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The average annual rainfall of the area analysed is 450 millimetres with a median rainfall of 425mm. The median plant available water (PAW) figure is 150mm. Plant available water is an estimation of the amount of water that is available for crop growth and has been calculated by adding 20% of November to April rainfall to 100% of May to October rainfall and deducting 110mm for evaporation.

By multiplying PAW by 16kg/ha/mm it is possible to determine the median wheat yield potential, which in this case is 2.4t/ha.

The key assumptions used in the analysis follow:

- Wheat price equals $230/t.
- Starter fertiliser (MAP) price equals $1300/t.
- Urea price equals $700/t.
- Non-fertiliser variable costs are $140/ha and are the same for both systems.
- Overhead expenses are $150/ha.
- Nitrogen application is made with perfect knowledge. Rates of applied nitrogen match crop requirements.
- Soil nitrogen levels are 40kg/ha/yr and mineralisation rates are 80kg/ha/yr under both strategies.
- 4kg/ha of applied phosphorus will provide 1t/ha of grain yield given average to below average rainfall
- 2.85kg/ha of applied phosphorus will provide 1t/ha of grain yield given above average rainfall.
- Yield is capped at 2.1t/ha and 3.5t/ha for the loss minimisation and profit maximisation strategies respectively.

Comparative yields

The solid bars in Figure 1 show the average wheat yield during a decile 1 and median decade for the loss avoidance and profit maximisation approaches.

The extent of the thin lines running through the solid bars represents the maximum and minimum yield achieved during the decade.

The minimum yield achieved for both strategies is 0.8t/ha during a decile 1 decade and 1.3t/ha during a decile 5 decade.

The maximum yield is capped to 2.1t/ha with the loss avoidance system increasing to 3.5t/ha with the profit maximisation system.

Figure 2 shows the yield distribution during a decile 1 decade. It shows that the reason for the difference in the average yield between systems (shown in Figure 1) is the three high rainfall years when far higher yields have been achieved with the profit maximisation approach relative to the loss minimisation approach.

The average yield for a loss avoidance system is 1.6t/ha and 1.9t/ha for decile 1 and decile 5 seasonal conditions respectively. The average yield for the profit maximisation system is 2t/ha and 2.4t/ha for decile 1 and decile 5 seasonal conditions respectively.

This demonstrates that the profit maximisation approach results in higher average production than the loss minimisation approach. There is still however insufficient data to provide an argument for one system over the other because the cost of achieving the additional yield has not yet been considered.

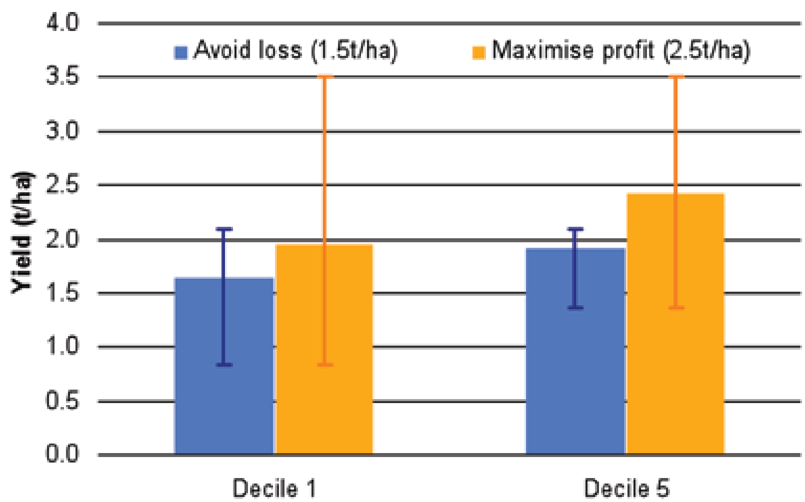

FIGURE 1 The loss avoidance approach caps the upside at just more than 2t/ha

Additional expenses

Figure 3 shows that the additional costs incurred to achieve the additional yield generated by pursuing a strategy that maximises profit compared with a strategy that avoids loss is $50 per hectare during a decile 1 decade or $65 per hectare during a median decade.

There is no variation in enterprise expenses with the loss avoidance strategy because there is sufficient soil nitrogen to achieve the target yield of 1.5t/ha. This means the target yield will be met with no additional input costs.

The variation in enterprise expenses in the profit maximisation strategy is due to the tactical application of nitrogen, which varies according to seasonal conditions.

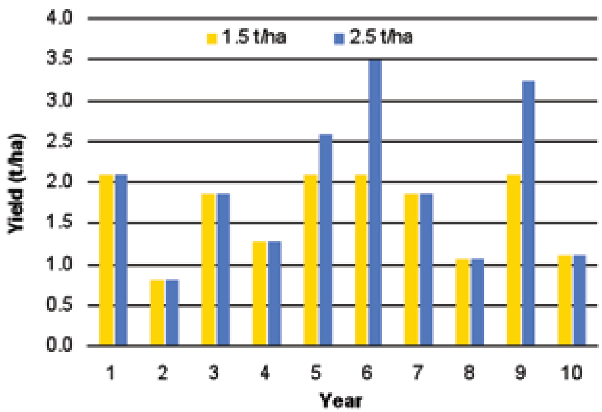

FIGURE 2 Three high rainfall years are responsible for the yield difference between strategies

The thin error bars in Figure 3 show the variability in enterprise expenses. These bars indicate that the lowest enterprise expenses of the profit maximisation strategy are nearly equivalent to the highest enterprise expenses of the profit maximisation strategy. These low points occur during the driest years of the decade.

At the other extreme, the profit maximisation strategy incurs an additional $137/ha when compared with the loss avoidance strategy. This cost is incurred in the wettest years of the decade, when yield potential is at its highest.

Relative profit

So far it has been established that yield increases by about 0.4t/ha and expenses increase by approximately $50/ha and $65/ha p with the profit maximisation strategy relative to the loss minimisation strategy. The comparison of the returns of the systems at the profit level will now be considered.

Figure 4 shows that the profit maximisation strategy is more profitable than the loss minimisation strategy by an average of $25/ha during a decile 1 decade and by $55/ha during a median decade.

However, the variability in returns from the profit maximisation strategy is $208/ha greater during a decile 1 decade than the loss minimisation strategy with a range in profits of about $500/ha.

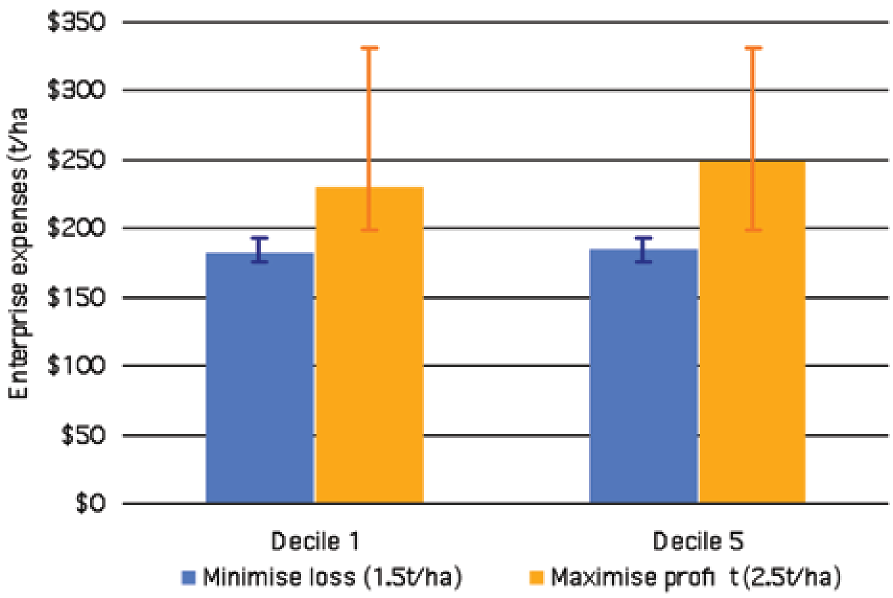

FIGURE 3 A system that maximises profit will require about $50/ha more capital

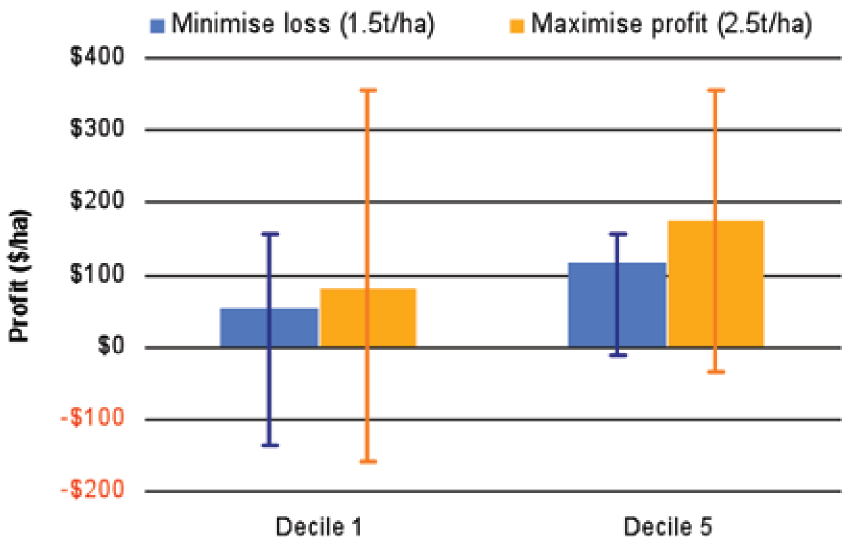

FIGURE 4 The variability in returns of the profit maximisation approach is greater relative to the loss minimisation approach but it is mostly upside return

It is important to note that the main source of the variability is in upside rather than downside variability. The difference in the minimum profit between the loss minimisation strategy and the profit maximisation strategy is $24/ha, while the difference in the maximum profit between strategies is $185/ha for both decile decades.

The variability in returns in this analysis is overstated due to the averaging of prices across the decade. This means the returns will be understated during the drought years and overstated during the high-rainfall years, when compared to actual events. This occurs because during drought years prices will be higher than those reflected in the analysis and during high-rainfall years prices will be lower than those reflected in the analysis. This is unlikely to have a major impact on the outcome of the analysis as it is the relativity of returns rather than the absolute return that is of interest.

The loss minimisation approach

Table 1 shows the marginal difference between the profit maximisation system compared with the loss minimisation system. The table demonstrates that, where decile 1 seasonal conditions occur, the loss minimisation approach provides superior returns to the profit maximisation approach in seven out of 10 years.

The total value of the losses during the decade however is only $148/ha or $15/ha/yr during the decade. The gains, on the other hand, while only being greater in three years of the 10, account for $384/ha or $38/ha/yr during the decade.

The difference between the average annual losses and the average annual gains provides the average annual profit difference of $24/ha.

During a decile 5 decade the value of the losses is even smaller at $115 while the value of the gains is higher at $650 during the decade.

The profit maximisation approach, when compared to the loss avoidance approach, provides an average advantage of $53/ha. This occurs because there is greater disparity between the losses and the gains during a decile 5 decade and there is a greater ratio of gains to losses when compared with a decile 1 decade.

Important qualifications

Much of the difference in the outcome between strategies depends on the variation in yields during the good years. Yield has been capped at 2.1t/ha for the loss minimisation strategy and 3.5t/ha for the profit maximisation strategy.

This was determined by increasing the target yield by 40% for each relative strategy. If the disparity between these yields is not as great as is assumed then the margin between strategies will be reduced.

If the yield cap increases to 2.6t/ha during a decile 1 decade or 2.9t/ha during a decile 5 decade then there is no relative difference in profitability between strategies.

TABLE 1 Performance of the profit maximisation approach compared with the loss avoidance approach during a decade

	Decile 1	Decile 5
Total value of the losses ($/ha)	-$148	-$115
Total value of the gains ($/ha)	$384	$650
Net profit ($/ha)	$236	$535
Average annual profit	$24	$53
Number of losses	7	5
Number of gains	3	5

No benefit of the additional phosphorus to the profit maximisation strategy has been allocated when compared with the loss minimisation strategy during the dry years. Trial data shows that yield responses, while marginally lower than in the good years, are still achieved in the dry years. These responses, when coupled with increased prices due to lower supply, can be of sufficient magnitude to result in no difference in profit between the two strategies.

Applying the outcome

The only system to pursue if you are to be a profitable cropper is the profit maximisation strategy.

If the additional cost of pursuing this strategy results in bank foreclosure then your business was doomed anyway. Implementing the loss minimisation approach in preference to the profit maximisation approach is just delaying the inevitable.

There is far greater variability in returns with the profit maximisation strategy relative to the loss avoidance strategy but most of the variability is in additional profits rather than larger losses.

Decile 1 seasonal conditions result in far more volatility in returns than decile 5 seasonal conditions but no-one know how the season will turn out at sowing. This means the strategy has to be in place for a good year every year. This system must come with an acceptance of small relative losses in the bad years.

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Organic matter — better soil structure and yields to boot

Performance: Increased soil organic matter can lead to a range of benefits including improved crop yields.

KEY POINTS

- **Increases in organic matter above one tonne per hectare per year could boost soil carbon levels by more than 0.2 percent over 10 years.**
- **Improved soil carbon levels can alleviate soil structural decline, particularly where initial levels are less than 2%.**
- **Trial results suggest improved soil carbon levels could play a more important role in increasing crop yields than previously thought.**

WRITTEN BY

Peter Fisher DPI Victoria, Tatura

The throughput of organic matter drives all soil biological processes, and potentially results in increased soil carbon, better soil structure, higher yields and lower inputs. Better still, recent research suggests the benefits could be greater than previously thought.

A recent study carried out by the Department of Primary Industries, Victoria has illustrated a wide range of rotational and management options available to increase organic matter throughput. But, growers need also to monitor their annual organic matter throughput to maintain the potential benefits of increased soil carbon levels.

Although the study was carried out across a wide range of management practices in the irrigated cropping industry, at sites in southern New South Wales and northern Victoria, many of the principles are expected to hold true in other farming situations.

Outcomes from the project include a better understanding of how varying organic matter inputs influences soil organic carbon and how soil carbon influences other soil physical, chemical, and biological properties, and ultimately crop performance.

The project was initiated in response to growers' concerns about the sustainability of their continuous intensive cropping systems, largely due to declining soil structure.

Soil structural degradation probably remains, after salinity, the key threat to the sustainability of agricultural production.

Soil structural decline is commonly associated with soil hardness, poor crop germination, restricted root growth, poor water infiltration, reduced water holding capacity and reduced yields.

Soil organic carbon is important in building and maintaining soil structure. But, a lack of clear understanding of the process and management of organic matter to optimise soil health benefits, while minimising detrimental crop effects, has also led to growers avoiding or withdrawing from conservation farming.

Excessive cultivation and continual removal of organic matter (by burning or grazing crop residues) are the main causes of soil carbon decline. Cultivation is often used to counter the limitations of poor soil structure, but is costly and can exacerbate soil carbon decline by exposing it to rapid breakdown processes.

A practical approach

The study of soil carbon dynamics is difficult as changes in the soil can occur slowly. Short-term rotation trials do not show the long-term effects, long-term trials are rare and often do not have management systems relevant to current management practices. Also, soil organic carbon levels need to be assessed according to differences in soil type, climate and management practices.

This project used paired paddocks to determine how the management of organic matter affects soil health and crop productivity. Crop rotation histories and soil measurements were taken from 13 paired paddocks across northern Victoria and southern NSW.

Each pair of paddocks consisted of one paddock with a relatively higher organic matter input scenario to another with a lower organic matter input scenario.

Organic matter boosts soil carbon

Despite the varied locations and different rotations for the 13 paired sites in all but one site, the paddocks with the higher organic matter rotation had higher soil organic carbon measurements across a range of soil depths (see Figure 1) although the size of the increase varied.

To explain these different soil carbon levels, researchers estimated the difference in organic matter applied to the soil during the past 10 years between the high and low organic matter scenario paddocks at each paired site.

The results suggest that as a rule of thumb (for these systems) that for every extra tonne per hectare per year of organic matter applied and maintained for 10 years, soil organic carbon levels, after this time, could increase by about 0.2 percent more than it would have done without the extra input. This does not necessarily mean the soil carbon level will increase, but could mean it declines less rapidly.

The organic matter includes the contribution from above ground plus the below-ground roots. This rate of increase is higher than would be expected from carbon modelling, and this is being further investigated.

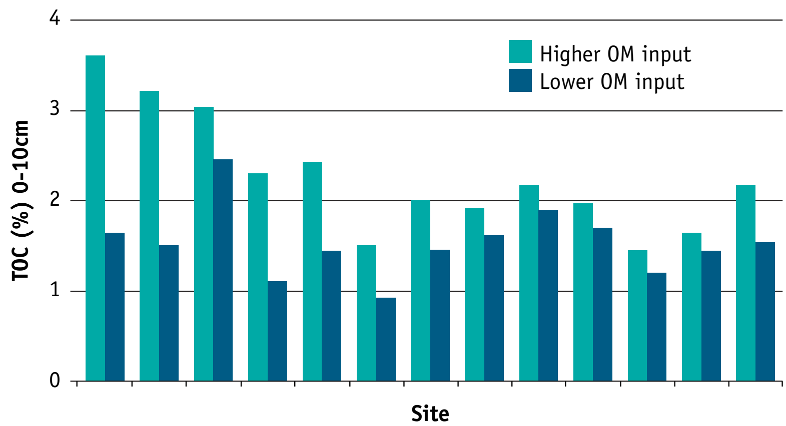

FIGURE 1 Total carbon in the high and low organic matter (OM) input paddocks

Source: Department of Primary Industries, Victoria

Soil carbon improves structure

Across the range of soil types tested, the value of soil carbon can explain about 60% of the variation in soil structure.

In this relationship with soil carbon, soil structure, measured as 'water stable aggregates', is a measure of the soil's ability to maintain structural integrity when wet.

Interestingly, the results revealed that when initial soil carbon levels are less than 2%, small increases in the carbon level could result in substantial improvements in soil structure.

If carbon values fall below 1%, soil structural stability is likely to be seriously compromised.

When soil carbon values reach about 2%, further improvements in soil carbon (in general) result in negligible change in soil structure. But, having soil carbon values of more than 2% may have other benefits such as increased nutrient supply and improved soil resilience. A more resilient soil structure will protect the soil during periods when organic matter inputs are periodically reduced, which may be required if occasional, strategic, operations such as stubble burning or cultivation are required.

Better organic matter, better yields

The yield benefits from higher soil carbon values are hard to measure and little hard data is available. This is because soil carbon changes occur slowly, especially in the recalcitrant pools, and the impacts are difficult to separate from other factors.

For sites in this study, where wheat and canola crops have been grown during the past 10 years, the average yields for each high organic matter paddock was compared with the average yields in the corresponding low organic matter paddock.

In most cases, the high organic matter paddocks had equal or higher yields than the low organic matter paddocks (see Figure 2). On average, the yield increases from these sites were in the order of 15%. Although not scientific proof, this data does constitute convincing evidence of the yield benefits of increased organic matter.

Reducing emissions

In addition to boosting soil structure and yields, soil organic matter can reduce greenhouse gas emissions.

Probably one of the most contentious issues concerning the accounting of soil carbon is accurately predicting the rate at which soil carbon accumulation can occur following adoption of an improved rotation or management practice.

Most carbon modelling suggests that increasing soil carbon is a slow process, taking many decades to make significant changes. For example, modelling a change in organic matter input from 6t/ha (above- and below-ground input) to 8t/ha resulted in a change in soil carbon value of about 0.13% after 20 years.

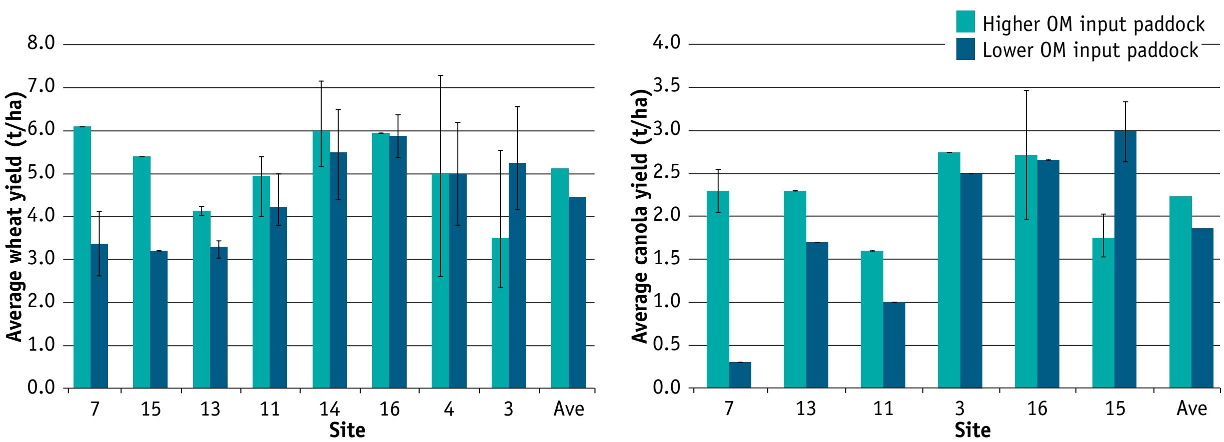

FIGURE 2 Average yields of the high and low organic matter (OM) paddocks for wheat (left) and canola (right)*

* Bars represent the maximum and minimum yields for each paddock

Source: Department of Primary Industries, Victoria

In contrast, the relationship developed between change in organic matter input and change in soil carbon at the 13 paired paddocks, suggested a change of 2t/ha organic matter might result in about a 0.4% change in carbon level after only 10 years. But, even if only a 0.2% increase in soil carbon is achievable after, say 30 years of no stubble burning, in Victoria where 671,225ha of stubble are burnt annually, then in this time the amount of extra carbon stored in the soil would be equivalent to 8,276,000 tonnes of carbon dioxide, or equivalent to 70,000 fewer cars.

More information

For more information visit www.farmingahead.com.au.

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OVERVIEW

Monitoring makes it easy

Monitoring each paddock's cumulative organic matter input is an easy way for growers and consultants to monitor improvements in soil health.

This project has provided convincing information that it is important for growers to manage their organic matter inputs. But, it is also clear there are many different management and rotational ways of changing the organic matter throughput, and it is confusing to know what the impact of these changes will be.

There are several carbon models available, but these can be difficult to run and the results variable, depending on many soil and climatic conditions. It is suggested that a more useful tool for growers and consultants is a simple carbon calculator (C-Calc) developed by the project, which provides a graph of cumulative carbon input (see Figure 3).

Year	Rotation1		Rotation 2	
	Crop	Residue man.	Crop	Residue man.
1	Wheat	Retained	Wheat	Burnt
2	Canola	Grazed	Canola	Grazed
3	Maize	Grazed	Maize	Burnt
4	Canola	Retained	Canola	Grazed
5	Wheat	Grazed	Wheat	Burnt
6	Canola	Retained	Canola	Grazed
7	Wheat	Grazed	Wheat	Burnt
8	Canola	Retained	Canola	Grazed
9	Wheat	Grazed	Wheat	Burnt
10	Canola	Retained	Canola	Grazed

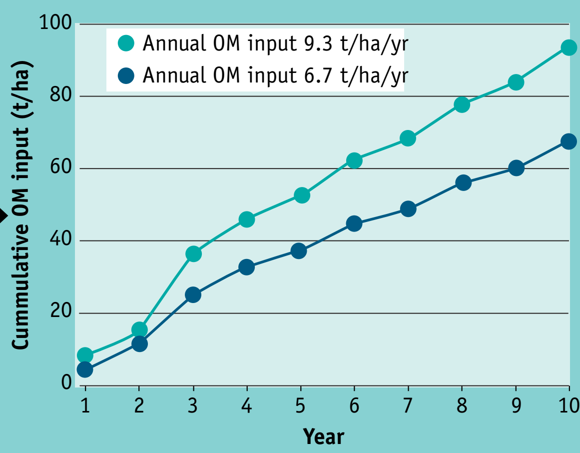

FIGURE 3 Carbon calculator (C-Calc) converts rotation information into an estimate of the cumulative organic matter entering the soil

Source: Department of Primary Industries, Victoria

New varieties show promise in a difficult season

Photo: Kondinin Group

Breeding better brassicas: Recent trials have shown that new canola varieties are set to outperform existing varities under challenging conditions.

WRITTEN BY

Kevin Morthorpe, David Coddington and Rob Wilson Pioneer Hi-Bred Australia

Research trials showed promise of significant improvement in yields in new canola varieties resulting in a greater gap emerging between the alternative canola systems and Triazine Tolerant (TT) canola in the future. New varieties and alternative canola systems require further evaluation for performance and fit into individual on-farm agricultural systems (where time of sowing, soil type, weed type and populations, tillage and sowing methods, fertility and moisture availability all need to be considered).

KEY POINTS

- **Due to large seed size, hybrid varieties outperformed open-pollinated varieties for initial plant vigour four weeks after sowing.**
- **Seasonal circumstances, combined with direct heading saw significant yield losses across all canola systems and trial sites.**
- **New varieties outperformed existing varieties for yield and oil content across most trial sites.**

During 2008 five replicated field trials were established across New South Wales, Victoria and South Australia to compare the three commercially available herbicide-tolerant canola growing systems; Triazine Tolerant (TT), Clearfield (CL) and Roundup Ready (RR).

A demonstration site was also run at the Henty Field Days, NSW. Pioneer carried out research trials at Howlong, Lockhart, Junee Reefs and Yarrawonga. Many farmers, advisers and industry representatives were given the opportunity to view the trials during the 2008 season.

Varieties trialled were commonly-grown varieties for each region with maturities varying from early to mid. The Roundup Ready canola system was demonstrated with 46Y20 (RR) hybrid, Clearfield was demonstrated with 45Y77/46Y78 and the new 46Y81 (CL) hybrids compared against 44C79 and the new 43C80 (CL) varieties. The Triazine Tolerant varieties were Bravo (TT) and Tornado (TT).

Plant vigour

Plant vigour assessments, taken four weeks after sowing, displayed visual differences between the canola systems. Triazine tolerant varieties were significantly lower in vigour at all sites when compared with the other two canola systems.

Plant vigour is an important trait that helps quicker canopy closure to compete with insects and weeds; particularly in conventional or Roundup Ready canola systems, where there is no residual herbicide available to control weeds in-crop.

Seed size has a large impact on the establishment vigour and plant population and therefore its ability to compete with weeds. Seed size of all varieties in these trials varied from 160,000 seeds per kilogram to 300,000 seeds/kg. This variation in seed size produced a close correlation to plant population and the observed vigour advantage of hybrids compared with open-pollinated varieties in all trials.

Weed pressure

Weeds present at the sites included annual ryegrass, wild radish and volunteer cereals with weed pressure at all sites being light to medium.

Post-emergent herbicides were applied at two-leaf stage of the canola for all systems. Rates and timing were consistent with district practice and label recommendations.

An advantage of herbicide-tolerant canola systems is being able to control weeds; subsequent yield advantages are therefore often observed over conventional canola. Due to the low weed pressure at the trial sites, the three herbicide-tolerant systems may not have shown their true yield potential as would be displayed in commercial practice (higher weed pressure).

Yield loss with dry finish

A dry finish to the season combined with frost damage and/or shatter losses from locust damage, in addition to losses due to the direct heading harvesting method, saw significant yield losses across most trials.

Table 1 shows the yield of the various canola systems from one of the trials at Rossbridge, Victoria. Yield results from this site were achieved with low sub-soil moisture at sowing and a decile 1 growing season rainfall (278mm).

This site was the only trial with low variability (CV < 15) and average site yields greater than a minimum 1 tonne per hectare.

Canola trials: Pioneer Canola Technology Systems Trials in the Riverina area of New South Wales (September 2008).
TOP: Temora ARS trial site. BOTTOM: Henty Field Days trial site.

New variety shines

The top yielding canola at this site was the new 46Y81 (CL) hybrid.

The average yield of the commercial Clearfield hybrids was not significantly different to the Roundup Ready 46Y20 (RR) hybrid tested. The Roundup Ready hybrid was 34% or 0.46 t/ha higher yielding than the Triazine Tolerant check varieties.

TABLE 1 Comparative yield and oil at Pioneer Technology System site, Rossbridge Victoria

Herbicide tolerant system	Yield (t/ha)			Oil (%)
	Average	Minimum	Maximum	
Clearfield (CL)*	1.28a	1.13	1.30	43.6
Roundup Ready (RR)	1.38ab	1.06	1.55	43.8
Triazine Tolerant (TT)	0.91c	0.83	1.03	42.2

* Average of four CL varieties (ranging from 1.13 t/ha to 1.47 t/ha)
Trial CV: 13.91
Trial conducted and data analysis by Southern Farming Systems.
LSD (P=0.05): 0.3185 t/ha

Oil contents were also 1.4% higher (range from 0.5% to 3.2%) in varieties from both alternative canola systems compared with Triazine Tolerant canola, with the highest oil of 45.4% measured in the new Clearfield hybrid 46Y81 (CL).

High yield potentials indicated by the Clearfield and Roundup Ready varieties during early spring at the Temora, NSW trial were not realised. The new early variety 43C80 (CL) topped this trial under the tight seasonal finish experienced. It was also the highest ranked gross margin of herbicide tolerant varieties at the Bernard Hart field site at Junee Reefs, NSW.

Again, oil contents were higher from both alternative canola systems compared with Triazine Tolerant canola. Highest oil content at Temora of 41.5% was measured in the Clearfield variety 44C79 (CL) compared with 37.8% for Bravo and Tornado TT varieties.

For further information on canola systems or specific varieties; see the National Variety Trial (NVT) data or discuss with relevant seed companies and fellow growers.

Acknowledgements

Site co-operators: Syngenta, Southern Farming Systems, NSW Department of Primary Industries.

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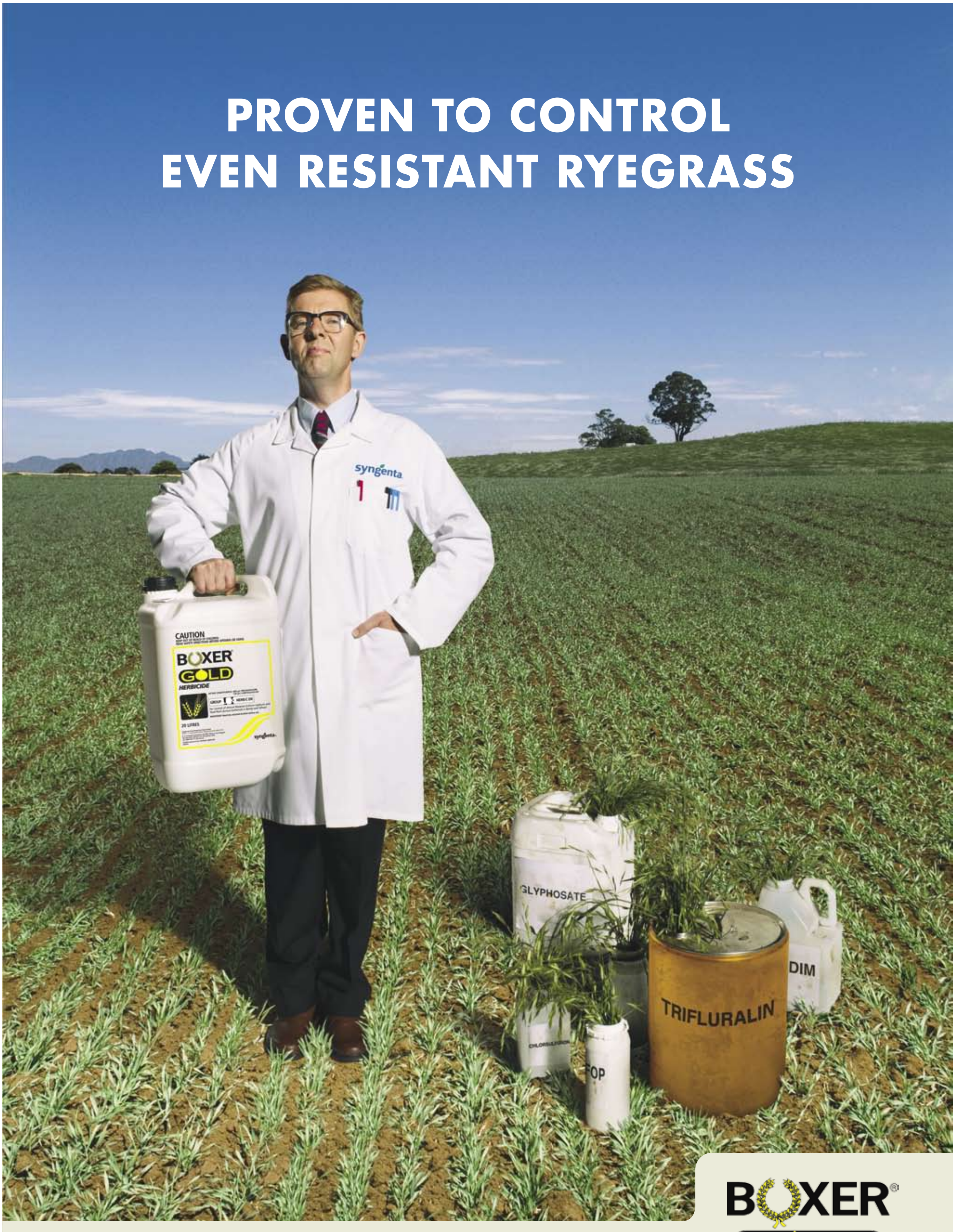
OVERVIEW

Keys to success

Key tips for growing the alternative Clearfield and Roundup Ready canola systems include:

- Select varieties (or hybrids where available) with maturity suitable for rainfall and length of growing season.
- Sow early (flexibility to sow dry in no-till systems).
- Use a pre-emergent herbicide for annual ryegrass and wireweed control.
- Use seed size to help calculate correct sowing rate.
- When applying two applications of herbicide; apply the first round at cotyledon (two-leaf stage), and the second before the six-leaf stage.



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Cultivating a healthy response to hay production


Photo: Kondinin Group

A balance of benefits: Dry matter production and feed quality of wheaten hay may be impacted by sowing method and weed control.

KEY POINTS

- Yields of wheaten hay significantly increased using cultivation at sowing compared with direct drill establishment during recent trials.
- Herbicide application to cultivated plots did not have a significant impact on yield.
- Herbicide application to direct drilled plots increased yield.
- Digestibility and metabolisable energy of hay from direct drilled plots superseded that from cultivated plots.

WRITTEN BY
Mark Lister, Gregory Dunn and Graham Brodie
University of Melbourne

Recent trials carried out by the University of Melbourne revealed that cultivating perennial pasture paddocks before sowing wheat for hay production could increase dry matter yields, but direct drilling and careful herbicide application could produce hay with higher feed values.

Agriculture uses most of Australia's water and the dairy industry uses about 70% of Victoria's water. Intense competition for water, with climate change projections forecasting lower rainfall and run-off in most of southern Australia, suggests that flood irrigated perennial pasture could give way to dryland agricultural practices.

This study compared the effects of direct drilling and sowing after cultivation on the emergence, growth and feed quality of Wedgetail wheat (*Triticum aestivum*) sown for hay production into a dried perennial pasture during 2008.

The experimental site was located in Dingee, Victoria, which has an average annual rainfall of 441 millimetres. Before the trial, the paddock was managed as an irrigated ryegrass and sub-clover dairy pasture. The soil was a grey sodisol with a sodic B horizon.

Six treatments, replicated three times, were arranged in a randomised block design. The pre-planting treatments consisted of:

a. no herbicide and direct drilling (NC1);

b. no herbicide and cultivation (C1);

c. a knockdown herbicide and direct drilling (NC2);

d. a knockdown herbicide and cultivation (C2);

e. a knockdown herbicide + pre-emergent herbicide and direct drilling (NC3); and

f. a knockdown herbicide + pre-emergent herbicide and cultivation (C3).

Cultivation was carried out March 9, 2008, using two-metre-wide Lely power harrows drawn by a 50 kilowatt John Deere 1640, two-wheel-drive tractor.

The herbicide application, depending on the imposed treatments, consisted of two litres of Roundup per hectare and 32 grams of Logran per hectare.

Sowing started April 14, 2008. Plant establishment and weed numbers were recorded on June 8, 2008. On September 28, 2008, plant samples were collected to determine potential dry matter (DM) yield and feed quality of the crop if it were cut for hay (see Table 1).

Data was analysed using a two-factor analysis of variance with Factor A being cultivation/direct drilling and Factor B being herbicide usage.

As may be expected, wheat yield increased significantly ($P < 0.01$) from 2.58t/ha (uncultivated, no herbicide) to 11.19t/ha with cultivation (no herbicide). The application of herbicide to cultivated plots did not significantly increase yield; however, the addition of herbicide to direct drilled plots significantly ($P < 0.05$) increased yield to 6.75t/ha and 6.23t/ha. This yield is significantly lower than all of the cultivated plots.

The establishment throughout the uncultivated, no herbicide plots was significantly different to the other plots with an establishment of 42.3 plants/m².

Establishment across all of the cultivated plots was not significantly ($P < 0.05$) different ranging from 87 to 93.3 plants/m².

The uncultivated plots, with herbicides applied, showed no significant ($P < 0.05$) difference to the cultivated plots, with plant number of 79 and 75.3 plants/m².

Weed presence throughout all plots with cultivation and all plots with herbicides applied was not significantly ($P < 0.05$) different, with weeds ranging from 0.5 to 5 weeds/m², however uncultivated plots with no herbicides had a significant increase in weed density with up to 54 weeds/m².

Acknowledgements

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TABLE 1 Feed quality results

Treatment	Dry Matter (%)	Crude Protein (%)	Neutral Detergent Fibre	Estimated Metabolisable Energy (MJ kg^{-1})	Dry Organic Matter Digestibility (%)	*In vivo* Dry Matter Digestibility (%)
C1	27.6	13.4	52.3^{a}	9.0^{a}	59.1^{a}	61.7^{a}
C2	29.4	12.4	54.2^{a}	9.0^{a}	59.1^{a}	61.7^{a}
C3	29.6	12.9	53.8^{a}	9.1^{a}	59.3^{a}	61.3^{a}
NC1	29.5	12.4	46.2^{b}	9.8^{b}	63.0^{b}	72.5^{b}
NC2	27.2	11.8	50.5^{b}	10.5^{b}	66.3^{b}	65.7^{c}
NC3	26.7	13.2	47.9^{b}	10.6^{b}	67.0^{b}	70.1^{b}
LSD ($P < 0.05$) — cultivation	Not significant	Not significant	0.7	0.5	2.4	0.7
LSD ($P < 0.05$) — herbicide	Not significant	Not significant	1.9	Not significant	Not significant	0.9
LSD ($P < 0.05$) all combinations	Not significant	Not significant	Not significant	Not significant	Not significant	2.7

Legumes — the benefits are greater than nitrogen alone

WRITTEN BY
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An investigation into the overall impact of legumes on soil nitrogen and the associated benefits for following crops has found that existing nitrogen budgets could be underestimating the total amount of nitrogen legumes contribute to the soil. The impact of legumes on crop nitrogen dynamics could also be much greater than predicted from the direct uptake of legume nitrogen, with benefits lasting for more than one year. Researchers remind growers that the direct effects of legumes on soil nitrogen fertility are not necessarily the main source of rotational benefits for following crops.

KEY POINTS

- **The amounts of nitrogen fixed by legumes are usually related to plant growth, with about 20–25 kilograms of shoot nitrogen being fixed for every tonne of above-ground dry matter produced.**
- **Between 30-60% of a legume's total plant nitrogen may be below-ground, associated with roots and nodules. Consequently crop legume residues can still contain significant amounts of fixed nitrogen even after large amounts are removed in grain at harvest.**
- **The conversion of legume organic nitrogen into inorganic nitrogen is mediated by microbes and only a fraction in legume residues becomes available as mineral nitrogen in the first year.**
- **Release of mineral nitrogen is influenced by soil water content, temperature and pH, the amount of residues returned to the soil after a legume phase, the 'quality' (particularly C:N ratio) of those residues, and the length of the fallow period between the end of the legume phase and sowing the next crop.**
- **Legume roots and nodules could be a more important source of nitrogen for crops than shoot residues.**

Measurements of nitrogen fixation undertaken on 140 pastures and 59 pulse crops growing at various locations in Victoria or southern and central New South Wales indicate that legumes have the potential to fix more than 100–200 kilograms of nitrogen (N) per hectare across a wide geographic area (see Table 1).

The amount of nitrogen fixed by a legume in any environment is regulated by two factors. The amount of nitrogen present in the legume's products of growth, and the proportion of that nitrogen derived from atmospheric N_2 (%Ndfa) as a result of symbiotic nitrogen fixation by rhizobia in the legume's nodules:

Amount nitrogen fixed = Legume nitrogen x (%Ndfa)/100

The nitrogen accumulated by a legume is in turn determined by the amount of dry matter (DM) produced and nitrogen content (%N) of that biomass:

Legume nitrogen = Legume dry matter x (%nitrogen)/100

Key factors influencing nitrogen fixation

There are a number of key factors that influence the amount of nitrogen fixed by legumes.

Rhizobia — In the absence of the appropriate rhizobial species in the soil %Ndfa will be zero (i.e. no symbiosis can be formed), and %Ndfa may be less than optimal if the rhizobial strains in the soil are poorly effective. This can generally be rectified by seed inoculation with rhizobia before sowing.

Soil nitrate — Legumes are similar to all other plants in that they can use forms of mineral nitrogen in soil (ammonium and nitrate) for growth (albeit generally not quite as efficiently as cereals or grasses). Since soil nitrate and nitrogen fixation are complementary

TABLE 1 Estimates of the amounts of shoot nitrogen fixed by various legumes growing at different locations in south-eastern Australia

Location	Legume species	Amount of shoot nitrogen (N) fixed[a] (kgN/ha/yr)	
		Range	Average
Victoria			
Horsham	Faba bean	82-174	128
	Lentil	60-110	90
	Field pea	85-166	138
	Vetch	72-160	116
	Annual medic	2-90	39
	Lucerne	19-90	43
Rutherglen	Lupin	59-244	150
	Sub-clover	99-238	160
NSW			
Junee	Field pea	133-183	160
	Sub-clover	21-118	56
	Lucerne	103-167	128
Stockinbingal/Temora	Faba bean [2002]	112-146	123
	Lupin/field pea [2008]	12-83	45
Condobolin	Lupin	26-93	51
	Field pea	35-111	58
Trangie	Lucerne	13-82	37

[a] The data set includes experimental trials and on-farm measures collected from commercial crops and pastures.

Source: Peoples *et al.* (2001) Plant & Soil 228: 29-41, and includes unpublished data of Cela, Angus, Swan, Crews and Peoples.

in meeting the nitrogen requirements for growth by a legume crop, nitrate effectively inhibits nodulation and nitrogen fixation processes.

In other words, a legume's reliance upon nitrogen fixation will decline with increasing concentrations of mineral nitrogen in the root zone.

High concentrations of soil nitrate can occur as the result of excessive tillage, heavy summer and autumn rainfall (provided weeds are controlled), a long fallow, which might be used to build up and conserve soil water (for example, such as is often the case in the cropping zones of northern NSW), or after a series of failed or droughted crops. For example, nitrogen fixation of several different legume crops grown at Stockinbingal between Temora and Cootamundra in southern NSW during 2008 ranged from just 8–29% compared with measurements of more than 70% in the same district during 2002.

Experimentation with pea crops in France indicated that nitrate inhibition of nitrogen fixation was absolute (i.e. seasonal nitrogen fixation = 0) when soil mineral nitrogen at sowing exceeded 380kg of nitrate-N/ha, and nitrogen fixation was not initiated until soil mineral nitrogen concentrations dropped below 56kgN/ha.

Similarly, research trials undertaken with productive chickpea crops in Queensland showed that little or no N_2 was fixed when the soil contained more than 350 kg of nitrate-N/ha, although data collected from commercial chickpea crops with lower biomass in northern NSW suggests the critical value could be closer to 200kg of nitrate-N/ha.

While the NSW results for chickpea could have been complicated by low rainfall, it was noteworthy that neighbouring faba bean crops sampled on the same farms maintained much higher levels of nitrogen fixation than chickpea crops at equivalent concentrations of soil nitrate.

Impact of legume growth

With the exception of the 2008 data from Stockinbingal shown in Table 1, the nitrogen fixation values for most legumes ranged between 60–90% (average nitrogen fixation of about 75% for both pulses and pasture legumes) and the amounts of shoot nitrogen fixed were closely related to the amount of biomass production, with about 20–25kg of shoot nitrogen being fixed for every additional tonne of shoot dry matter produced (see Figure 1).

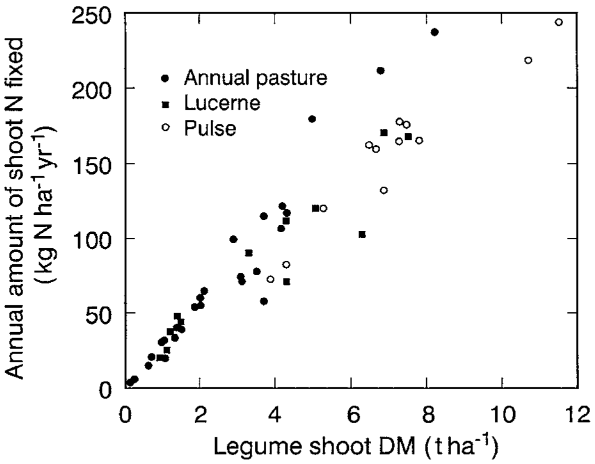

FIGURE 1 The relationship between shoot dry matter (DM) accumulation and estimates of the annual amounts of shoot nitrogen fixed by rainfed annual pasture legumes, lucerne, or pulse legume crops growing in south-eastern Australia (Peoples *et al.* 2001 *Plant and Soil* 228: 29-41).

So although the levels of nitrogen fixation are important, provided there are adequate numbers of effective rhizobia in the soil and concentrations of soil mineral nitrogen are not too high, N_2 fixation is overwhelmingly regulated by legume growth rather than by fixation alone.

Apart from climatic extremes almost every other factor that has been identified as influencing nitrogen fixation as done so through a direct impact on legume growth potential (for example, nutrition, weed control, disease, pests, or cropping sequence and intensity), and consequently can potentially be addressed or manipulated by grower management.

Therefore, basic improvements in crop agronomy probably hold the greatest promise as a means of enhancing inputs of fixed nitrogen through increasing legume biomass. A significant strategy involves the use of legume genotypes adapted to the prevailing soil and environmental conditions.

Contributions of residual fixed nitrogen to soil fertility

With pasture legumes the fixed nitrogen in foliage tends to be returned to the soil either in urine or faeces following grazing, or via dead and fallen plant materials that might remain unconsumed by livestock. But in the case of crop legumes, much of the nitogren in the shoot is harvested in the high protein grain.

Often it is assumed that because such large amounts of nitrogen are removed from the field as grain that legume pulse crops might not return much fixed nitrogen to the soil for the benefit of following crops. However, the values such as those presented in Table 1 have usually been determined solely from measures of legume shoot biomass — below-ground contributions of fixed nitrogen have often been ignored.

Field research now suggests that nitrogen associated with nodules and roots may represent between 30% and 60% of the total nitrogen accumulated by legumes. Therefore, total inputs of fixed nitrogen by pulses are likely to be much greater than had previously been believed from shoot-based determinations (for example, compare Figure 2a with 2b).

It follows that, when below-ground contributions of fixed nitrogen are included in nitrogen budgets compared to when they are not, different conclusions would be drawn about the potential for legume crops to return fixed nitrogen to soil following grain harvest (for example, Figure 2c, 2d).

Patterns of nitrogen release for crops

It is incorrect to assume all of the nitrogen fixed by legumes will immediately be available to crops following either a pulse or a pasture phase.

The nitrogen in legume organic matter decomposes to produce ammonium and a specialised group of microorganisms (nitrifiers) convert the ammonium nitrogen to nitrate. Both ammonium and nitrate can be used by plants for growth, but many plants prefer nitrate.

Since the conversion of organic nitrogen into inorganic nitrogen (the process of mineralisation) is mediated by soil microbes only a portion of the nitrogen in legume root and shoot residues will become available for plant uptake in the short-term and this can be influenced by:

- **Soil water content and temperature** — Peak rates of mineralisation during autumn or a favourable spring where soil water and temperatures are optimal are about 1.0–1.2 kgN/ha/day. Winter temperature of about 7°C reduces the rate to about 0.2 kgN/ha/day, but the rate essentially falls to zero in a dry soil.
- **Soil pH** — Low soil pH inhibits the activity of nitrifiers. In acid soils the conversion of ammonium to nitrate might be restricted to the top few centimetres where the soil pH is likely to most favourable due to the buffering capacity of organic matter near the soil surface.

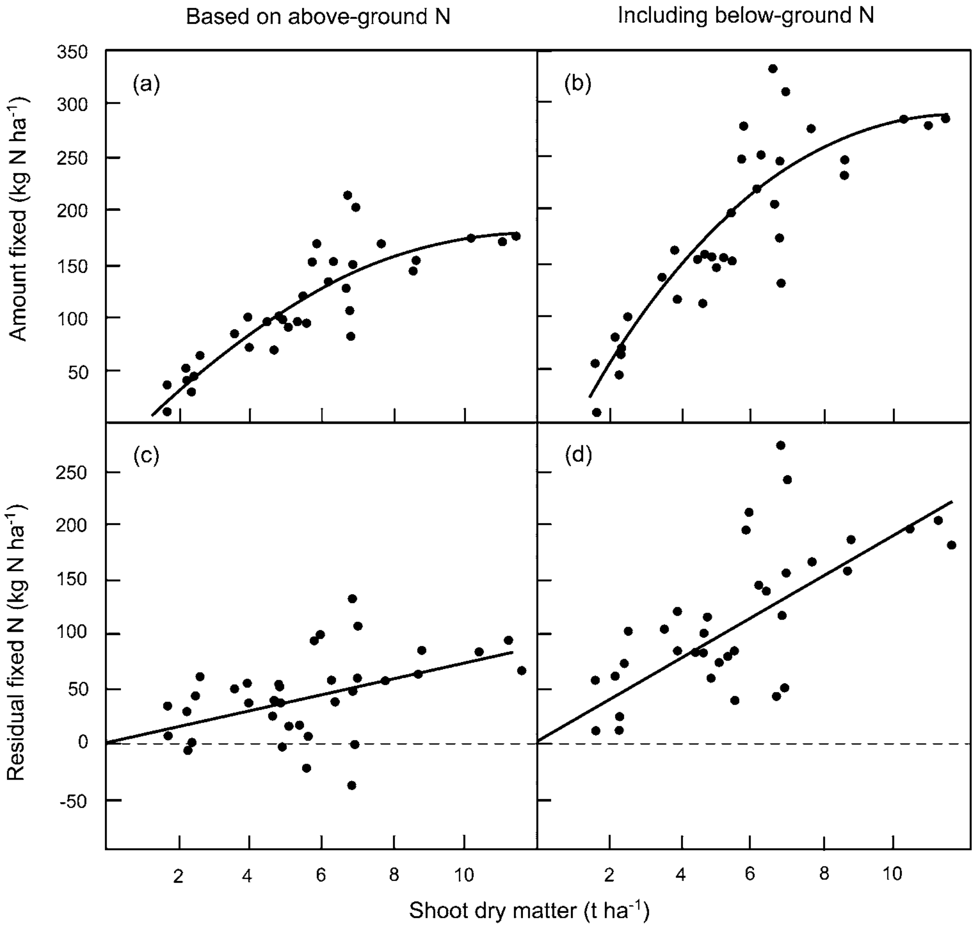

FIGURE 2 Data obtained from irrigated commercial faba bean crops in northern NSW illustrating the consequences of (i) ignoring the contribution of below-ground nitrogen (a,c), or (ii) including the contribution of below-ground nitrogen (b,d) on determinations of amounts of N2 fixed (a,b) and residual fixed nitrogen remaining after grain harvest (i.e. fixed nitrogen — seed nitrogen removed). Calculations of positive measures of residual fixed nitrogen indicate a net input of fixed nitrogen, while negative values represent a net export of nitrogen from soil. The broken line represents the situation where the estimate of the amounts of N2 fixed equals the seed nitrogen removed. Data modified from Rochester *et al.* (1998) *Aust J Expl Agric* 38: 253-260.

- **The 'quality' of the residues** — Decomposition studies of shoot and root residues indicate that differences in patterns of nitrogen release are strongly linked to tissue C:N ratios. Residues with a low C:N ratio decompose fastest, and those with a high C:N ratio can actually lead to a reduction in mineral nitrogen by absorbing nitrogen mineralised from the soil organic matter (this process is called immobilisation). Not all legume residues are the same. For example, the quality (C:N ratio) of shoot residues and the rate of mineralisation will differ if a legume crop is grown for grain or used as green manure since the mature, dead vegetative residues remaining after grain harvest have a much higher C:N ratio than young foliage material either green or brown manured earlier during growth. Similarly stems and pods of pulses tend to decompose more slowly than leaves for the same reason.

At the end of a growing season roots are likely to represent the single largest pool of legume nitrogen for mineralisation. In the case of the roots of species such as sub-clover the breakdown is usually rapid because of the low C:N ratio (about 13:1), and is often complete by the second or third year of a cropping phase (see Table 2).

The C:N ratio for lucerne roots, on the other hand, is 25–30:1 and this results in an initial transient immobilisation of nitrogen followed by a slow mineralisation of lucerne residues. This may partly explain why there is sometimes nitrogen deficiency in crops immediately after lucerne. However, the slower initial mineralisation and larger pool of lucerne nitrogen in the soils means the supply of nitrogen after a lucerne pasture is likely to continue much longer into the cropping phase than following sub-clover (see Table 2).

TABLE 2 Grain yield of wheat harvested during 2001 grown in the absence of fertiliser nitrogen for different periods after either sub-clover- or lucerne-based pasture phases[a]

Values followed by the same lower case letter are not significantly different at P=0.05

Sequence of pastures or crops					2001 yield (t/ha)
1997	1998	1999	2000	2001	
Barley	Canola	Wheat	Canola	Wheat[b]	2.8(a)
Barley	Sub-clover	Sub-clover	Canola	Wheat	3.4(b)
Barley	Sub-clover	Sub-clover	Sub-clover	Wheat	4.2(c)
Lucerne[c]	Canola	Wheat	Canola	Wheat	3.9(c)
Lucerne[c]	Lucerne	Wheat	Canola	Wheat	4.1(c)
Lucerne[c]	Lucerne	Lucerne	Canola	Wheat	4.1(c)
Lucerne[c]	Lucerne	Lucerne	Lucerne	Wheat	4.1(c)

[a] Unpublished data (Angus, McCallum, Peoples and Swan) from an on-farm trial site located near Temora in southern NSW.
[b] Wheat yield of the continuous cropping control involving a rotation of canola and cereals during 2001 was increased to 3.4t/ha with the addition of 60kg fertiliser N/ha applied as urea.
[c] The grower's lucerne pasture was four years old at the start of experimentation.

Factors that can influence concentrations of inorganic nitrogen after a pasture include:

- **The botanical composition of the pasture and the amount of legume grown during the pasture phase** — Generally mixed legume-grass pastures decompose more slowly than pure legume stands. However, data from different pastures at two locations that differed in total average annual rainfall (550mm at Junee, NSW and 430mm at Ardlethan, NSW) suggest that concentrations of soil nitrate and subsequent crop responses following a pasture phase tend to be related to the cumulative amount of legume biomass grown, with on average an additional 15kg of nitrate-N/ha being accumulated over and above background mineralisation of soil organic nitrogen for every additional tonne of legume dry matter (DM) accumulated (see Figure 3).
- **Grazing intensity** — High grazing pressure results in greater concentrations of mineral nitrogen as a much higher proportion of the nitrogen in the foliage of pasture legumes is consumed by livestock to be excreted as urine, which in turn is rapidly converted to ammonium and nitrate in the soil.

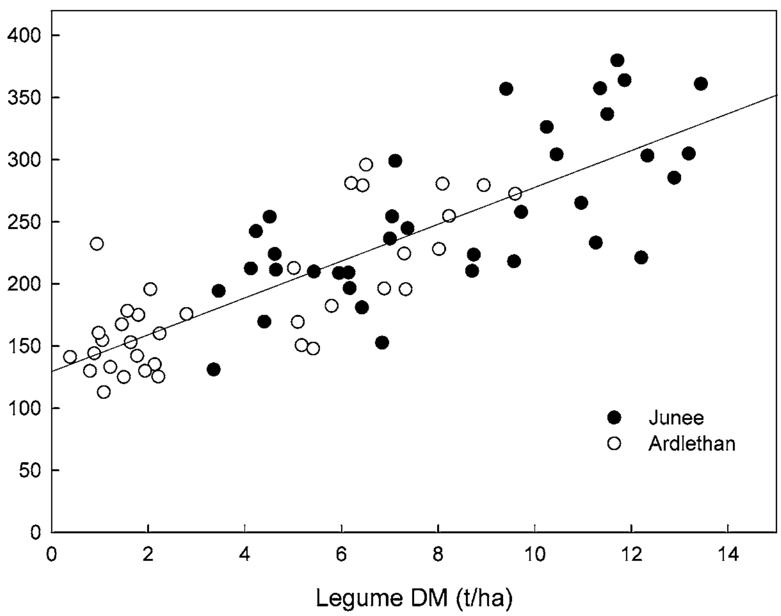

FIGURE 3 Relationship between concentrations of mineral nitrogen in the top 1m of soil just before cropping and the total above-ground legume dry matter (DM) accumulated during the previous three-year pasture phase (regression equation: mineral nitrogen = 130 + 0.0148 x legume DM, r^2 = 0.66). Data are derived from experiments undertaken at two locations in southern NSW (courtesy of Virgona, Dear, Sandral and Swan).

TABLE 3 Example of the effect of timing of removal of lucerne before cropping on concentrations of soil mineral nitrogen (top 2m) measured at the time of sowing the first wheat crop, and the subsequent crop uptake of nitrogen and grain yield[a]

Time of lucerne removal (months before sowing)	Soil mineral nitrogen at sowing (kgN/ha)	Wheat above-ground nitrogen at maturity (kgN/ha)	Grain yield (t/ha)
6	206	137	5.9
4	111	109	5.0
2	59	86	3.8

[a] Results from an on-farm trial near Junee in southern NSW (Angus *et al.* 2000 *Aust J Agric Res* 51: 877-890). Values represent the combined data from both cultivation and herbicide removal treatments.

- **The timing of lucerne removal of before cropping** — On-farm experimentation near Junee in southern NSW indicated that concentrations of soil mineral nitrogen measured at sowing a following wheat crop and its impact on crop nitrogen uptake and grain yield was closely related to the time of removal of the lucerne pasture before cropping (see Table 3). In this particular experiment soil mineral nitrogen was increased by about 0.75kgN/ha of every additional day of fallowing, or by 0.5kgN/ha per millimetre of rainfall during the fallow period.

Legume nitrogen versus fertiliser nitrogen

The fate of nitrogen in legume residues is often measured using legumunious materials labelled with the stable (non-radioactive) isotope of N, ^{15}N. Such studies generally indicate that subsequent crops take up less than 30% of the legume nitrogen (see Table 4).

Such data have led to suggestions that legumes are an inefficient short-term source of nitrogen. Certainly there are examples in Table 4 where less than 10% of the nitrogen in a following crop appear to be derived from the previous legume crop. However, there are also situations where legume sources have provided a significant proportion (about 20% or more) of the next crop's nitrogen requirements (see Table 4).

Often the ^{15}N-labelled legume inputs used in experiments such as those presented in Table 4 represent only shoot material. This ignores the potentially large amounts of below-ground legume nitrogen associated with, or derived from, roots and nodules discussed above.

Under Australian field conditions wheat has been reported to use between 3–10% of the residual below-ground nitrogen from a previous lupin crop, or 8% and 16% of the below-ground nitrogen of previous faba bean and chickpea crops, respectively.

In the case of faba bean and chickpea, this uptake of below-ground nitrogen contrasted with an uptake by wheat of just 3% of the residual shoot nitrogen.

Other studies have suggested that below-ground legume nitrogen could be the source of between 30–75% of the total mineral nitrogen accumulating after legumes. As such, the below-ground pool of legume nitrogen appears to be an important source of nitrogen for following crops — paradoxically, it has often not even been considered.

TABLE 4 Examples of the extent of uptake of ^{15}N-labelled nitrogen from legume residues by a following cereal crop

Species	Amount of residue nitrogen returned (kg N/ha)	Crop uptake of legume nitrogen (% residue N)	Proportion of cereal nitrogen derived from legume (% crop total N uptake)
Grain legumes			
Chickpea	183	9	19
Lentil	45	6	1
Pea	49-130	6-15	6-13
Faba bean	73-96	11-17	11-19
Lupin	36-86	21-27	6-18
Pasture legumes			
Annual medic	48	24	8
White clover	50-81	25	12-25
Lucerne	40-112	12-21	7-15

Source: Peoples *et al.* (2009) Symbiosis (in press), and Khan (2000 PhD thesis Melbourne University)

Studies that estimate uptake efficiencies of labelled nitrogen from legume residues also have a tendency to underestimate the overall nitrogen — supplying capacity of a legume-based system. This is likely to be the result of nitrogen 'pool substitution' whereby the newly applied ^{15}N-labelled legume nitrogen is immobilised in the microbial biomass and unlabeled nitrogen is mineralised. The importance of pool substitution was illustrated in a ^{15}N field experiment in Western Australia. In the second year of a lupin-wheat rotation, researchers found gross nitrogen mineralisation in the top 10cm of soil to be 120kgN/ha, and net nitrogen mineralisation (gross mineralisation — immobilisation) to be only 59kgN/ha, 69% of which (41kgN) originated from the soil microbial pool.

These data suggest that most of the nitrogen initially released from lupin residues was immobilised and thus inaccessible to the wheat crop in the short-term. This was compensated for by mineralisation of older (unlabelled) microbial — nitrogen that subsequently became available for crop uptake.

The net result of such processes is that calculations based on crop recovery of ^{15}N-labelled leguminous material are often lower than determinations of 'agronomic' nitrogen benefits derived from including a legume in a rotation.

Nitrogen use efficiency — the low-down

Unfortunately there are only relatively few studies where ^{15}N-labelled inputs have been used to compare legume with fertiliser sources of nitrogen under the same experimental conditions. Such comparisons in rainfed farming systems indicate that cereal crops, on average, tend to recover more than twice the nitrogen from fertiliser than from legume residues (see Table 5).

However, the estimates of nitrogen losses from legume sources tend not to be very different from fertilisers (mean 23% cf 33% of the fertiliser nitrogen applied), despite a higher proportion of the legume nitrogen generally remaining in the soil at harvest as compared with fertiliser (see Table 5).

These general conclusions about the relative use and losses of legume and fertiliser nitrogen should be qualified by acknowledging that:

1. The comparative studies summarised in Table 5 have not necessarily always used 'best management practices' when applying either the fertiliser or legume residues.
2. As discussed, the ^{15}N-labelled legume inputs utilised in most experiments tends to represent only shoot material. This ignores the potentially large amounts of crop and pasture legume nitrogen below ground associated with, or derived from, roots and nodules.
3. Also as discussed, studies that estimate uptake efficiencies of labelled nitrogen from recently applied legume residues have a tendency to underestimate the overall nitrogen — supplying capacity of a legume-based system. This suggestion is also supported by studies that have observed similar grain yield by crops grown on legume or fertiliser sources of nitrogen despite lower apparent utilisation of the legume nitrogen.
4. Often investigations compare nitrogen recovery and losses for a single year or just the first crop following a legume phase, and this may be too short in duration to fully demonstrate the consequences of utilising fertiliser or legume nitrogen (see following sections).

Impact of legumes on grain yield

It is well known that cereal grain yields can be enhanced by including a legume in the rotation. Researchers have reported that pulse legumes can enhance wheat yields by 1–1.7 t/ha across a range of environments. Such yield responses should not be attributed only to nitrogen. For example, reductions in cereal leaf and root disease have been demonstrated to be major factors contributing to observed yield advantages after legumes and other break crops. One way of estimating the relative value of the nitrogen contribution and other rotational benefits of legumes is to compare the quadratic response curves for cereal grain yield with different rates of applied fertiliser nitrogen in legume-cereal and cereal-cereal sequences. Where the cereal-cereal response curves converge and intersect the legume-cereal line with increasing rates of fertiliser nitrogen, the legume benefit is considered to largely be due to nitrogen (such as in Figure 4a).

TABLE 5 Examples of the fate of either ^{15}N enriched fertilisers or legume residues applied to cereal crops, indicating the range of estimates of crop nitrogen recovery and the extent of losses of the applied nitrogen. Values in parentheses represent the average.

Source of nitrogen applied	Crop uptake (% applied N)	Recovered in soil (% applied N)	Unrecovered [assumed lost] (% applied N)
Fertiliser	17–50 (36)	21–40 (31)	16–62 (33)
Legume	5–27 (15)	37–90 (62)	4–54 (23)

Source: Peoples *et al.* (2009) Symbiosis (in press)

Converging curves, which do not intersect, indicate a combination of nitrogen and non- nitrogen benefits (see Figure 4b).

Finally if the yield response curves after the legume and non-legume are parallel, then factors other than nitrogen are primarily involved (see Figure 4c).

One study compared grain yield responses to increasing rates to applied fertiliser nitrogen for a series of wheat-wheat and lupin-wheat rotations in WA during the 1980s. It concluded that enhanced nitrogen availability derived from lupin either dominated the rotational effect, or was important contributing factors in the subsequent yield improvement by wheat in less than half of the experiments (only 9 of the 21 comparisons fell into categories such as those depicted in figures 4a and 4b). Few similar studies have been undertaken elsewhere in Australia so it is difficult to say how representative such general conclusions may be in the south-eastern cropping zone at the start of the 21st Century.

Long-lasting benefits

Legume effects on grain yield and protein have been observed to occur for several years of cropping. The net result of a larger residual pool of legume nitrogen combined with a slower pattern of nitrogen mineralisation following a perennial pasture legume such as lucerne is that crops grown after lucerne can be supplied with nitrogen for a much longer period (typically more than three years, see Table 2), although possibly in lesser amounts during the first year, than following annual pasture legumes or pulses (usually only 1–2 years, see Table 2).

The relative size of the nitrogen benefit obtained after lucerne depends upon a combination of the density and productivity of the lucerne and the duration of the pasture phase. However, as mentioned, there is also a number of other non- nitrogen rotational benefits that can be very important in contributing to improvements in subsequent crop productivity.

Acknowledgements

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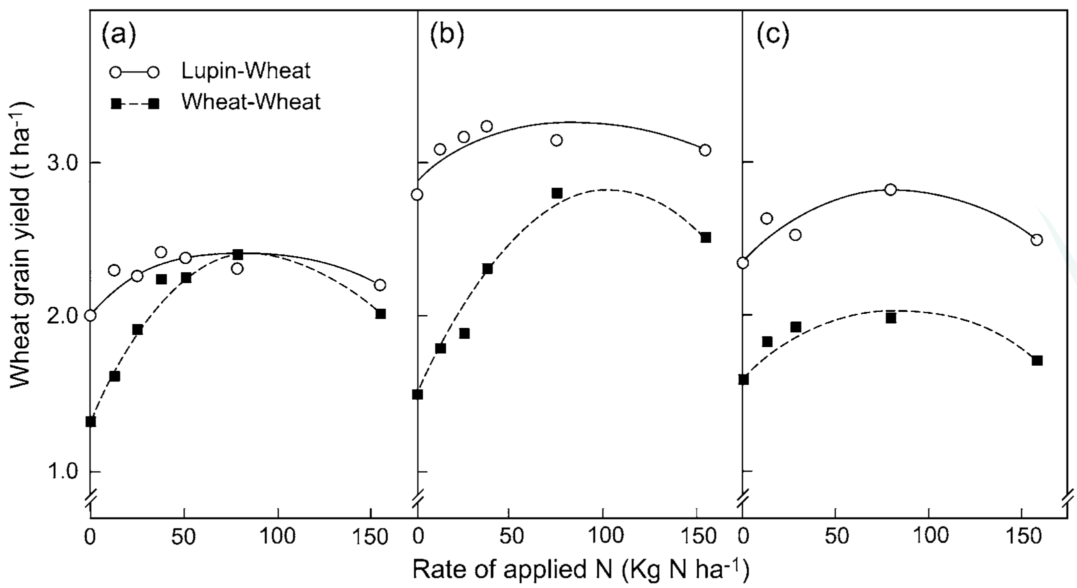

FIGURE 4 Examples of different grain yield responses of wheat to increasing rates of applied fertilizer N in wheat-wheat sequences (■- -■) or lupin-wheat rotations (o–o). Modified from Chalk (1998) *Aust J Agric Res* 49: 303-316.

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Break-crop benefits under review in dry seasons

Dubious benefits: A run of dry seasons has prompted a re-evaluation of the value of break crops for improving wheat yields in subsequent years.

WRITTEN BY
John Angus CSIRO Plant Industry

Introduced during the 1980s and 90s, broadleaf break crops brought multiple benefits — higher yields in following wheat crops, disease breaks, increased soil nitrogen, greater weed control options before re-entering the wheat phase and additional grazing and fodder opportunities. But a recent succession of dry seasons, with late starts and dry springs, calls for a re-evaluation of the true value of break crops in many dryland farming systems.

KEY POINTS

- **A recent review of break crop experiments shows that the previous conclusions about a percentage yield increase from break crops is inaccurate. It is more correct to express the increase as an absolute amount than a percentage.**
- **The gross margins of canola-wheat-wheat are greater than for wheat-wheat-wheat, but only when sowing the canola before mid May.**
- **Grazed canola has higher gross margins than grain-only canola when sown before early May, but sharply lower returns for later sowing.**
- **Grain-only wheat followed by two other wheat crops gives the highest gross margin for crops sown after late May. Grazing the first wheat crop gives higher gross margins than grain-only wheat.**
- **Gross margins for lupin-wheat-wheat were close to the values for wheat-wheat-wheat when the first crop was sown during late May.**
- **Reasons for persisting with some break crops are control of herbicide-resistant weeds and the hope of capturing their benefits during wetter seasons.**

Broadleaf crops became significant parts of Australian dryland farming systems during the 1980s, starting with lupins and followed by canola during the 1990s.

Experiments during the 1980s and 90s showed that much of the value of broadleaf crops was from the increased yield of the following wheat crop. A review of 135 experiments during 2001 showed that wheat after canola yielded about 20% more than wheat after wheat, and wheat after grain legumes yielded 40–50% more than wheat after wheat.

For the gross margin of a canola-wheat sequence, about three-quarters of the value of a break crop was from the additional yield of the following wheat crop and only one-quarter was from the canola crop itself.

It's time to re-examine the value of break crops. The recent series of dry seasons with late starts and dry springs appear to have caused greater yield loss to broadleaf crops than cereals. Cereal root disease may be less prevalent now because of the dry springs and the cumulative effects of previous break crops.

During 2008 in southern NSW, the yield of wheat after cereals exceeded wheat after broadleaf crops, apparently because cereal stubbles conserved more rainfall during the previous summer. Offsetting these disadvantages are a greater appreciation of hay cut from failed canola crops, new opportunities for grazing canola and the weed control options using herbicide-tolerant canola.

Mechanisms of the break crop effect

The long-recognised benefits of break crops are reducing cereal root disease and, for legumes, increasing the net supply of soil mineral nitrogen. Root diseases are suppressed because they are deprived of a host for a year. Recent research suggests there are additional mechanisms for the break-crop effect and there is also more information about the magnitude of the break-crop effect from a review of published experiments.

We now know the rhizobia in the nodules of legumes release hydrogen gas into the soil and this hydrogen is taken up by other soil microbes, which stimulate the growth of the following cereal. Field experiments suggest that hydrogen released by a legume increases growth of a following cereal by at least 10 per cent (article by Mark Peoples on page 106).

It is also possible that the nitrogen benefit of legumes is not only due to the additional nitrogen from biological fixation. The root residues of legumes normally have a higher carbon to nitrogen (C:N) ratio than cereals so there is less potential for immobilisation of soil mineral nitrogen by the root residues of legumes than by cereal residues.

However, legumes are not the only crops to boost soil mineral nitrogen. There is strong evidence that soil mineral nitrogen is greater after canola than after cereals, possibly because of reduced immobilisation by the root residues.

There is some evidence that part of the break-crop benefit of canola and lupin is because they are not hosts of *arbuscular mycorrhizal* fungi (AMF). Normally AMF colonisation in the roots of cereals growing after canola and lupin is lower than cereals growing after AMF hosts. AMF use carbohydrates from crop roots as an energy source so they are effectively parasites when they are not needed to take up the immobile nutrients phosphorus and zinc from the soil. AMF are more likely to be beneficial in soils with low phosphorus and zinc levels.

Magnitude of the break-crop effect

A recent review of break crop experiments shows the previous conclusions about a percentage yield increase from break crops are inaccurate. It is more correct to express the increase as an absolute amount than a percentage. In other words the increase is relatively constant across a range of wheat yields. A more complete discussion is available on the web at www.regional.org.au/au/asa/2008/concurrent/rotations/5786_angusjf.htm.

The absolute yield increase is best shown in Figure 1a where the yield of wheat after oats averaged 0.47 tonnes per hectare more than wheat after wheat in 113 experiments.

It is known that oats are a non-host of the take-all pathogen but they share several other root diseases with wheat.

Based on 35 experiments, wheat after canola yielded 0.85t/ha more than wheat after wheat (see Figure 1b). Canola breaks the life cycle of most root pathogens of wheat, so the additional yield of wheat after canola compared with wheat after oats provides an estimate of the effect of these other pathogens on wheat yield. Figure 1b also shows the effect of linseed on wheat yield. Linseed is similar to canola in not hosting cereal pathogens but linseed is a host of AMF, while canola is not. In Figure 1b there was no difference between the average break-crop benefits of canola and linseed. This result suggests that suppression of AMF by a single non-host does not contribute to increased yield of a following crop.

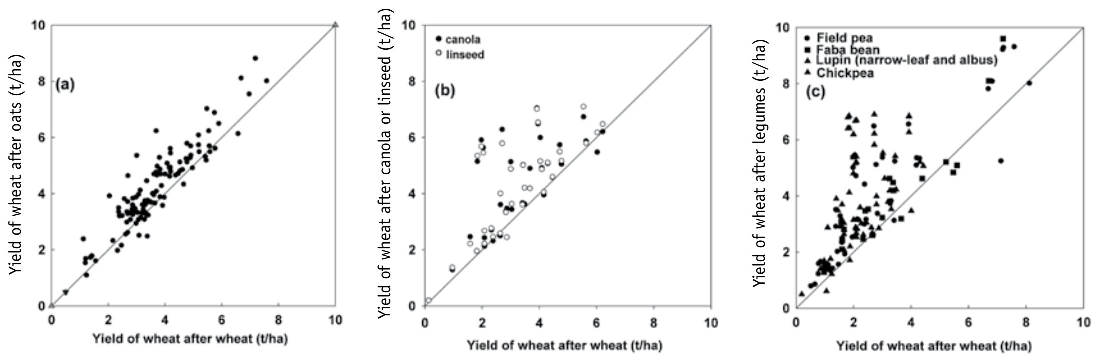

FIGURE 1 Yield of wheat after break crops compared with wheat after wheat, based on a survey of published experiments

Each data point represents average yields in replicated experiments — (a) oats (b) canola and linseed (c) grain legumes.

The grain legumes lupin, field pea, faba bean and chickpea increased yield of the following wheat crops, on average, by 1.21t/ha over 98 experiments (see Figure 1c). The increase varied from 1.81t/ha after lupin to 1.10t/ha after field pea. The low value for field pea could reflect the dry regions where many of the experiments were carried out.

The yield responses for wheat are much greater than for oats or oilseeds, reflecting the combined disease break, additional residual nitrogen and growth stimulation by hydrogen gas released into the rhizosphere.

Putting together the yield responses of wheat to previous crops we can estimate the contributions of different processes, which can be added where appropriate, for example adding disease control to the other benefits of legumes (see Table 1).

The yield benefit from take-all suppression is estimated from the oats data and the suppression of other root diseases from the additional yield after canola.

An additional contribution is assumed for stimulation of nitrogen mineralisation by canola. Estimates of the yield effect of hydrogen fertilisation by legumes vary from 0 to 15% and we have assumed a value of 10%.

There is little hard evidence for a yield benefit from AMF-suppression after a single break crop, but a small benefit is included because of previous evidence from double break crops and the extraordinarily high yield of wheat after lupin, a non-host of AMF.

The nitrogen benefit from legumes is estimated as the residual needed to explain the average break-crop effect shown in Figure 1.

TABLE 1 Contributions of different processes to the break-crop effect for a 4 t/ha wheat crop

Process	Additional wheat yield (t/ha)
Take-all suppression	0.5
Suppression of other root diseases	0.3
Net nitrogen benefit of canola	0.1
Hydrogen fertilisation by legumes	0.4
Suppression of AMF by non-host crops	0-0.1
Net nitrogen benefit of legumes	0.5

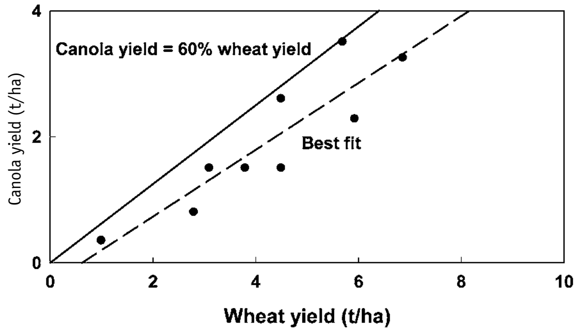

FIGURE 2 Canola yields compared with wheat yields in the same experiments in southern NSW

Table 1 applies to relatively moist growing seasons but does not apply when water supply is insufficient for wheat crops to express the additional yield after break crops.

Canola yield versus wheat yield

Based on the energy content of the seeds, the highest canola yield is expected to be about 60% of wheat yield. Figure 2 shows wheat and canola yields from experiments where most of the yield variation was due to water supply.

In high-yielding environments, canola yield approached 60% of wheat yield but canola yields dropped faster than wheat yields in low-yielding environments.

Based on the line of best fit through the data, canola yield is expected to be 42% of a 3t/ha wheat crop, 36% of a 2t/ha wheat crop and 20% of a 1t/ha wheat crop.

Second wheat crop after a break crop

Thirty experiments in the dataset include comparisons of two wheat crops after a break crop, compared with two wheat crops after wheat.

In these experiments the break crops included canola, Indian mustard, Linola, field pea, chickpea and oats. There were not enough measurements to distinguish between the second-year break-crop effects between species so the results are combined.

The additional yield for the first wheat crop after a break crop was 0.41t/ha and for the second wheat crop was 0.19t/ha.

Compared with the larger datasets reported earlier, this dataset underestimates the effect of a break crop on the first wheat crop so it probably also underestimates the effect on a second wheat crop. In the following gross margin analysis the effect of a break crop on the second wheat crop is estimated to be 45% of the effect on the first wheat crop.

Gross margin analysis

Figure 3 shows gross margins estimated for three-year crop sequences, using 2009 prices and variable costs. Each three-year system consists of a break crop (or wheat as a control) in year 1 followed by two years of wheat, with yields modified by the relationships shown in Figure 1.

Each line in Figure 3 represents different sowing dates for the first crop, followed by a standard sowing date for the following two grain-only wheat crops.

The assumed maximum wheat yield is 4t/ha, reflecting the low yields since 2001. The yield of canola relative to wheat is as shown by the line of best fit in Figure 2.

Yields are assumed to decrease with delayed sowing by 4% per week for cereals and 8% per week for broadleaf and grazed crops. The assumed sowing dates for grazing and broadleaf crops are 14 days before sowing grain-only wheat. The livestock returns from grazing wheat and canola are as reported in recent experiments.

The highest gross margins estimated by this approach are when grazing canola is grown in year 1, provided it is sown by early May. The next highest gross margin is when grain-only canola is sown in year 1, provided it is sown by mid May. Grazing wheat also has high gross margins for early sown crops, but as with grazing canola, delayed sowing reduces the three-year gross margin more sharply than grain-only crops.

The gross margins for early-sown grazing canola and grazing wheat are high because of the additional returns from livestock, but the calculation is based on the assumption that grain yield is not affected by grazing.

If canola is not sown by mid May, the three-year gross margin for wheat-wheat-wheat is slightly higher than for canola-wheat-wheat.

If sowing is delayed after late May the advantage of a first wheat crop becomes progressively greater than a first canola crop. This is because the break-crop benefit of canola is not large enough to offset the low returns from the canola crop itself.

Lupin-wheat-wheat also gives high gross margins for early sown lupin crops because the large break-crop effect compensates for the relatively low returns from the lupin itself. However the lupin-wheat-wheat result depends on adequate water supply to support the high yield potential of the following wheat crops.

The results of this approach apply to dry growing seasons. They may even overestimate the value of break crops because they do not account for the apparently poor retention of summer rain by the light stubbles of break crops and the low incidence of cereal root disease during dry seasons. These are grounds for restricting the area of break crops in dry seasons. Reasons for persisting with some break crops are control of herbicide-resistant weeds and the hope of capturing their benefits during wetter seasons.

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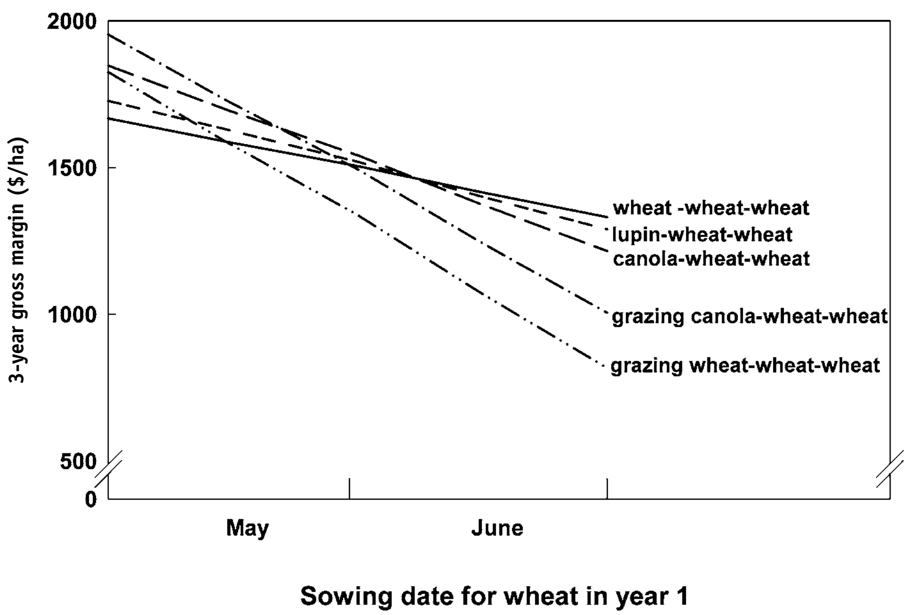

FIGURE 3 Estimated gross margins for three years of crops in relation to sowing date in year 1.
The assumed sowing date of broadleaf crops and grazed crops is 14 days before the sowing date of wheat.