GRDC Grains Research Update Coonamble

Wednesday 29th July 2015, Bowling Club

Registration: 8:30am for a 9am start, finish 2:55 pm

Agenda

Time	Topic	Speaker (s)
9:00 AM	Welcome	GRDC
9:10 AM	Summer and winter forage crop options - likely fit in central West farming systems	Lindsay Bell, CSIRO
9:35 AM	Managing the yield gap to achieve your yield potential. • Benchmarks for yield and water use efficiency, how WUE increases with yield and harvest index and changes with planting time. • What is an extra 20 mm of soil water worth? • Water, yield and profit – the important connection • Setting yield estimates and adjusting crop frequency to avoid low margin crops.	Chris McCormack, AgriPath
10:20 AM	Farming systems performance: A major new farming systems project on the constraints to performance and efficiency. What's planned, where and how to engage.	Lindsay Bell, CSIRO
10:35 AM	Morning tea	
11:05 AM	Panel discussion: Closing the yield gap - what leading growers are doing to optimise water use efficiency.	Tony Single & Bill Burnheim
11:35 AM	Herbicide resistance - what's coming and what's already here.	Maurie Street, GOA
11:55 AM	Residual herbicides - plantback, weed control and fitting them into farming systems.	Richard Daniel, NGA
12:25 PM	Panel session: managing problem weeds - implications for farming systems.	Panel session: Maurie Street, Richard Daniel, Graeme Callaghan.
12:45 PM	Lunch	
1:45 PM	Managing high level phosphine resistance in on-farm storage. • Profume® (sulfuryl fluoride) • Diatomaceous earth - use in grain storage & grain handling equipment • Does your storage get a AAA score? A check list for quality grain.	Philip Burrill, DAF Qld
2:20 PM	The what, where and why of soil testing for crop nutrition in the Coonamble area.	Mike Bell, QAAFI
2:55 PM	Close	

Contents

Compiled by Independent Consultants Australia Network (ICAN) Pty Ltd.
PO Box 718, Hornsby NSW 1630
Ph: (02) 9482 4930, Fx: (02) 9482 4931, E-mail: northernupdates@icanrural.com.au
Follow us on twitter @GRDCUPDATENORTH or Facebook: http://www.facebook.com/icanrural

Summer and winter forage crop option – likely fit in Central West farming systems

Lindsay Bell, CSIRO

Key words

Field pea, vetch, brassica, lablab, hay, biomass

Take home message

Several winter forages provide alternative break crop options for grain cropping systems.

Forage brassicas could provide similar crop rotation benefits to canola, can produce > 5 t DM/ha reliably in drier regions (typically 60-80% of forage cereal options) and are resistant to key soil-borne pathogens.

Several field pea varieties could provide flexible dual-purpose options which can produce forage yields of up to 80% of oats, to provide N inputs, weed management and crop rotational benefits.

Summer forage options such as millet, sorghum and legumes like lablab could be used to transition to summer crop phase to provide disease and weed management benefits.

Introduction

Across the northern grains regions, annual-cereal forages, particularly oats and forage sorghum, are the most common forage crops grown for livestock in mixed farming enterprises. Yet there are a range of other forage options such as forage legumes and forage brassicas that could provide rotational benefits in cropping systems. Forage brassicas could be used in a similar break crop role to canola in southern Australia, without the high risk associated with canola production in drier and hotter environments in the northern grains region. Summer and winter annual and short-lived perennial legumes are also available (e.g. lablab, burgundy bean, sulla, field pea, vetch) that can also provide break crop benefits along with fixing atmospheric nitrogen for subsequent crops.

In this paper we provide some data on the relative biomass production of a range of forage crop options that might be utilised in grain crop rotations in the central west region. A summary of these various characteristics amongst the forage options discussed are provided in Table 2.

Winter forage break crop options

Forage brassicas

Forage brassicas are often used in high rainfall livestock systems but could also provide an alternative break crop option in the place of canola in northern farming systems. Where the viability of canola is compromised by dry conditions and/or hot conditions during grain fill, a forage brassica could perform a similar role in the rotation to provide weed and disease management without the high risks associated with canola production. Forage rape are very high quality and remain leafy throughout the growing season because they possess a high vernalisation requirement, which prevents them from becoming reproductive.

We have compared the forage production of forage cereals with some readily available cultivars of forage rape (cv. Winfred, Interval and Leafmore), leafy turnip (cv. Hunter) and kale at several locations in southern Queensland and northern NSW (see Figures 1-3). This has shown the production from forage brassicas to be less than from forage cereals, typically around 60-80%, but nonetheless they have reliably produced > 5t/ha of forage in dry winter conditions. The leafy turnip and kale generally produced less biomass than the forage rape, and the leafy turnip were more affected by dry conditions. Most of these experiments involved forage brassicas sown in late autumn or early winter, yet their sowing window opens much earlier and is likely to provide more forage production in regions with more winter rainfall.

Like forage brassicas, several winter canola varieties, which also require vernalisation that delays (but doesn't stop) reproductive development, are now available commercially (e.g. CB-Taurus, Hyola® 971). These can be sown early (March or April) to provide early winter grazing and then can either be locked up for grain yield in favourable seasons or continue to be grazed.

We have also conducted some preliminary testing of the effects of the forage brassicas on root lesion nematode populations (*Pratylenchus thornei*) to see if they are effective at reducing populations. The current research indicates that like canola, most varieties do not host RLN but they do not greatly reduce the population either (see Figure 5 and Table 1). There appears there could be some variation amongst cultivars in their resistance to RLN but this requires more investigation before it can be confirmed.

A range of questions remain about how best to utilise forage brassicas in a grain cropping system. For example, they may have potential as part of an integrated weed management program by sowing in spring to provide strong competition and diversified weed control options over summer. However, this remains to be tested experimentally.

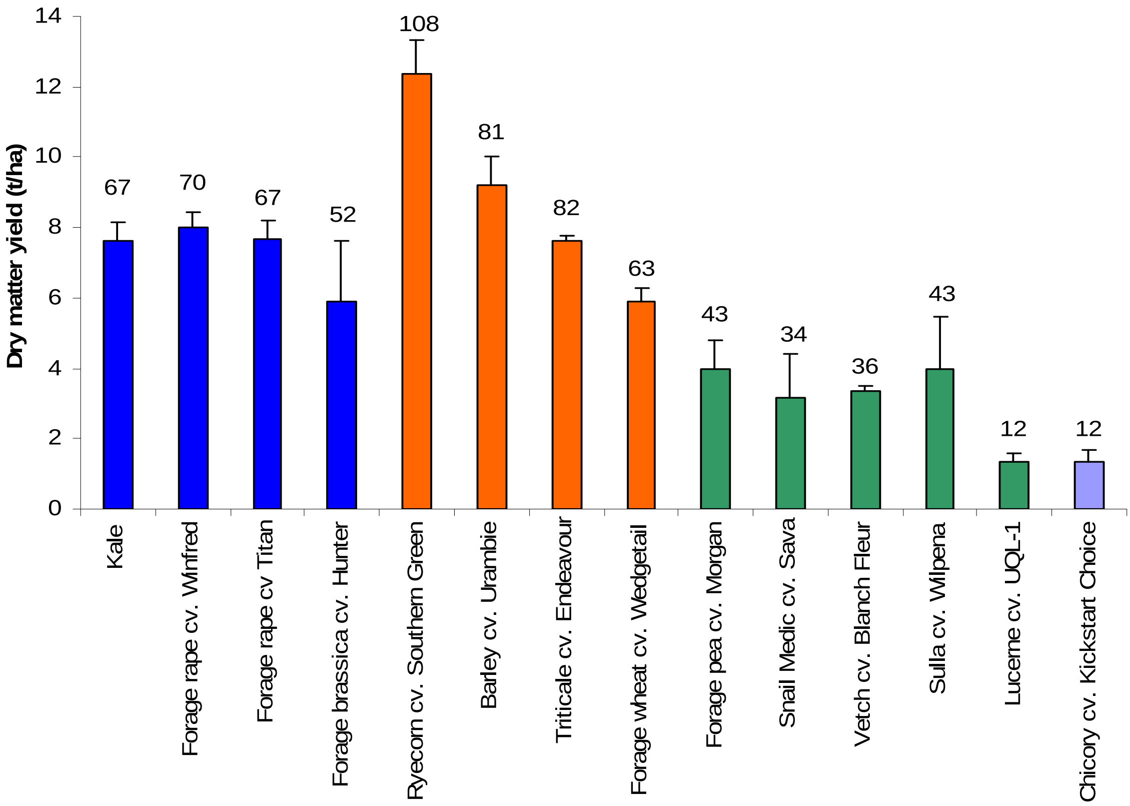

Figure 1. Comparison of biomass production (bars) and growth rate (label; kg/ha/day) of 4 forage brassicas (blue), 4 forage cereals (orange), 5 forage legumes (green) and 1 herb (light blue) grown at Pilton, southern Qld in 2011.

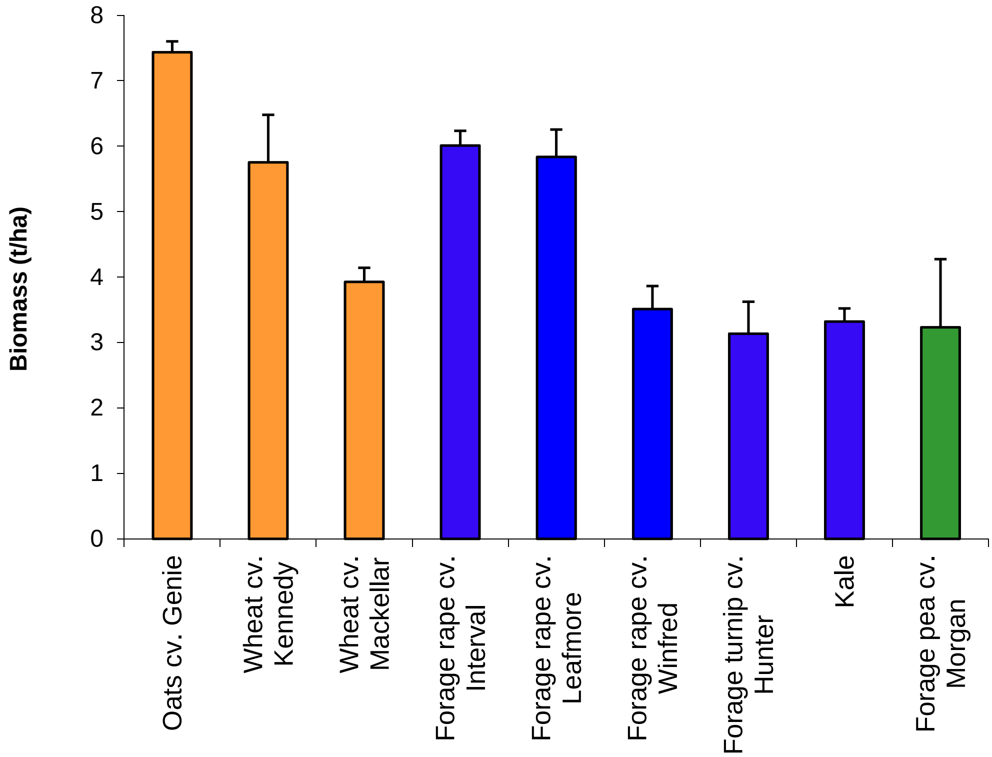

Figure 2. Biomass production from 3 winter forage cereals (orange), 5 forage brassicas (blue) and a forage pea on the Eastern Darling Downs in 2012.

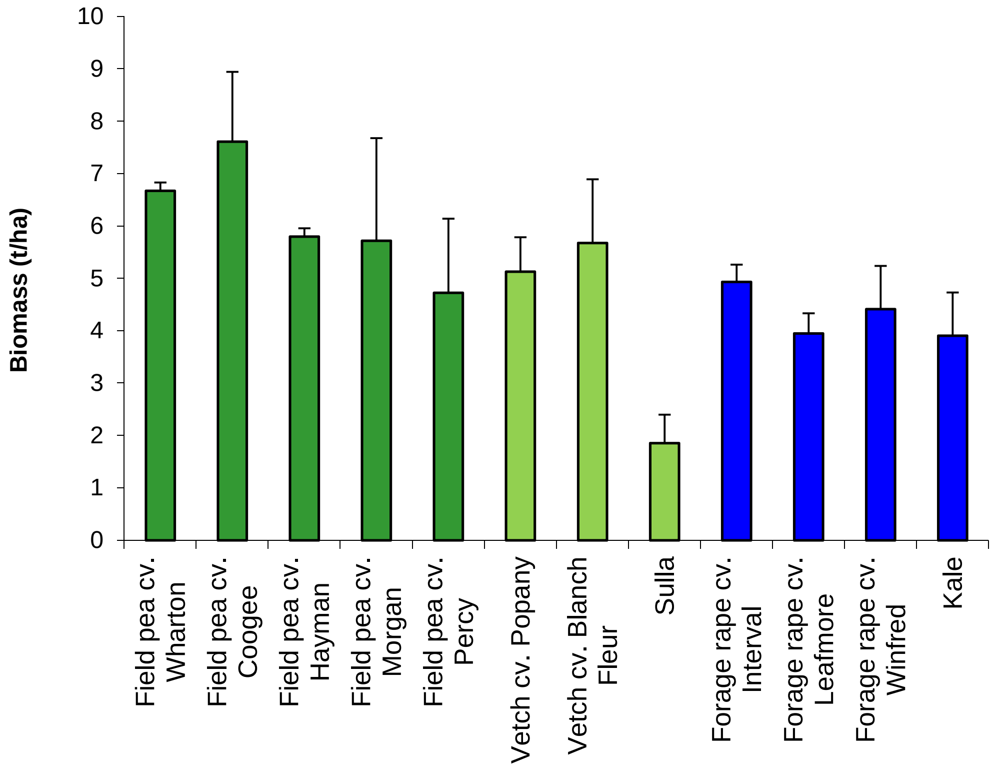

Figure 3. Comparison of biomass production from 5 field pea cultivars (green), 2 vetch cultivars (red), the perennial legume sulla (light green) and 4 forage brassicas at Tulloona, NSW in 2013.

Field pea – a flexible dual-purpose option

Field peas also provide a highly flexible option that could be used for either grain or forage that provide alternatives to other winter pulses (e.g. chickpea, fababeans). In poorer seasons, when forage availability is limited they might contribute forage to livestock, while in better seasons, when forage is more plentiful, they are grown for grain. One disadvantage of field pea compared to other winter forage options is that they typically have poor regrowth after grazing and are probably better suited to crash grazing (i.e. high intensity grazing over a short period of time) or cutting for hay.

We have compared the forage production of several field pea types and varieties and found little difference amongst them (See Fig 3 and 4). In our experiments over several seasons and conditions in southern Queensland and northern NSW, field peas have yielded between 4 and 8 t DM/ha. Again this is typically less than can be achieved from a forage cereal sown under the same conditions. Forage production of field pea is also similar to common vetch but higher than the first year production of perennial legumes such as Lucerne or sulla.

Field peas also offer several rotational benefits in grain cropping systems. Firstly, some varieties of field pea provide one of few winter legumes that are known to be resistant to root lesion nematodes. Cultivars Morgan and Percy have been shown to be resistant and don't increase RLN numbers.

Using field peas for hay making could also be a useful tool for managing weed seed set in problem weeds. Secondly, being a legume they can provide significant amounts of nitrogen to subsequent crops. Nitrogen inputs are also higher if grazed by livestock (because N is retained in the field) rather than if cut for hay or harvested for grain, where much of the N in biomass is removed. Field peas are effective fixers of atmospheric N, with 50-80% of plant N fixed. This means that a field pea crop producing 5 t DM/ha of forage would have fixed 110-170 kg of N/ha (including root material). If the crop was grazed by livestock 75-100 kg of N/ha retained in the field, while if it was harvested for grain or hay only 60-80 or 35-60 kg N/ha would be retained, respectively.

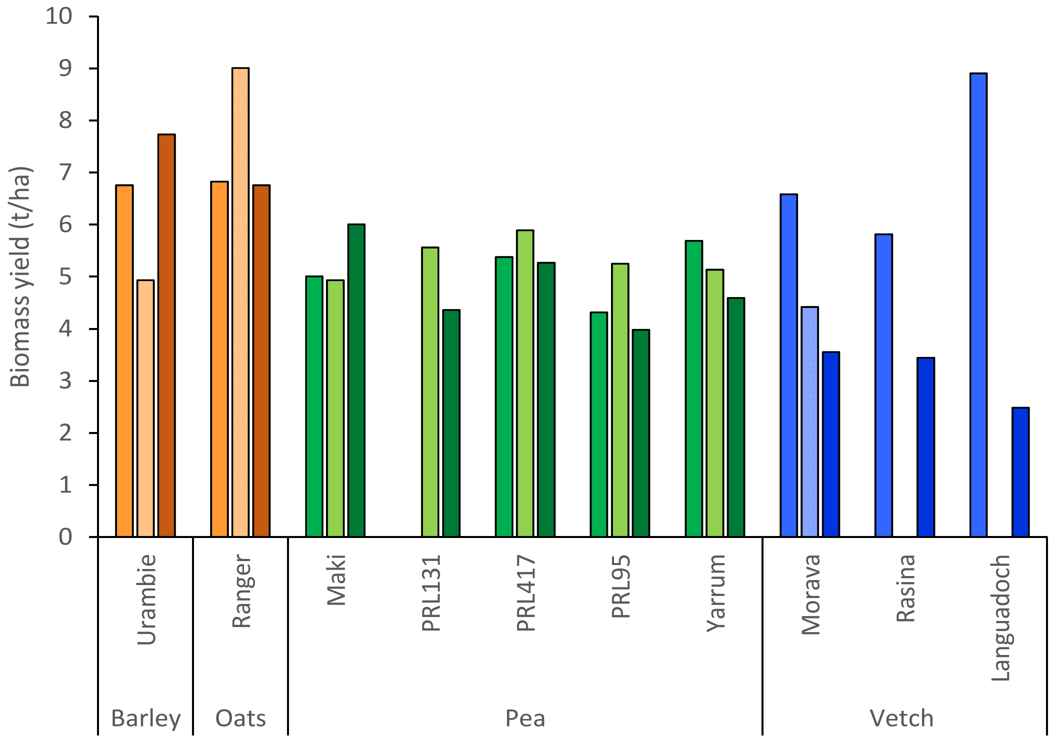

Figure 4. Comparison of biomass production from 2 forage cereals (orange), 5 field pea cultivars (green), and 3 vetch cultivars (blue) at 3 sites in 2010 in south-western Qld; Billa Billa sown on 10 June (medium colour), Billa Billa sown 18 July (light colours) and Inglestone (darkest colours).

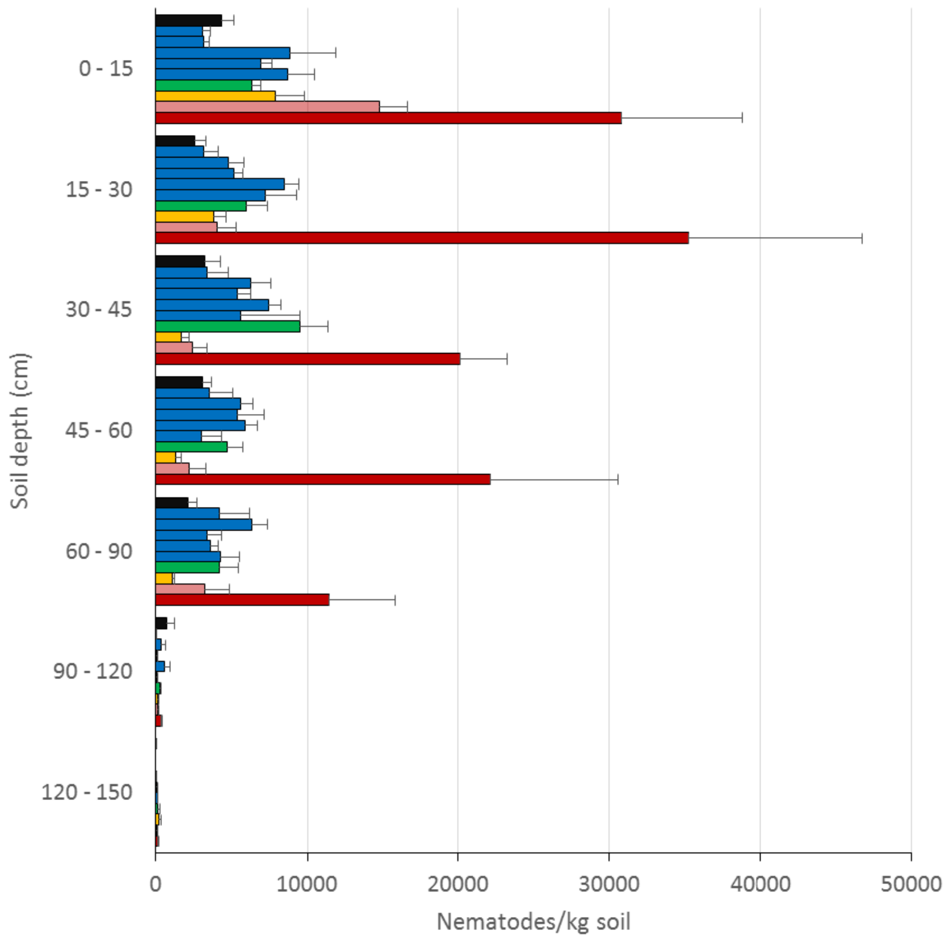

Figure 5. Populations of *Pratalenchus thornei* through the soil profile following 5 cultivars of forage brassica (blue), field pea cv. Morgan (green) and oats cv. Genie (orange) compared to wheat cv. Kennedy (dark red), wheat cv. Mackellar (light red) and starting nematode levels (black).

Table 1. Populations of *Pratalenchus thornei* (0-30 cm) following various forage break crop options at Tulloona, NSW in 2013. No statistically significant differences were evident.

Crop sown	Nematodes/g soil
Chickpea (PBA HatTrick⚘)	5.5
Sulla	4.1
Kale	2.1
Forage rape cv. Leafmore	18.6
Forage rape cv. Interval	3.4
Forage rape cv. Winfred	3.9
Vetch cv. Blanch fleur	10.8
Vetch cv. Popany	4.1
Field pea cv. PBA Coogee⚘	14.3
Field pea cv. PBA Hayman⚘	8.4
Field pea cv. Morgan⚘	2.8
Field pea cv. PBA Percy⚘	2.7
Field pea cv. PBA Wharton⚘	11.5

Other annual or short-lived perennial forage legumes

Like field peas (discussed above), several other annual and short-lived perennial forage legumes could play a useful role as rotation crops for cereals in farming systems. They provide high quality forage and can provide significant nitrogen inputs to the cropping system, though their other rotational benefits are less well understood or quantified.

Common and purple vetch are more tolerant of grazing than field pea and are capable of producing similar levels of biomass (Fig 1, 3 and 4). Common vetch are soft-seeded and should not cause long-term issues of weed control in subsequent crops, however, wooly pod vetch (e.g. Namoi) should be avoided as it is hard seeded and seed can last for several years in the soil. Several experiments in southern Queensland showed Purple vetch cv. Popany to be less productive than snail medic and sulla (below), but at Tulloona in 2013 it produced similar biomass to the field pea and other vetch cultivars and more than sulla.

Annual medics that can regenerate from seed have historically had a role in cropping systems on alkaline clay soils; the most suitable is snail medic. *Snail medic* can produce equivalent of other legumes in its establishment year (see Fig. 1) and in subsequent years can establish quickly from seed following autumn rains so that it can often out-yield other sown annual forage crops including oats. However, control of recruiting seedlings in crops for several years after the medic is a major problem to their wider use in cropping systems, unless they are to be used regularly in the crop rotation (e.g. 1:1 with a cereal crop).

On sandy and/or acidic soils other annual pasture legumes such as *Biserulla* or *Pink Serradella* should be used in preference to medics. Though there is limited data on their performance in the northern grains region.

Sulla (*Hedysarum coronarium*) is a short-lived winter-growing perennial legume from the Mediterranean. Sulla is slower to establish and produce forage over winter than the annual legumes (e.g. vetch, medics and field pea) but is more productive than Lucerne over its first winter and spring (see Fig 1 and 3). Sulla can have very high growth rates of 60-80 kg DM/ha/day during early spring and on several occasions has produced equal forage yield to oats; in most cases production is 50-75% of oats. Sulla has the potential to survive 2-3 years, but root rot diseases, wet or exceptionally dry conditions over summer will greatly reduce plant numbers (30-50% of first year density). Sulla can provide higher N inputs than the annual legumes (60-150 kg N/ha/yr) but little is known about its impacts on soil-borne diseases of crops. There is some evidence at one experimental site where numbers of *Pratylenchus thornei* were twice as high under sulla than adjacent oats and lucerne, but this remains to be validated elsewhere. Sulla does dry the soil profile more than annual forage crop options (25-50 mm), but less than Lucerne. Its other features are:

- Best suited to alkaline clay soils
- Non-bloating
- High quality forage (3% N, 70% DMD)
- Contains compounds that may help control worms
- Dormant over summer, growth peaks in autumn and spring

Summer forage crop options

Several summer-growing forage crops could be used in cropping systems in the central west of NSW. They could provide options to utilise summer rainfall and manage ground cover over summer in crop rotations (e.g. following winter pulse crops), while also filling seasonal feed gaps in summer or autumn. Double cropping into a summer forage out of a winter legume or cereal could be an effective ways to break out of a winter crop rotation for 18 months – 2 years to allow control of winter crop weeds and diseases and use of alternative herbicide chemistry. The summer forage would allow some return to be achieved as opposed to a long fallow (12 months) leading into and out of summer crop (e.g. grain sorghum) in the sequence.

Table 2. Summary of relative performance of winter and summer forage crop options for key attributes in grain cropping systems in central west NSW (*** - high, **-moderate, *-low).

Forage option	Forage production	Grazing tolerance	N inputs	RLN control	Crop weed management	Residual soil water	System role/fit
Winter forages							
Oats	***	***	-	**	*	**	Alternative to winter grain cereals
Forage brassicas	**	***	-	***	***	**	Replace canola where unviable or risky
Field pea	**	*	**	**	**	***	Replace Chickpea or Fababean, dual-purpose
Vetch	**	***	**	?	**	***	Replace winter pulses
Snail medic	**	***	**	?	**	***	Rotation with cereals, hard seed problem
Sulla		***	***	?	**	*	2-3 year phase, alternative to lucerne
Summer forages							
Forage sorghum	****	***	-	**	***	**	Transition to summer crop phase
Millet	***	**	-	***	***	***	Soil cover after winter pulses, dual-purpose
Lablab	***	**	***	***	**	**	Alternative to mungbeans
Cowpea	**	*	**	**	**	**	Alternative to mungbeans
Soybeans	***	*	***	*	**	**	Dual-purpose alternative to mungbeans

Forage sorghum

A large variety of forage sorghum hydrids are available that can provide very rapid summer production (growth rates > 100 kg/ha/d are typical). Biomass yields of >10 t DM/ha are reported at Trangie, 80 days after sowing. However, grazing should be initiated earlier (height 60-80cm) to maximise forage quality, which declines rapidly as the crop develops. Forage sorghum also require high levels of available N to optimise their production and quality. Forage sorghum is better suited to cattle grazing than sheep, as it quickly gets too high for sheep grazing,

The advantage of a forage sorghum over a grain sorghum in the farming system is that it could be terminated earlier (e.g. 70 days c.f. > 100 days) after providing some grazing and allow the soil profile more time to refill.

Millet

Several millets can be utilised as forage crops but also be continued to harvest grain should the opportunity present itself. Millets are less productive (50-60%) than forage sorghum but have higher forage quality and maintain this for longer than forage sorghum. If grazing is managed carefully millet also provides excellent stubble cover over summer and hence could be an effective option in the system following a winter pulse (e.g. chickpea) to increase soil cover. Most millets have been found to be resistant to both *Pratylenchus thornei* and *P. neglectus*. Millets are probably more susceptible to establishment problems, owing to their small seed and need to be sown shallow (< 30 mm).

Annual legume forages

Three annual legumes have some potential for use as summer forage break crop options in grain cropping systems. They have the advantage of providing significant N inputs, and produce higher quality forage than grasses above. These could be used instead of Mungbeans in the system to provide a better disease break and greater N inputs owing to higher biomass production.

Lablab is the most productive summer legume forage option and is able to produce 5-8 t DM/ha reliably in southern Qld and northern NSW; it performs best on alkaline clay soils. Lablab is the more tolerant of grazing than the other two annual legumes mentioned here, and can be used to build a high quality forage bank over summer to be utilised in autumn. Two main varieties are readily available, cv. Highworth is later flowering with higher biomass production potential and cv. Rongai is earlier flowering and typically less productive.

Lablab is large seeded allowing it to be drilled 5-10 cm into the soil. Lablab is resistant to both RLN species and can provide a dense canopy good for breaking down crop residues that harbour crown rot and other cereal diseases. Because of its high productivity lablab is capable of fixing large amounts of nitrogen and frequently contributes 50-150 kg of N to the soil. Some evidence of double cropping lablab and wheat has shown to be highly effective at capturing summer rainfall and providing N inputs, but in dry conditions there is likely to be an impact on yield of following wheat due to lower soil water.

Cowpea is typically less productive than lablab and less tolerant of grazing but is better suited to lighter textured or acidic soils. It too is resistant to *P. neglectus* and moderately resistant to *P. thornei* and would provide disease break benefits to cereal crop diseases. Because of its lower biomass production, cowpea will contribute less fixed N than lablab.

Soybean can also be used as a high quality forage-hay crop, but recovers poorly after grazing or cutting, so generally only provides 1 cut or grazing opportunity. Some dual-purpose varieties are available now for this purpose. Soybean can produce similar biomass to lablab, but is less tolerant of moisture stress than lablab. In some areas in northern NSW, growers sow soybean to provide a flexible option to be grazed or cut for hay in poor seasons or is left to produce grain in better seasons. Soybean is less beneficial to managing nematodes, it is susceptible to *P. thornei*, but can also contribute large amounts of N to subsequent crops if biomass is not removed from the field.

Burgundy bean

Burgundy bean is a perennial summer growing legume that can persist for 3-4 years. It is suitable on a wide range of soil textures and is the most cold tolerant of the available tropical forage legumes, though it still goes dormant in winter (from late May to early Sept). Burgundy bean can produce in excess of 5–8 t/ha/yr of DM in pure swards in southern Queensland, but is generally less productive than annual lablab in the first year, but produces similar or higher yields in subsequent years. If allowed to set seed it will recruit to produce thicker and more productive stands in the second year. Experimental data on N fixation in burgundy bean suggests that N fixation is less efficient than lablab and soybean. The impacts of burgundy bean on soil-borne diseases are unclear, but the crop can handle non-selective herbicides once it is dormant in winter; this could be used strategically to control winter weeds and/or oversow other forages in winter. It’s other features are:

- Non-bloating

- Germinates and grows under cooler conditions than other tropical legumes
- Easily established & regenerates well from seed each year
- Extremely palatable and selectively grazed – often grazed out unless spelled regularly and to allow seed set
- Might be grown in association with grasses, but may be difficult to maintain beyond 3-4 years because of its high palatability

Some further considerations for alternative forages

There are some additional aspects that should be considered in order to optimise the performance of forage crop options in cropping systems

1. *Residual herbicides* – many legumes and other broadleaf options are highly susceptible to residual chemicals often used during cereal crop rotations (e.g. Ally® or Glean®).
2. *Livestock grazing* – some of the forages mentioned here can have risks of adverse animal health impacts if not managed carefully. In particular, the risk of bloat on high quality winter legumes and the risk of high nitrate in forage brassicas need to be considered. In forage brassicas, the risk can be reduced by avoiding grazing shortly after fertiliser if applied or on fertile paddocks before the crop is sufficiently large to dilute nitrate in the forage.
3. *Legume innoculation and fertilisation* – the forage legumes mentioned here all require inoculation with their appropriate inoculant group to maximise their performance. Forage legumes also benefit from application of P and S at sowing – they often have higher P requirements than cereal crops.
4. *Sowing depth* – sowing depth of several forages is also important to optimise establishment, particularly in small-seeded species. Forage brassicas, sulla and burgundy bean all require seed depth of < 25 mm – depths greater than this will reduce emergence. Other larger seeded species (e.g. snail medic, vetches, pea, lablab) can be drilled much deeper.

Acknowledgements

The results of research reported here were undertaken as part of the Grain and Graze project was made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

We would like to thank those growers who hosted the experiments reported here.

Contact details

Lindsay Bell
CSIRO
PO Box 102, Toowoomba 4350, Qld
Ph: 07 4688 1221 or 0409 881 988
Email: Lindsay.Bell@csiro.au

ⓓ Varieties displaying this symbol beside them are protected under the Plant Breeders Rights Act 1994.'

Managing the yield gap to achieve your yield potential

Simon Fritsch, Agripath Pty Ltd.

Key words

attainable yield, water use efficiency, farming systems, profit, farm management

Take home message

Good crop yields result from storing water in the soil and converting this water and the in-crop rainfall efficiently into grain. Water Use Efficiency (WUE) Benchmarks can help to make better decisions on the use of soil moisture by developing yield estimates. They can be also used to compare yields or examine them in hindsight to check whether the crop has performed well at turning water into grain. More accuracy can be derived by using WUE benchmarks which are set for low, medium and high yields.

There are many aspects of farming systems which improve moisture storage and the water use efficiency of the crops being produced. Doing a good job with controlled traffic and zero-tillage will help maximise water storage. A sound rotation can help to minimise weeds, pests and diseases and boost farm yields and profits.

Good water use efficiency also needs weed control and optimum fertiliser use. Farm operations need to be done well and on time. This requires good labour management and finance to optimise inputs and keep machinery up to date.

When all these aspects are put together well, it is likely that the average farm can double profit.

1. Attainable yields

Water Use Efficiency benchmarks can be used to derive attainable yield for a location and season. At Coonamble it should be possible to store 90 mm of summer rainfall on average, which added to 16 mm of rainfall left over as harvest soil water, means 106mm is stored in the soil at planting. With 159mm of in-crop rainfall on average, the attainable yield of short fallow wheat is 2.86 t/ha at a target WUE of 11.5 kg/ha/mm.

Attainable yields for grain sorghum, are around 2.7 t/ha where water available to the crop is around 245mm and WUE 11kg/ha/mm. Figures shown in Table 1 are shown for a September plant, but this could be higher where sorghum is grown on long fallow with an extra 50mm of water, and where the crop is planted in December or early January to maximise the chance of in-crop rainfall.

Table 1. Attainable yields of wheat and sorghum calculated from WUE and by APSIM

Wheat May 30 Plant		Planting soil water	In-crop Jun - mid-Oct	Harvest soil water*	WUE kg/ha/ mm	Yield** average	APSIM 150 mm PAWC #	APSIM 180 mm PAWC #
Northern NSW								
High yield	Gunnedah	149	236	31	12.5	4.43	3.94	4.41
Medium yield	Moree	146	191	21	12	3.79	3.33	3.52
NW NSW								
High yield	Coonamble	106	159	16	12	2.98	2.72	3.10
Medium yield	Walgett	106	142	20	11	2.51	2.53	2.90

Sorghum **Sep 30 plant**		**Planting soil water**	**In-crop Oct - mid-Jan**	**Harvest soil water**	**WUE kg/ha/ mm**	**Yield average**	**APSIM 150 mm PAWC**	**APSIM 180 mm PAWC**
Northern NSW								
High yield	Gunnedah	136	274	14	13	5.14	3.65	4.29
Medium yield	Moree	121	252	22	11	3.85	3.08	3.72
NW NSW								
High yield	Coonamble	126	137	23	11	2.64	2.28	2.54
Medium yield	Walgett	125	148	28	11	2.70	2.3	2.59

*Average soil water at harvest calculated by APSIM

**Yield calculated from average rainfall data and water use efficiency figures

Yields modelled using APSIM show attainable yield is higher with increasing soil water capacity

2. Benchmarking yields using local WUE numbers

The French and Schultz model has been widely used in southern Australia to benchmark wheat yield for a given water use, with a target of 20 kg/ha/mm, allowing for 110 mm of soil evaporation. Current varieties and farming practices now produce WUE closer to 25 kg/ha/mm (Sadras and McDonald 2011).

Benchmarks of WUE are improved if soil stored moisture is included in calculations, even if only an estimate. The application *CliMate* or the model *How Wet* can be used to estimate soil water, but even better measurements are now being made using EM 38 (Foley 2013). Deducting 110 mm for soil evaporation should be ignored because if winter rainfall and soil evaporation is low the deduction leads to spurious results where WUE is high in a poor yielding year, when in fact it is low due to a low harvest index.

In most years, there is little or no moisture left in the soil at harvest, but when there is spring rainfall, some account should be made of *left-over* water by adjusting the estimate of in-crop rainfall.

This approach, where evaporation is ignored, is supported by Hunt and Kirkegaard (2011) who say; "It is water use efficiency that is important as a benchmark when reviewing management, not transpiration efficiency". Doherty et al (2010) and Sadras and McDonald (2012) also conclude that the most practical way of estimating WUE is to subtract soil water at maturity from soil water at sowing and add the rainfall that falls in between. This is what is proposed in this paper as the most appropriate way to use WUE in the Northern Region.

WUE should be more than a single number

The accuracy of using WUE to estimate yield can be improved by using a range, rather than a single number. WUE improves with yield, as a result of a better harvest index. In extremely low yielding situations, the crop has used a lot of the available water growing to the flowering stage and the WUE can be less than a half of the WUE of a high yielding crop. As yield potential improves there is generally better tiller survival, more heads per hectare, more grains per head and higher grain weights. This all serves to improve the WUE.

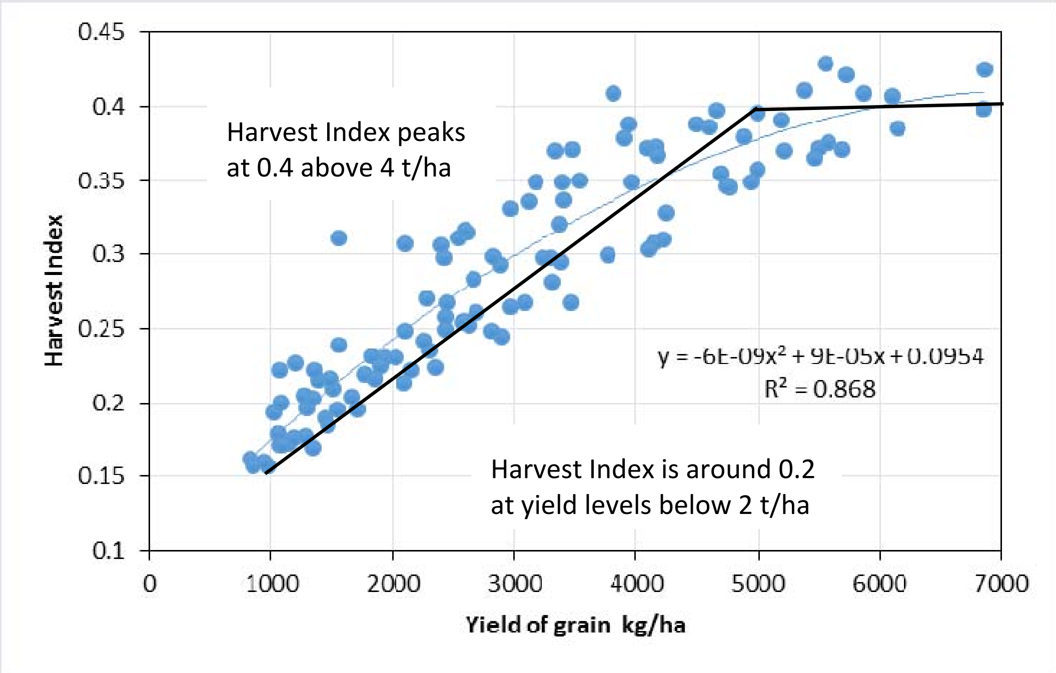

Figure 1. Harvest Index of wheat at Gunnedah, over 100 years, modelled by APSIM

The maximum efficiency of water transpired into biomass is 55 kg/ha/mm, according to French and Schultz (1984). This means the maximum WUE at a harvest index (HI) of 0.2 is 11, a figure which increases to 22 for a harvest index of 0.4. In the French Schultz equation around one third of the growing season rain was assumed to be lost through evaporation, so the WUE, as distinct from transpiration efficiency, would then convert to 7.3 for a HI of 0.2 and rise to 14 for a HI of 0.4.

In practice, in the Northern region, the WUE of wheat increases from around 9 kg/ha/mm where yields are less than 3 t/ha, to 12 kg/ha/mm for yields between 3 and 4 t/ha and is usually above 14 where there are yields exceed 4 t/ha due to a favourable season and high harvest index. (See Figure 2) In cereal crops, harvest index increases with tiller survival, grains per head and grain weight, all of which boost yield and WUE in favourable seasons.

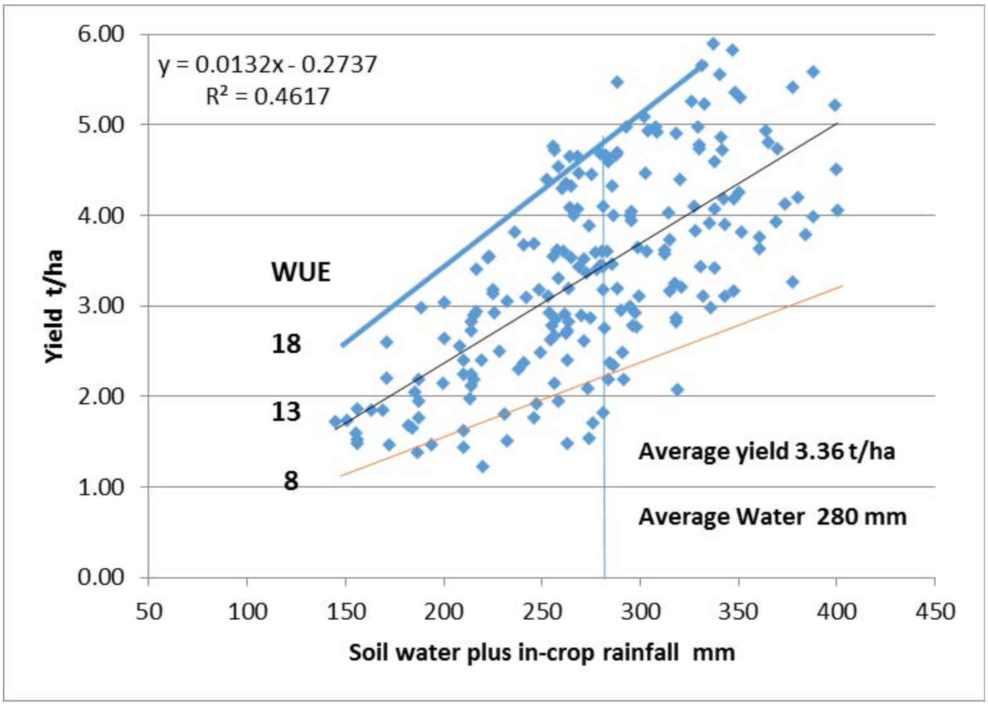

Figure 2. Yield of wheat produced by different amounts of soil water plus in-crop rainfall. Northern Grains Region 2007-2013. Farm plus trial data collated by Agripath.

3. What is an extra 20mm of soil water worth?

The improvement which occurs in water use efficiency with extra soil water, means that as little as 20mm extra can go close to doubling crop profit. This is demonstrated from results of wheat yields (modelled using APSIM) at Gunnedah and Coonamble for soils with 150 and 180 mm of plant available water capacity. At Gunnedah, an extra 22mm of soil water increased WUE from 11 to 12 kg/ha/mm and yield by 537 kg/ha. At Coonamble an extra 16 mm increased yield by 381kg/ha, which means an extra 20mm should result in a yield increase of 476 kg/ha.

Table 2. Effect of soil water capacity on water storage and crop yield

Soil PAWC mm	Wheat May 30 Plant	Planting soil water	In-crop Jun - mid-Oct	Harvest soil water	WUE kg/ha/mm	Yield average
150	Gunnedah	136	236	28	11.1	3814
180	Gunnedah	158	236	30	12.0	4351
	Increase	22			24.1	537
150	Coonamble	126	201	16	8.7	2716
180	Coonamble	142	201	17	9.5	3097
	Increase	16			23.4	381

APSIM modelling by G. Mclean, DAFF Qld. 2014

Profit would increase from $286/ha to $408/ha with an extra 20mm at Gunnedah, a rise of 43% and from $123 to $217/ha at Coonamble, a rise of 76%. See Table 3.

Table 3. Effect of an extra 20mm of soil water on wheat profit

	Wheat Gunnedah		Wheat Coonamble	
	average yield	Extra 20 mm	average yield	Extra 20 mm
Yield (t/ha)	3.75	4.3	2.7	3.19
Price	240	240	240	240
Gross $/ha	900	1032	648	757
Fertiliser:	123	123	70	70
Seed	30	30	28	28
Fallow sprays	60	60	50	50
Weeds, Pests	35	35	35	35
Fuel & Repairs	52	52	48	48
Harvest costs	55	55	50	50
Freight & Misc.	91	101	106	121
Labour	80	80	60	60
Machinery costs	88	88	78	78
Total costs	614	624	525	540
Gross Margin	286	408	123	217
Gross Margin %	70%	143%	57%	176%
Data from Agripath benchmarking				

4. Water, yield and profit - the important connection

The relationship between wheat yield and water available is shown in Figure 2. In this data, the average yield is 3.36 t/ha from 280mm of soil water and in-crop rainfall – a WUE of 12 kg/ha/mm.

Every disease problem, every mistake with seed, planting or variety selection, or not enough spent on inputs such as weedicide and fertiliser, can cost more than 10% in yield. It is common for three or more of these issues to be dragging down crop yields by some 30% and profit by 50-60%.

Control of crown rot is important for good WUE and yield of wheat. Rotation is important, but if wheat has to be sown after wheat, it should be planted into the middle of the old wheat rows for up to 9% extra yield (Verrell 2014). Varieties of wheat such as Suntop, offer potential to suppress nematode populations and avoid heavy losses from these pests, not only in wheat but in subsequent legume crops. Rotation plans which include some long fallows can pave the way for increased use of residual herbicides to help reduce costs and to better manage glyphosate resistance.

Good crop yields are a result of good planning and implementation of crop production involving a myriad of details, starting with the crop choice and variety, the rotation program and how moisture is stored and used on the farm. Combine this with good planting technology and timeliness, and the right details of fertilisers, weeds, pests and other aspects of crop agronomy and there is potential to substantially improve grain yields and profitability.

5. Adjusting crop sequence to avoid low margin crops

Long fallow crop sequences can sometimes be more profitable than double crops. It is all about the margin left over at the end of selling the crop. There is little point growing a string of low margin crops.

Table 4. Margins from a double-crop sequence compared to a long fallow

	Chickpea double-crop	Wheat after Chickpea	Chickpea on long fallow
Yield (t/ha)	1.2	2.7	2.6
Price	400	240	400
Gross $/ha	480	648	1040
Fertiliser:	30	95	30
Seed	40	30	40
Fallow sprays	24	48	60
Weeds, Pests	72	15	80
Fuel & Repairs	52	52	60
Harvest costs	55	50	60
Freight & Misc.	53	76	74
Labour	45	60	72
Machinery costs	55	78	94
Total costs	426	504	570
Gross Margin	54	144	470

A double-crop of chickpea with a yield of 1.2 t/ha followed by wheat yielding 2.7 t/ha might have a combined margin of less than $200/ha. A chickpea crop on a long fallow with a yield of 2.6 t/ha, should have a margin close to $470/ha and could help to double farm profit. Good margins are important and too much opportunity cropping can result in reduced margins over the longer term.

6. Setting yield estimates for better decisions

Average data of WUE for wheat, sorghum and chickpea and suggested benchmarks at different yield levels are presented in Table 5. Calculation of yield estimates can be done at any time to help make decisions on planting, fertilisers and adjustments to varieties, seeding rates or row spacings.

At Coonamble, if soil moisture is low at say 80mm, then a low WUE benchmark of 9 kg/ha/m would be used. If the average in-crop rainfall of 159mm is used, the yield estimate is 2.15 t/ha. If moisture was particularly high, at 160 mm, the WUE should be better than 12 kg/ha/mm and yield potential from 319 mm of soil water plus in-crop rainfall would be 3.83 t/ha.

Table 5. Average WUE for various yield levels and suggested benchmarks in the Northern Grains Region (trial and paddock data collated by Agripath).

Wheat	Low	Medium	High
Yield Range	<2.5 t/ha	2.5-4 t/ha	>4 t/ha
Average WUE	9.01	11.86	15.07
STDEV	1.87	1.92	2.04
Benchmark WUE	9	12	15
Sorghum	**Low**	**Medium**	**High**
Yield Range	<3 t/ha	3-5 t/ha	>5 t/ha
Average value	8.4	11.5	15.1
STDEV	1.64	2.13	2.60
Benchmark WUE	9	12	15
Chickpea	**Low**	**Medium**	**High**
Yield Range	<1.5 t/ha	1.5-2.5 t/ha	>2.5 t/ha
Average value	6.55	8.55	10.46
STDEV	1.02	1.61	1.81
Benchmark WUE	7	9	11

References

Doherty A. et al. 2010. Quantification of wheat water use efficiency at the shire level in Australia. Crop and Pasture Science, 61, 1-11.

Foley J. 2013. A 'how to' for getting soil water from your EM38 field measurements. Accessed 7.01.15 from: http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/03/A-how-to-for-getting-soil-water-from-your-EM38-field-measurements

French R. and Schultz J. 1984. Water use efficiency of wheat in a Mediterranean-type environment. 1 The relation between yield, water use and climate. Aust. J. Agric. Res. 35(6) 743-764

Hunt J and Kirkegaard J. 2011. Dryland water use efficiency -What is it and how to improve it. http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/08/Dryland-wateruse-efficiency-What-is-it-and-how-to-improve-it

Sadras V and McDonald G. 2012. Water use efficiency of grain crops in Australia: principles, benchmarks and management. GRDC publication.

Verrell A. 2014. Row placement strategies in a break crop wheat sequence. Northern Grains regional trial results. Accessed 7.01.15 from: http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0007/520666/Northern-grains-region-trial-results-autumn-2014.pdf

Acknowledgements

Many of the ideas presented here have been developed as part of a GRDC project: The *Economics of Closing the Yield Gap in the Northern Grains Region.* The author would like to thank the GRDC and the growers who provide contributions for research for their continued support.

Contact details

Simon Fritsch
Agripath Pty Ltd
21 Bourke St, Tamworth, NSW 2340
Ph: 0428638501
Email: simon@agripath.com.au

Reviewed by

Peter Wylie and Chris McCormack

Northern farming systems performance: can it be improved?

Lindsay Bell[1], David Lawrence[2], Kaara Klepper[2], Jayne Gentry[2], Andrew Verrell[3], Guy McMullen[3]

[1] CSIRO
[2] DAF Queensland
[3] NSW Department of Primary Industries

Key words

Crop rotation, sequence, efficiency, system, economics

GRDC codes

CSA00050, DAQ00192

Take home message

GRDC is investing in research aimed at understanding how the performance of current farming systems can be improved.

Systems with different crop intensity (or frequency), crop sequences, system inputs and practices aimed at maintaining long-term soil resources are being compared experimentally.

System modifications and their interactions of these various modifications are being examined at a core experiment site on the Eastern Darling downs, and 6 regional sites across the northern region are examining locally relevant system modifications.

Experimental data and modelling are being used to assess changes and effects of the different farming systems on several attributes (e.g. water use efficiency, nutrient use efficiency, soil resource, pathogen and weed populations).

Rationale

Recent analysis suggests that there is potential to increase the efficiency of current farming systems. An analysis of surveyed crop sequences found that only 29% were achieving 80% of their potential water use efficiency. Similarly farming systems are facing emerging challenges of increasing herbicide resistance, declining soil fertility and increasing soil-borne pathogens all which require responses in farming systems in order to maintain system productivity.

The northern farming systems initiative aims to address these emerging challenges by investigating the question: Can systems performance be improved by modifying our farming systems?

The research aims to deliver information on the following issues:

- Key issues or areas where current systems are underperforming
- Benchmarks for, and gaps between, current and potential system water use efficiency (not just crop water-use-efficiency)
- What changes in farming systems enable further increases in system efficiency
- Benefits and costs of crop choices on various aspects of farming systems (water, nutrients, weeds, pests)
- Identify any possible future issues that are likely to arise in response to changes in farming systems

Experimental plans

The northern farming systems initiative will implement a co-ordinated experimental program to examine a range of modifications to farming systems and quantify their relative impact on a range of measures of system performance. These modifications have been chosen following consultations with growers, advisors and other researchers across the northern region and are targeted to address apparent current and emerging challenges to farming systems. The range of systems have been chosen to capture the range of possible cropping systems operating in the northern region.

The combined experimental program will consist of 1 core site located at Pampas on the Eastern Darling Downs and 6 regional sites located at Emerald Agricultural College (Central Queensland), Billa Billa (Western Downs/Border Rivers), Mungundi (Western NSW and Qld), Plant Breeding Institute, Narrabri (Northern NSW), Nowley Research Station, Spring Ridge (Liverpool Plains), and Trangie Research Station (Central West NSW).

The core site will compare 34 farming systems (see Table 1). These include 8 summer crop dominated systems, 8 winter crop dominated systems, 14 mixed summer-winter crop systems and 4 systems involving ley pastures. The cropping systems (not ley pasture systems) involve factorial combinations involving different crop intensity (i.e. the number of crops sown/yr), crop sequences (including the range of crops grown) and nutrient supply/balance. Each of these systems are based on differences in key decision points or rules which aim to bring about these distinct changes in the farming systems. The systems tested at the core site are common with systems being tested in the regional experimental sites.

At each regional site a ‘benchmark’ system, based on current decision rules used in the district, will be compared with a common set of 4 individual system modifications (i.e. higher crop intensity, higher crop diversity, high nutrient supply and high legume frequency) (see Table 2). Additional regionally relevant modifications to systems may also be included based on local demand for these treatments. Table 2 summarises the common set and different modifications to be tested at each region and the equivalent system in the core site.

Key metrics of systems performance

Over the life of the project each experimental farming system will be compared in terms of several attributes:

- Total grain production and quality
- Economics (inputs and returns)
- Efficiency of use of water and nutrients,
- Changes in soil nutrient stocks and soil health indicators
- Dynamics and populations of soil pathogens and weed populations

Together this information will be used to assess the relative performance of the farming systems against several metrics. This will help us understand the strengths, weaknesses and identify any future risks associated with particular system modifications.

Systems modelling and analysis

A combination of several modelling approaches will be used in the project to examine the performance of current farming systems across the northern region. These models will provide predictions of the likely effects of the various systems modifications over the time and extrapolate experimental information to compare system performance under a range of climatic conditions and predict the implications at other locations and/or other combinations of systems (e.g. different sequences of crops) across the northern region. In particular, the simulation modelling will enable climate and price risk factors to be analysed for each of the systems.

Table 1. List of key modification foci for changes to farming systems, their associated rationale and impacts and how the characteristics or decisions would be altered to achieve the desired outcome. System treatments in italics are those that make up the current 'benchmark' system; System treatments denoted with a ^ are included in a full factorial at the core site and denoted with a # are only singular treatments or partial factorials at the core site.

#	System modifications	Strategy	Anticipated impacts	Key characteristics & decision point change
1. CROP INTENSITY				
1A	*Moderate crop intensity ^*	*Sowing on a conservative PAW threshold*		*Higher PAW requirement to trigger a crop sowing event (e.g. 150 mm)*
1B	High crop intensity ^	Increase the frequency of crops sown in order to maximise proportion of rainfall transpired by crops	- Reduced fallow herbicide use - Increased C inputs & soil OC - Increased soil biological activity & nutrient cycling - Reduce losses of water during fallows	Lower PAW requirement to trigger a crop sowing event (e.g. 75 mm)
1C	Low crop # intensity	Reduce the risk for a particular crop by maximising soil water at sowing by proceeding with a long fallow period.	- Greatly reduced number of crops - Higher profitability per crop - Long fallow periods requiring large herbicide program and low ground cover risks	Crops only sown when very high PAW or full profile Higher value/profitability crops are sown
2. CROP DIVERSITY				
2A	*Limited crop options ^*	*Only crops with higher direct profitability are grown*	- *Soil-borne pathogens increase* - *Limited weed control & herbicide choices*	*Crop options limited to: wheat, barley, chickpeas, sorghum*
2B	Diverse crop options ^	Utilise a wider range of crops to manage the build-up and damage from soil-borne pathogens and weeds in cropping systems	- Increased soil biological activity & diversity - Alternate herbicide chemistry & hence slow HR onset	Crop choice altered to ensure 50% of crops are resistant to nematodes and no more than 2 non-resistant crops in a row. Two crops with same in-crop mode of action can't follow each other
3. NUTRIENT SUPPLY/BALANCE				
3A	*Conservative nutrient supply^*	*Manage synthetic fertiliser input costs*	- *Soil fertility declining and likely crop yield penalties in good seasons*	*Crop fertiliser budget to achieve 50th percentile yield*
3B	High nutrient supply ^	Background soil fertility is boosted and crops provided with adequate nutrients to maximise yield potential.	- Soil chemical & biological fertility is maintained or increased - Crops able to maximise their seasonal yield potential	Initial organic amendments and subsoil P application Fertiliser budget to achieve 90th percentile yield.
3C	High legume ^	Increase inputs of biological N from legumes in system to reduce fertiliser N inputs	- Reduced N fertiliser requirements - Altered weed & pathogen populations	Legumes make up 50% crops sown High biomass legumes chosen in preference
4. SOIL QUALITY RESTORATION				
4A	*No soil restoration*	*Non-grain crops are not included in crop sequences*	- *Soil quality declines and hence water capture and nutrient supply may limit system productivity*	*Grain crops only grown in crop sequences*
4B	Cover crops #	Cover crops used to restore soil cover, increase organic inputs and manage weeds and diseases	- Reduced herbicide use - Reduce N inputs for crops in rotation - Altered weed and disease populations	Cover crops after crops leaving low ground cover Brown manure (i.e. spray out) crops with yield < 50% of potential
4C	Ley pasture #	Perennial ley pastures phases to rebuild soil organic matter, nutrient levels and build disease suppressive soil biology.	- Reduced herbicide use - Reduce N inputs for crops in rotation - Altered weed and disease populations	A phase of grass and/or legume based pastures are sown in rotation with grain crops

Table 2. System modifications for experimental program at regional locations and the reference benchmark at the core site. Note the core site will also represent the Eastern Downs region farming systems.

Trt #	System	Regional sites					
		Emerald	Billa Billa	Mungindi	Spring Ridge	Narrabri	Trangie
1	'Benchmark'	*	*	*	*	*	*
2	High nutrient supply	*	*	*	*	*	*
3	High legume	*	*	*	*	*	*
4	Diverse crop options	*	*	*	*	*	*
7	High crop intensity	*	*		*	*	*
14	Low crop intensity		*	*	*	*	*
15	Ley pasture (grass only)		*				
16	Ley pasture grass + N		*				
	Integrated weed mgnt	*					
No. of systems		6	8	5	6	6	6

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

We would like to thank those growers and advisors who have given their time to be involved in focus group meetings, who shared their perspectives and provided their input into the design of this project.

Contact details

Lindsay Bell (Complex systems team leader)
CSIRO
PO Box 102, Toowoomba 4350, Qld
Ph: 07 4688 1221 or 0409 881 988
Email: Lindsay.Bell@csiro.au

Panel discussion: Closing the yield gap - what leading growers are doing to optimise water use efficiency.

Report on the 2013 GOA Herbicide Resistance Survey

Maurie Street, Grain Orana Alliance

Keywords

Herbicide, resistance, survey, testing, Central West NSW, GOA

GRDC code

GOA00001

Background

Herbicide resistance could possibly be one of the greatest threats to the sustainability of our current grain production systems. The dominant minimum or zero tillage systems typical of the region have evolved to place a heavy reliance on herbicides for weed control and, in many cases no other alternate methods of control are being employed. This reliance on herbicides has already led to the development of resistance in many cropping regions of the world with Australia being no exception.

So it lends to reason that the Central West of NSW is not immune from the development of resistance either but the extent of which resistance exists in the region has not yet been quantified. Prior to this survey the only formal confirmation of resistance was through ad-hoc resistance testing by advisors or growers mainly in situations where herbicides had previously failed. Or more informally, resistance was only diagnosed by “gut feel” or educated guess by advisors.

This survey is the first attempt to quantify both the extent and types of resistance presently in the Central West of NSW.

In contrast, other cropping regions in Australia have undertaken a number of surveys and these have started to form sound evidence of the level and types of herbicide resistance present. In other regions this evidence would be crucial in convincing growers for the need to address the issue of resistance and provide the insight into the characterisations of resistance to make informed decisions for its management.

Local advisors within the Central West region have suggested there is an inherent lack of recognition and acceptance by many growers of the presence of herbicide resistance in the region and the threat and severity it poses. Partly because of this many growers are not often prepared to act to prevent, slow or combat resistance. GOA’s engagement with local stakeholder groups expressed a clear need and desire to assess levels of resistance within the region and the products that were affected. In doing so it would help raise awareness of the issue through hard evidence, the presence of herbicide resistance.

Aims

The aims of this survey were to establish what the current level and types of herbicide resistance are in the Central West of NSW. In doing so, this would raise awareness of the issue to foster a change in attitude and following on from this, a greater willingness to address the issue. The information provided from this survey would aid growers and agronomists to make more informed decisions around herbicide choices or in fact even management strategies beyond simple herbicide rotations

Methodology

In November of 2013, all growers and agronomists on the GOA contacts list were offered an opportunity to submit weed seeds of any of four common species for testing for resistance to a range of common herbicides. The four weed species were:

- Annual ryegrass (ARG)

- Wild or black oats (BO)
- Wild radish (WR)
- Sow or milk thistle (ST)

These species were chosen as they were either already noted as key weeds in the region that were either commonly demonstrating herbicide resistance such as ARG and BO, or those that are thought likely to develop herbicide resistance such as WR and ST.

Samples were limited to two per grower in an effort to survey a wider cross section of the GOA region. Weed seeds were to be sampled from cropping paddocks in the local region with no stipulation as to their suspected resistance status. That is they could be taken from paddocks regardless of whether they were suspected resistant or not.

Samples were to be collected in accordance with commercially accepted sampling instructions provided by Plant Science Consulting (www.plantscienceconsulting.com/seedtest), the commercial testing service that undertook the herbicide testing on the seed samples provided. The herbicide testing was carried out to industry accepted standards in calibrated spray cabinets with control populations introduced to ensure confidence in testing procedures.

A range of herbicides specific to the weed species were applied and these are listed in tables 1 and 2 below. The herbicide types and rates used were developed with input from a number of sources with an aim to characterise the resistance status of each population to commonly used products and if for some products at multiple rates to examine any rate responsiveness. The options tested are not completely exhaustive as cost would have been prohibitive but the results do serve to give a significant characterisation of the resistance status of the populations tested.

Details regarding the herbicide history from the paddocks were also collected when samples were submitted for testing. Information such as the suspected resistance status, length of farming history and details regarding the number of herbicide applications of each mode of action that had been applied in the last 10 years.

A total of 123 weed seed samples were collected, 79 ARG, 41 BO and 3 WR. No ST samples were received. The WR samples have been combined into Dr Christopher Prestons project monitoring WR for resistance and the results have not been included in this report.

GOA returned the individual results growers or agronomists who submitted the samples so as to allow them to make informed decisions regarding the management of those weeds. This report however concentrates on the combined results and the broader overall impact of the survey.

Table 1. Herbicides and rates tested on annual ryegrass samples

Herbicide tested	**Common trade names**	**Rate applied L/ha or g/ha**
Haloxyfop	Verdict®	0.1L
Clethodim	Select®	0.35 L
Clethodim	Select	0.5 L
Butoxydim	Factor®	180 g
Pinoxaden	Axial®	0.3 L
Triasulfuron	Logran®	35 g
Iodoulfuron-methyl sodium	Hussar OD®	0.1 L
Imazamox & Imazapyr	Intervix®	0.6 L
Atrazine	Gesaprim®	2000 g
Trifluralin	Triflur X®, Treflan®	2 L
Glyphosate 540 g/L	Round Up Powermax®	1 L
Glyphosate 540 g/L	Round Up Powermax	1.5 L
Glyphosate 540 g/L	Round Up Powermax	2 L

Table 2. Herbicides and rates tested on wild/ black oat samples

Herbicide tested	Common trade names	Rate applied L/ha or g/ha
Clodinofop	Topik®	0.1 L
Haloxyfop	Verdict	0.1L
Clethodim	Select	0.35 L
Clethodim	Select	0.5 L
Pinoxaden	Axial	0.2 L
Mesosulfuron-methyl	Atlantis OD®	0.33 L
Flamprop-M-methyl	Mataven 90®	1.8 L

The herbicide resistance testing reported upon two measurements:

1. The percentage of the treated population that survived the herbicide quoted as % survival
2. A rating of the herbicide effect on the surviving plants as follows
    - "R" indicates surviving plants were significantly stunted and only recovered with a few tillers
    - "RR" indicates plants suffered stunting in the order of 40-70% relative to untreated plants
    - "RRR" rating which indicates survivors showed virtually no herbicide effect.

This report concentrates mainly on the percentage survival to the individual herbicides as this gives a better indication of the potential frequency of resistance in the region. The second measurement aims to offer some insight into the relative "strength" of the resistance in the surviving plants.

The industry accepted terminology for herbicide resistance is that:

1. "Developing Resistance"-Survival of up to 19% but no more of the treated population
2. "Resistant" -Survival of 20% or more of the treated population

However, to simplify the reporting of the findings of this survey, any populations with survival greater than 10% is termed resistant. This approach has been taken for the following reasons-

- To report on the levels of both "developing resistance" and "resistant" would serve only to complicate the message, lengthen the report unduly and potentially confuse the reader.
- We cannot be 100% certain that very low levels of survival are not just an anomaly in testing
- Differences in resistance between 10 to 20% survival would be indistinguishable in paddock situations and therefore irrelevant to managing such populations
- Growers could expect a higher % survival to herbicides applied outside the "ideal" conditions under which testing so even these lower level of survival would be considered commercially unacceptable.

Results

Ryegrass

79 samples of annual ryegrass were submitted to the survey. Of the samples submitted, one seed lot was unviable (poor germination) so 78 samples underwent testing. 91% of samples were collected and logged by advisors and only seven samples were collected and submitted by growers.

The distribution of the sample locations is detailed in Figure 1 below and provides a reasonable cross section of the GOA region, with the notable exceptions of the western area beyond Trangie and Warren and the north eastern areas around Coolah where no samples were submitted.

Figure 1. Locations from where ryegrass samples were taken from.

NB Multiple samples may have been taken from the general locality marked by only a single pin marker

There appeared to be little clear correlation between the patterns of past herbicides usage or the length of cropping history indicated in the survey questions to the demonstrated resistance to those herbicides. However a number of populations demonstrated resistance to a particular herbicide where there has been no or very little previous use indicated. For example,

- 15 populations demonstrated resistance to Axial® where it was indicated it had not been used in the past
- Two of the four populations demonstrating resistance to trifluralin where it was not reported to have been used in the past.
- Two populations had been reported to have not used a Group B applied however demonstrated 100% resistance to Logran®
- 22 samples reported having less than two Group B applications yet all demonstrated resistance, 12 of which demonstrated 100% resistance to Logran®.

Of all the samples submitted, 30% of samples were predicted to be “possibly resistant”, 70% of samples were predicted to be “resistant” but no samples submitted were predicted to be “susceptible” in the submission questionnaires.

There were no samples submitted that were susceptible to all the herbicides tested. In other words there was not one sample that was not resistant to at least one of the herbicides tested. Table 3 below details the demonstrated resistance of the submitted ARG samples to individual herbicides tested.

Table 3. Number of AGR samples demonstrating resistance to the various herbicides and rates tested

Herbicide and rate tested	No of samples >10% survival	% of samples with > 10% survival
Verdict 0.1L/ha	59	75%
Select 0.35L/ha	17	22%
Select 0.5L/ha	6	8%
Factor 180g/ha	1	1%
Axial 0.3L/ha	47	60%
Logran 35g/ha	77	99%
Hussar OD 0.1L/ha	64	82%
Intervix 0.6L/ha	44	56%
Atrazine 900WG 2000g/ha	7	9%
Triflur X 2L/ha	4	5%
Glyphosate 540 1L/ha	5	6%
Glyphosate 540 1.5L/ha	4	5%
Glyphosate 540 2L/ha	3	4%

Only ten samples, or 13%, demonstrated resistance to only one of the herbicides tested. Multiple herbicide resistance, where a sample demonstrates a resistance to more than one herbicide type, was found in 86% of the samples tested as detailed in Table 4 below. 54% of samples demonstrated resistances to four or more herbicide groups or sub-groups and the largest single group, constituting 37% of the samples demonstrated resistance to four groups or subgroups.

Note that for the purpose of this table fops, dims and dens are considered as subgroups of Group A because it has been previously shown that differential levels of control can be expected when using these herbicides. Similarly for the Group B's they are in two subgroups being the sulfonylureas (SU's) and the imidazolinones.

Table 4. Number of ARG sample populations demonstrating resistance to multiple herbicide groups and sub groups.

No. of herbicide groups or sub groups with demonstrated resistance#	No of samples	% of samples submitted
1	10	13%
2	15	19%
3	10	13%
4	29	37%
5	12	15%
6	1	1%
7	1	1%

Herbicides groups and subgroups considered- Fop, Dim (Select® only), Den, SU, Imi, Triazines and Glycines.

Further analysis of the levels of cross resistance due to the significant number of resistance combinations over such a number of herbicides is quite difficult and potentially unsound. However it is interesting to note some of the variations within a particular herbicide group and/or over a number of rates.

Group A's - fops, dims & dens

- 59 (75%) samples were resistant to Verdict but only 17 of those were resistant to Select® @ 350ml/ha and only six to the higher rate of 500ml/ha.
- Of the samples resistant to Select®, all were also resistant to Verdict.
- Only one sample demonstrated low level resistance (10% survival) to Factor and it was also resistant to both Select® and Verdict®.

- 47 (60%) samples demonstrated resistance to Axial®, of these 100% demonstrated resistance to Verdict but only 17 populations were also resistant to Select® (350ml/Ha)

Group B's - SU's and imidazolinones

- Logran® was all but ineffective with 77 of the 78 (99%) samples demonstrating resistance
- 64 (82%) of the samples demonstrated to be also resistant to both Hussar OD® and Logran®
- 43 samples were resistant to Intervix® and both Logran® and Hussar OD®.

Group M

- Only five samples demonstrated resistance to Glyphosate 540
- Three of these demonstrated significant levels of cross resistance to more than two other herbicide groups or sub groups

This is only a small sample of resistant populations so any characterisation of a glyphosate resistant population based on this would be not well founded. However it should be noted that for most populations tested glyphosate is still effective but for some of the more resistant populations tested (multiple resistances) found it was one of the last few effective options left.

Wild oats

41 samples of wild or black oats were submitted to the survey. All samples were collected and submitted by advisors.

The distribution of the sample locations is detailed in Figure 2 below where a reasonable cross section of the GOA region has been taken in by this survey but noticeably the area around and east and north east of Dubbo had no samples submitted.

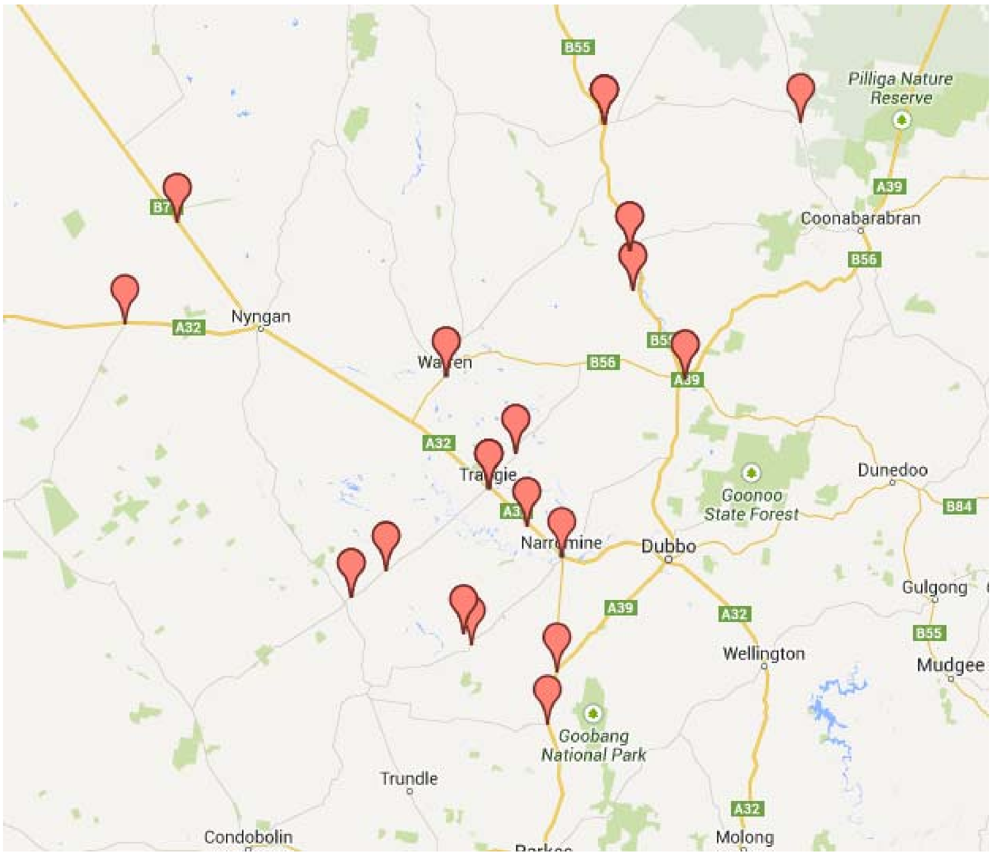

Figure 2. Location of wild oats sampling locations.

NB Multiple samples may have been taken from the general locality marked by only the one pin marker

There appears to be little clear correlation between the patterns of past herbicides usage or the length of cropping history indicated in the survey questions to the demonstrated resistance to those herbicides. But similarly to the ARG samples, a number of herbicides demonstrated resistance where it has been indicated that no applications of that herbicide had been applied. For example,

- 16 samples demonstrated resistance to Mataven® where no Mataven® had been applied.
- Four samples demonstrated resistance to Axial® where no Axial® had been applied

Of all the samples submitted, 56% of samples were predicted to be "resistant", 41% were predicted to be "possibly resistant" and none were predicted to be "susceptible", and two samples did not indicate their suspected resistance status on the submission questionnaires.

Despite the strong predictions for the samples to be resistant, 29% of the samples demonstrated no resistance to any of the herbicides tested with five of these predicted to be "resistant" and the balance only "possibly" resistant.

73% of the samples submitted demonstrated some level of resistance to the herbicides tested as detailed in table 5 below. The most common resistance in these samples has been demonstrated to be Topik® (56%) but closely followed by Mataven® 90 (51%). Resistance to Axial® has been demonstrated to be 37%, nearly three times greater than that for Verdict® at 12%. Interestingly there was no demonstrated resistance to Select® in the samples tested and only two samples resistant to Atlantis OD®.

Table 5. Number of samples demonstrating resistance to the various herbicides and rates tested.

Herbicide and rate tested	No of samples >10% survival	% of samples with >10% survival
Topik 0.1L	23	56%
Verdict 520 0.1L	5	12%
Select 0.5L	0	0%
Axial 0.2L	15	37%
Atlantis 0.33L	2	5%
Mataven 90 1.8L	21	51%

Table 6 below details the level of multiple resistances in the samples submitted. 22% of samples demonstrated to be resistant to two herbicide groups or sub groups and a similar number (22%) were three herbicides groups or sub groups. A much smaller number were resistant to four, at 7% of the samples submitted.

Table 6. Number of sample populations of black oats demonstrating resistance to multiple herbicide groups and sub groups.

No. of herbicide sub groups with demonstrated resistance#	No of samples	% of samples submitted
0	11	27%
1	9	22%
2	9	22%
3	9	22%
4	3	7%

Herbicides groups and subgroups tested- Fop, Dim, Den, SU, Grp Z.

Of the six herbicides tested on these samples they all belong to only three different herbicide groups, Group A, B's and Z.

- Of the 23 samples that demonstrated resistance to Topik® only five were resistant to Verdict® which is also a Fop herbicide, but 15 demonstrated to be resistant to Axial®, a Den herbicide.

- All samples resistant to Axial® were also resistant to Topik®
- In those cross resistant samples, the level of resistance demonstrated to Verdict® and Axial® was much lower than that was shown to Topik® in the majority of cases - but not all
- As shown above there was no demonstrated resistance to Select®.
- There were only two samples with Atlantis OD® resistance at a low level - for one sample it was the only resistance demonstrated, the other sample was also resistant to Topik®, Axial® and Mataven® as well but susceptible to Verdict®.
- 15 of the 21 samples resistant to Mataven® were also resistant to Topik®, 11 were resistant to both Topik® and Axial®.
- Six samples were resistant to Mataven® but demonstrated no cross resistance to the other herbicides tested.

Discussion

Acknowledgement should be first given to the collection method and the potential bias that may have given to the samples submitted to this survey. This was not a random survey of the region and most likely growers and advisors would most likely sampled weed seeds from more suspicious populations than not. This is highlighted in the sample submission questionnaire where all samples were either suspected to be "resistant" or "possibly" resistant. Therefore it should be considered the outcomes and information presented from this survey maybe a "worst case scenario".

In defence of this approach, testing is carried out through seed testing and that the target populations for this survey are from cropping paddocks. Therefore it is most likely the only seed available to sample would be those from plants at maturity that have survived in crop herbicide applications. This scenario would by definition support a theory they are possibly resistant to at least some herbicides. Another way to put it is that susceptible plants would have been controlled by herbicide applications and simply not available to sample- suggesting seed tests will always bias towards a greater level of resistance whether the collection method is random or directed.

A "Quick Test" which samples live seedling plants from populations not already "selected" for a resistance by herbicide application and as such may not have as stronger bias for resistance applied.

Given this bias towards sampling populations suspected of resistance the finding of some levels of resistance is no surprise. That said though for both ARG and BO, the samples that were submitted have overwhelmingly demonstrated a high level of resistance to many of our common herbicides. Nearly all (99%) the samples of ARG and 73% of BO samples submitted were resistant to at least one of the herbicides tested.

The higher level of susceptibility in the BO samples is interesting given that 27% of the samples submitted showed complete susceptibility to the range of herbicides tested yet sufficient survivors were available to sample from (assuming the paddock was treated for BO) which does fly in the face of the above comments. There are a number of potential explanations however no clear evidence in the data set is available to confirm as to which one. BO is well noted for seed dormancy and possibly the plants sampled germinated after the paddock was treated with herbicides. Alternatively does the presence of susceptible plants at maturity suggest reduced effectiveness of the herbicides through poor application or the impact of plant stresses? This could suggest that more attention and care should be paid to application of BO herbicides to ensure the highest level of control.

Multiple resistances

As detailed above in tables 4 & 6, multiple resistances are common with only 13% of ARG samples and 22% of BO samples demonstrating resistance to just a single herbicide group or subgroup. The clear majority of the samples submitted from both species demonstrated multiple resistances.

Therefore within this set of samples, multiple resistances are significantly more common than no resistance or just single product resistance. Put another way, samples with no resistance or single product resistance is a rarity.

It was found that the levels and types of cross resistances, as discussed below, for each population tended to be unique. Hence the reader should exercise caution as what is demonstrated in this data will not necessarily be applicable to all populations. Further to this the complexity of relationships between the large numbers of herbicides tested can be overwhelming and the results potentially completely unrelated.

Source of resistance

As detailed in the results above there are a number of samples that have demonstrated resistances to a number of products where it has been indicated that the particular herbicide group has not previously been used.

For example there were-

- 15 populations of ARG that demonstrated resistance to Axial® where use of Axial® was not indicated,
- Two of the four populations of ARG demonstrating resistance to Trifluralin had not reported its application,
- Two populations of ARG had not reported the use of a Group B herbicide yet demonstrated 100% resistance to Logran®
- Four BO samples demonstrated resistance to Axial® where its use was not reported
- 16 BO samples demonstrated resistance to Mataven® where its use was not reported.

This phenomenon is not uncommon and potentially could occur through a number of mechanisms.

- The population is naturally resistant to the herbicide, explained by simple genetic variability within species
- Some resistances can simply be selected for indirectly. That is selection for resistance by use of one particular herbicide may at the same time select for a resistance for another unrelated herbicide.
- Resistant plants or seeds can be introduced into your system, carried in on machinery and stock or in seed, wind or flood waters.

There is no way to confidently identify which mechanism has resulted in the outcomes in the examples listed above but their occurrences do highlight challenges for management of herbicide resistance. There are unfortunately no defence growers and advisors can employ to manage the natural presence of resistance in a population. For the second mechanism there is also little that can be done to avoid this other than sound and informed chemical rotations. However for the third mechanism sound farm hygiene for machinery, seed and stock can slow the spread or incursions of resistant weeds.

Knowing your resistance status

For the set of samples provided to this survey we have detailed the frequencies of individual resistances as well as a number of generalisations about levels of cross resistances between some herbicides. However it should be again noted these apply to this set of samples only and may not apply beyond these in the wider farming systems or other regions. There is no unique and distinct characterisation of a “resistant” ARG or BO plant- each one can be different.

As growers and advisors this survey showed our predictive skill for identifying resistance without testing may be variable. For ARG, all samples were predicted to either possibly or definitely resistant and that was shown to be true. For BO however 29% of the samples that were predicted to be possibly or definitely resistant were not resistant to any of the products tested.

So given our questionable skill at predicting resistance and that it can occur somewhat independent of past herbicide use, resistance testing is a must. The results from this survey have demonstrated populations where some products have retained effectiveness when it could easily be assumed that they would be ineffective and visa-versa. To highlight this point;

- 56% of BO samples demonstrated resistance to Topik®, but only 12% demonstrated resistance to Verdict® with both herbicides in the same herbicide group
- 99% of ARG samples demonstrated resistance to Logran®, only 82% demonstrated resistance to Hussar OD® and 56% to Intervix®- all Group B herbicides
- 51% of samples demonstrated resistance to Mataven® but only one quarter of those had Mataven® applied previously.

This highlights the value in herbicide resistance testing not so much to confirm that a particular product has not worked due to resistance, but to identify which products may still work in the future.

Worthy of a mention

As discussed above, the identification of resistance to a number of key products such as the Fop herbicides and Group B herbicides such as Logran® have come as no surprise. Alarmingly though the testing has highlighted some cases of resistance to a few “less used” products thought to be safe and still effective and which many growers would be potentially relying on for herbicide control in the future.

Atrazine and trifluralin have had much less reliance or use in the region compared to many other products for the control of these weeds. Experience from other regions also indicated that resistance can take much longer to develop and are much less common. However six populations (10%) of ARG samples demonstrated resistance to atrazine with another six populations demonstrating 5% survival in testing which could indicate very early stages of developing resistance. There were also four populations of ARG that demonstrated resistance to trifluralin.

Similarly Intervix®, as a product mainly utilised in Clearfield canola and hence only a small proportion of our annual cropping area, demonstrated resistance in 56% of the ARG samples.

Identification of resistance to Select® in the region is not a total surprise but for many populations of ARG it was the only reliable in crop selective herbicide available and is therefore a key in the management of ARG. But nearly a quarter of the samples submitted (22%) of ARG samples demonstrated resistance at the lower application rate of 350 ml/ha. All of these populations were already resistant to Verdict®, Axial®, Logran®, and Hussar OD®. Increasing the application rate to 500ml/ha did decrease the survival to 8% of the populations but this for many populations is the last lever to pull for ryegrass control.

Mataven® is often talked of as an alternate herbicide product for the control of BO and in recent times had very little use with only six samples indicated to have received any applications of Mataven® in the past 10 years. However 51% of the BO populations demonstrated resistance to Mataven®. As an alternate product to control Topik® resistant BO only 36% of the Topik® resistant populations would be susceptible. There are currently questions over the continued manufacture and supply of Mataven® but its usefulness on these populations would be limited.

Finally, herbicides play a pivotal role in our current minimum-till or zero till farming systems. Possibly the most important product in the northern farming region is glyphosate. This herbicide is invaluable in the control of weeds in our fallow systems which are essential to conserve out of season rainfall to achieve profitable crop yields. It is also important for managing pre-planting flushes of weeds, potentially the largest germination of winter weeds. Loss of the effectiveness of this herbicide will seriously challenge the sustainability of this otherwise profitable system.

Testing of the ARG samples submitted to this survey has revealed 6% of them demonstrated resistance to Glyphosate 540 @ 1lt/ha. Higher application rates improved control but only marginally. Although this is only a small proportion of the samples tested the importance of the product and lack of comparable alternatives is reason enough to be very alarmed by these results.

Conclusion

As intended, the survey included weed seed samples from a healthy cross section of the GOA region of the Central West of NSW. Both AGR and BO were submitted to the survey with ARG samples attributing approximately two thirds of the total samples and BO one third.

Testing revealed that herbicide resistance was common place and that in the vast majority of the samples submitted multiple resistances were most dominant. In a number of cases the broadness of multiple resistances was such that there are only a few potentially effective herbicide options left that might control those weeds.

This survey has proven herbicide resistance is not an issue confined to Western Australia or other regions only. This survey has identified many populations in the Central West of NSW that rival and possibly surpass the severity of Western Australian herbicide resistance. It should no longer be considered “someone else’s issue” and that “it’s not that bad”.

The survey was also invaluable in identifying what some of the most challenged herbicide groups are in terms of effectiveness. But the survey also served a warning to growers particularly for what many have thought to be “safe” and “effective” herbicide options such as Select®, Atrazine and Trifluralin and even glyphosate with clear signs of resistance developing.

The results of this survey are damning and its strength may be the force that has been needed to change attitudes, to acknowledge the issue of herbicide resistance which of course is the first step to better manage the issue of herbicide resistance into the future.

Acknowledgements

This survey would not have been possible without the support and funding of GRDC. GOA would like to acknowledge this as well as the efforts of growers and advisors who participated in this survey.

Contact details

Maurie Street
Grain Orana Alliance
PO Box 2880
Dubbo NSW 2830
Ph: 0400 066 201
Email: Maurie.street@grainorana.com.au

Pre-emergent herbicides: part of the solution but much still to learn

Richard Daniel and Anthony Mitchell, Northern Grower Alliance

Key words

Residual herbicides, annual ryegrass, fleabane, feathertop Rhodes grass, awnless barnyard grass, crop safety, incorporation by sowing

GRDC code

NGA00003: GRDC Grower Solutions for Northern NSW and Southern Qld

Take home messages

1. The use of a disc planter for incorporation by sowing (IBS) of residual herbicides resulted in significantly reduced wheat emergence for all four herbicides evaluated
2. The disc planter 'set-up' actually increased the risk of crop damage
3. These results reinforce the need to only use narrow point tynes when using residual herbicides with IBS recommendations
4. Residual herbicides are important tools for the effective and economic management of key summer fallow weeds
5. Use of residual herbicides in fallow may suit operations with access to optical sprayers
6. Individual paddock rotations may need to change to enable use of residual chemistry in preceding fallows or in-crop

The issue

The widespread adoption of minimum tillage has provided many agronomic and sustainability benefits to our farming system. However it is a system that has led to an overreliance on knockdown herbicides to achieve effective weed management. As a consequence we are faced with management issues in two main 'herbicide-driven' scenarios; control of herbicide resistant weeds e.g. annual ryegrass (ARG) - *Lolium rigidum* and a selection of weed species with higher levels of natural herbicide tolerance e.g. feathertop Rhodes grass - *Chloris virgata* (FTR) and flaxleaf fleabane - *Conyza bonariensis*.

Residual herbicides are an important tool to assist in the control of weeds in both these scenarios but the issues that have always dogged residual products will be important to better understand and manage e.g. consistency of efficacy across varied soil types, incorporation requirements and stubble loadings, plantback restrictions and how to best maximise crop safety without reducing weed efficacy.

This paper is split into two sections. The first section deals with results from two trials conducted in 2013 evaluating the crop safety and efficacy of registered residual herbicides for the control of ARG in wheat. The second section is a more general discussion of the fit for residual herbicides in the farming system.

1) Winter cereal 'at planting' residual herbicides and crop safety

In these trials the majority of treatments were managed by the incorporation by sowing (IBS) approach. IBS specifies the use of narrow point tynes on the planting equipment. This approach helps to ensure sufficient soil is thrown across the inter-row space to effectively 'incorporate' the herbicide plus it removes most of the herbicide treated soil from the planting furrow to improve crop safety. The negative consequence is that IBS generally provides poor weed control in the zone immediately around the planting row. In many cases, post sowing pre-emergent application (PSPE) is also being evaluated as it provides more uniform weed efficacy but requires herbicides or rates with improved crop safety together with reduced incorporation characteristics.

What was done?

At a site near Mullaley NSW, the grower had adjoining paddocks which he intended to plant with the same wheat variety (Crusader) but with two different planters; a tyned planter in one paddock and a single disc in the second. The trials were located within ~300m of each other.

Both trials were sprayed and planted on the 20/6/13, with a single tank of each treatment used to spray both trials. Planting occurred immediately after herbicide application.

Soil type

Although the two trials were located within 300m of each other, there were distinct differences in the soil type. The soil type where the disc planter was used was a black vertosol with the tyne planter used in a lighter red soil.

Rainfall

The site had good planting moisture with ~48mm of rain received in the three weeks prior to planting. Table 1 shows the rainfall received between planting and the assessment of crop establishment, three weeks after planting. There was a total of 31 mm received in the first 9 days after planting. The only rainfall in the first week after planting was 4mm on day 4. It was not considered that this level of rainfall would have created a high risk scenario.

Table 1. Rainfall in first 21 days after planting

Date (days after planting)	24/6 (+4)	27/6 (+7)	28/6 (+8)	29/6 (+9)	**Total**
Rainfall (mm)	4	16.6	7.0	3.4	**31**

Crop safety results

Figure 1 shows the wheat emergence data relative to the untreated. The actual plant population of the untreated in the disc sown trial was ~108 plants/m^2 and ~66 plants/m^2 when planted by tynes. NB the two planters were not set up to plant an equivalent rate of seed.

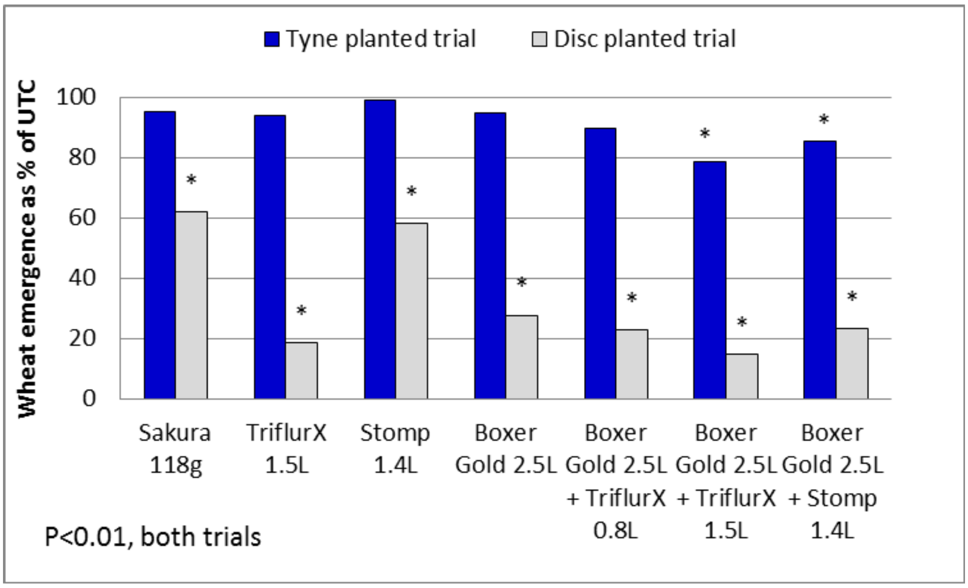

Figure 1. Wheat emergence as a % of untreated (11/7/13, 21 days after planting)
UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa
* = significantly reduced wheat emergence compared to untreated within same trial

In the tyne planted trial, the mixture of 2.5 L/ha Boxer® Gold (800g ai/L prosulfocarb and 120g ai/L s-metolachlor) with either 1.5L/ha trifluralin 480g ai/L (eg TriflurX®) or 1.4 L/ha pendimethalin 440g ai/L (eg Stomp® 440) resulted in significantly reduced wheat emergence compared to the untreated. There was no significant difference between the untreated and any other treatment.

In the disc planted trial, all treatments significantly reduced wheat emergence compared to the untreated. TriflurX alone, Boxer Gold alone and all Boxer Gold mixtures also significantly reduced wheat emergence compared to 118g/ha Sakura® (850g/kg pyroxasulfone) or Stomp alone.

Depth of sowing

Depth of sowing can impact on crop safety with disc planted seed generally shallower than tyne plantings. Seedlings were dug up to measure the effective planting depth with the results shown in Table 2. Samples were also evaluated from the ’guess rows’ in the disc planted trial as it appeared that wheat emergence was less affected in those rows.

Table 2. Mean depth of sowing under different planting configurations

Planting configuration	Tyne	Disc	Disc ‘guess rows’
Mean depth (cm)	2.2	1.7	1.9

Depths shown are a mean from ~40 seedlings in each comparison

A PSPE application of Boxer Gold was also evaluated in both trials. This treatment was expected to cause the greatest level of crop damage as there was no removal of herbicide above the planting furrow.

This treatment actually resulted in significantly improved emergence counts compared to the IBS treatment in the disc sown trial. This indicated that the single disc setup was actually causing greater levels of crop damage by concentrating treated soil over the planting furrow rather than ‘removing’ treated soil.

Crop safety summary

- Wheat emergence was significantly reduced by all herbicide treatments when disc planting was used for IBS
- Sakura or Stomp alone were significantly safer than TriflurX or Boxer Gold alone or Boxer Gold in mixture with either TriflurX or Stomp when planted with discs
- Crop safety was dramatically improved when the tyned planter was used for IBS with only Boxer Gold plus Stomp or TriflurX 1.5L/ha significantly reducing plant stand
- Depth of sowing may have contributed to crop safety with the guess rows in the disc planted area appearing less affected although only marginally deeper (~2mm)
- Soil type may also have contributed to the varied level of crop affect between the two sites

Efficacy results

In the tyne planted trial there was a population of ~13 ARG plants/m^2 in the untreated. Similar levels of ARG control were achieved by all IBS treatments (~93-97% control) with the only exception being Stomp. Stomp provided significantly lower levels of control than the other IBS treatments at 94 days after planting (Figure 2). Boxer Gold applied PSPE in this trial also resulted in significantly poorer control than the IBS treatment.

In the disc planted trial there was a more variable population of ~7 ARG plants/m^2. There was no significant difference in level of ARG control between any herbicide applied as IBS (~87-99% control). Boxer Gold applied PSPE provided similar levels of control to the IBS treatment (Figure 2).

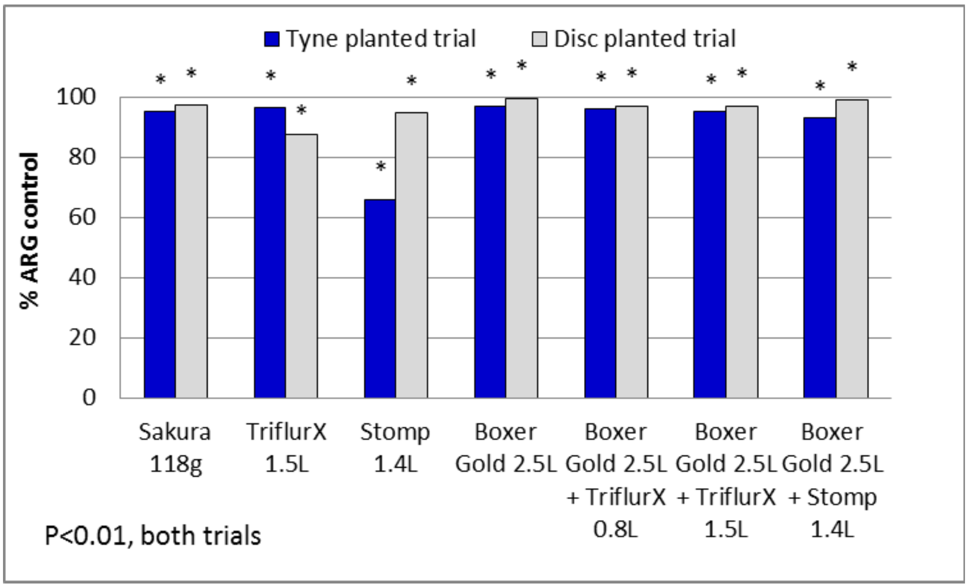

Figure 2. % annual ryegrass control based on counts (22/9/13, 94 days after planting)

UTC = untreated control. All treatments applied in 70 L/ha total volume using AIXR110015 nozzles at 300 kPa
* = significant ARG control compared to untreated within same trial.

Efficacy summary

- High levels of ARG control were achieved by most IBS treatments
- The most consistent product were Boxer Gold or Sakura
- Weed control from Boxer Gold was significantly reduced in one of the two trials when applied by PSPE

Conclusions - winter cereal 'at planting' residual herbicides and crop safety

This project was conducted due to commercial crop safety concerns arising from the use of residual herbicides at planting for ARG control. These two trials highlighted some key points:

1. Crop safety was significantly reduced when a disc planter was used for incorporation
2. The disc setup appears to have exaggerated crop safety issues by planting seed in an area with increased herbicide concentration
3. Observation suggested that small differences in planting depth may have impacted on crop safety in this scenario
4. Additional trial activity in 2015 is showing similar crop safety results and reinforces the need to only use these herbicides with tyned planters

This work reinforces some of the difficulties growers and agronomists face with the use of residual herbicides. Crop safety and efficacy are influenced by a range of factors including planting equipment, planting depth, soil type, stubble load together with rainfall quantity and timing. As an industry we need to have a more thorough understanding of the impacts from these (and perhaps other factors) to ensure we get the best from these important weed management tools.

2) Residual herbicides for fallow weed management

NGA has been involved in a large number of projects to screen registered herbicides for residual control of 'difficult fallow weeds'. Important target species have included fleabane, FTR and awnless barnyard grass - *Echinochloa colona*.

For both fleabane and FTR, the primary reason for evaluating residual herbicides was the high cost and difficulty of knockdown control of these weeds in the summer fallow. For awnless barnyard grass, it is broadly distributed, previously effectively controlled with glyphosate but we now have concerning levels of glyphosate resistant populations in the northern region.

Residual herbicide registrations in fallow

Flaxleaf fleabane

- 100g/ha isoxaflutole 750g ai/kg (eg Balance®)
- 0.86-1.2kg/ha of terbuthylazine 875 g ai/kg (eg Terbyne® Xtreme)
- Prior to sorghum only for knockdown and residual control: 700mL/ha FallowBoss® Tordon® (300g ai/L 2,4 D + 75g ai/L picloram + 7.5g ai/L aminopyralid) + 3-5L/ha atrazine 600g ai/L

Additional product registrations for in-crop knockdown and residual herbicide use, particularly in winter cereals, are still being sought. There are a range of commonly used herbicides, registered in winter cereal and broadleaf crops that can provide useful residual fleabane activity. Trial work to date has indicated that increasing water volumes from 50-100L/ha may help the consistency of residual control with application timing to ensure good herbicide/ soil contact also important.

Feathertop Rhodes grass

- 100g/ha isoxaflutole 750g ai/kg (eg Balance)

Additional product registrations for in-crop and fallow use are still being sought. Similar to fleabane, there are a range of commonly used herbicides that provide useful residual FTR activity. Other herbicides used to provide residual control of summer grass weeds have been noted to reduce emergence of FTR.

Awnless barnyard grass

- 150-200mL/ha imazapic 240g ai/L (eg Flame®)
- 100g/ha isoxaflutole 750g ai/kg (eg Balance®) – suppression only

There are a number of registered active ingredients that provide residual 'in-crop' control of awnless barnyard grass from an 'at planting' application. These include

- 2kg/ha atrazine 900g ai/kg in sorghum and 2.5-3.3kg/ha in maize
- 1-2L/ha Dual® Gold (960g ai/L s-metolachlor) in Concep II sorghum seed safener treated sorghum, maize, soybeans and sunflowers and 1L/ha in cotton
- 1.8-2.2L/ha Stomp® Xtra (pendimethalin 455g ai/L) in mung beans, soybeans and sunflowers and 2.2L/ha in cotton when pre plant incorporated
- 1.2-1.7L/ha trifluralin 480g ai/L (eg TriflurX®) in mung beans and sunflowers and 1.2-2.3L/ha in soybeans and cotton

Optical weed sprayers

One of the reasons knockdown herbicides are generally preferred over residuals is the consistency and robustness of control. Effective management of any weed species is heavily focussed on reducing the seed bank ie stopping any weed from setting seed.

Even under ideal conditions, it is highly likely there will be survivors from residual herbicide use in fallow partly due to the absence of crop competition. Use of a residual herbicide in fallow frequently suits a follow up with an optical spray operation. An alternative use for this technology is to apply the residual herbicide through an optical sprayer when a fallow knockdown is being applied. This approach can limit the area of application of the residual (and reduce potential crop effect issues) but also focus the residual herbicide in the patches with highest potential for subsequent weed emergence.

Conclusions - Residual herbicides for fallow weed management

Our management issues with fleabane, FTR and awnless barnyard grass have all in part stemmed from an over reliance on glyphosate in the summer fallow. To successfully manage these weeds the industry must start to adopt a range of integrated management practices using both non herbicide measures eg crop rotation, strategic and salvage tillage, intensive patch management for new incursions and even salvage burning together with a wider range of herbicide options eg residual herbicides as well as double-knock strategies to effectively manage these weeds but also ensure we don't lose glyphosate completely.

Profitability is of course still paramount. The suggestion with these problem weeds is to focus on individual paddocks and adjust rotations to crops that most suit your environmental conditions but also enable the use of effective residual herbicides in the previous fallow or even in crop. Particularly for FTR, the seed bank is only short lived and two years of effective management can ensure that paddocks return to full flexibility of rotational choice.

Acknowledgments

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the author would like to thank them for their continued support.

Our sincere thanks to Josh Bell for his patience and co-operation with the annual ryegrass trials and Aaron Goddard (Landmark) for trial site assistance.

Contact details

Richard Daniel
Northern Grower Alliance
Ph: 07 4639 5344
Email: richard.daniel@nga.org.au

® Registered trademark

Panel session: managing problem weeds - implications for farming systems

Practical management of high level phosphine resistance in Rusty grain beetle

Philip Burrill, DAF Qld.

Key words

Grain storage, rusty grain beetle, flat grain beetles, Storage checklist, Diatomaceous earth (DE), ProFume®

GRDC code

PAD 00001

Take home message

Rusty grain beetle (RGB) is one of three Flat grain beetle species seen in Australian stored grain. If flat grain beetles survive a fumigation using phosphine, it is important to send the live insects to a laboratory for resistance testing. ProFume® may be recommended if it is the strong resistant strain of RGB.

Consider using this simple "farm storage checklist" that works towards establishing best practice and building a professional, mutually beneficial relationship with your key grain buyers

To achieve reliable grain quality and pest control results, use an integrated strategy of good storage hygiene, monthly monitoring / recording, aeration cooling and appropriate use of protectants and fumigation when required.

A. Integrated pest control

The rusty grain beetle (RGB), (*Cryptolestes ferrugineus*), is one of three flat grain beetle species found in stored grain throughout Australia. They are a small (2mm long), fast moving beetle with long antennae that readily flies. Sieving grain or using insect probe traps is usually required to detect this pest as it hides and avoids exposure on the grain surface. See Figure 1.

In 2007 a strong phosphine resistant strain of RGB was identified which is now present in the northern and southern grain production regions of Australia. ProFume, (sulfuryl fluoride), may be required to control an infestation of this resistant RGB.

To reduce the risk of RGB and other common storage pests developing resistance, causing grain quality problems and delays in marketing, combine the strategies listed below.

Hygiene

Regular clean up of grain residues in empty storages and grain handling equipment significantly reduces the number of breeding sites for insect pests. For storages and equipment, physically clean &/or water wash out grain residues and dust on a sunny day, then consider using a diatomaceous earth (DE) structural treatment. e.g. Dryacide®

Aeration

Fit aeration fans to storages and use them to reduce grain temperature. Cooling grain either slows or stops the insects breeding life cycle. Rust red flour beetle stops breeding at 20 °C; lesser grain borer stops at 18 °C; rusty grain beetle (RGB) stops at 17 °C, and all insects stop breeding below 15 °C. Maximum breeding rates for most storage pests occurs at the typical warm grain temperatures during harvest of around 30 °C.

Aerate grain as soon as it is put into storage. Grain temperatures of less than 23 °C in summer and less than 15 °C in winter are achievable targets. For reliable results use a good quality automatic controller to run fans, as they select air with the best temperature and humidity available.

Monitoring grain

Never 'store and forget': Sample, sieve and check insect probe traps in your grain at least once per month. Identify pests and keep monthly storage records, including any grain treatments or fumigations. See "On-farm storage Checklist" section.

Grain protectants

Grain protectants are applied to clean grain, typically at harvest time while auguring grain into storage. They are not registered for use on grain that is already infested with insect pests. Misuse of these products results in poor adult insect control and selection of resistant insects.

For cereal grains, consider applying grain protectants such as Conserve On-farm® (Dow AgroScience), or K-Obiol® (Bayer) to planting seed in storage, grain held for stock feed on-farm, or grain held for extended periods in sheds or other non-sealable storage where fumigation is not possible.

Prior to using any treatment, always check the label, then discuss with potential grain buyers, as some markets do not accept grain treatments.

As a resistance management strategy, after two consecutive years of using Conserve On-farm (chlorpyrifos-methyl, S-methoprene, spinosad), rotate with one year of the Bayer product K-Obiol (deltamethrin + piperonyl butoxide).

Storage choices / fumigation

Many older silos were not designed to be sealed gas-tight for the purpose of fumigation. Fit these silos with aeration fans and do a good job with hygiene. When buying new silos, look for a quality design, easy to clean, sealable and fitted with aeration fans.

Ask the silo manufacturer if the silo meets the Australian Standard (AS 2628) for sealable silos (i.e. passes a pressure test). Aim to have at least two sealable, aerated silos on your farm. This allows you to achieve an effective fumigation of any infested grain. As a general rule, only leave a silo sealed for the actual time required for the fumigation period of 7 to 20 days.

Major pests

Table 1. Major pests of stored grain

		
Sawtoothed grain beetle *Oryzaephilus surinamensis*	**Flat grain beetles & Rusty grain beetle** *Cryptolestes* spp	**Psocids** *Liposcelis* spp.
		
Lesser grain borer *Rhyzopertha dominica*	**Rust red flour beetle** *Tribolium castaneum*	**Rice weevil** *Sitophilus oryzae*

Figure 1. Rusty grain beetle (RGB) *Cryptolestes ferrugineus*

B. Diatomaceous earth (DE) - storage hygiene treatments

DE is one of the few products available as a silo structural treatment suitable for all cereal grains, pulses and oilseeds. By using DE, rather than insecticides like fenitrothion, the problem of unwanted chemical residues on oilseeds and pulses being detected by domestic and export grain buyers is minimised.

At the start of a recent wheat harvest on the Darling Downs, over 1000 lesser grain borers were found in the first 30 kg of wheat passing through the header. If the header had been cleaned down and treated with DE after the previous season's sorghum harvest, this early infestation problem may have been avoided. Any warm, sheltered location with grain residues is a good breeding site for storage pests. The best hygiene results come from physically cleaning out residues, followed by a DE treatment.

"Clean as you go", for empty storages and grain handling equipment significantly reduces the number of pest breeding sites on farm. During most of the year, particularly in the warmer months, storage pests fly looking for fresh grain to infest.

DE (amorphous silica) is an inert dust made from the fossil remains of diatom skeletons, which are known to have insecticidal properties. Diatoms are a type of green or brown algae that grows in fresh-water lakes and marine estuaries. There are many thousands of species of diatoms. The skeleton of each species has a unique size and shape. DE products produced from the various mine sites in Australia and overseas have different properties. The way DE is processed also affects its properties. It should therefore be of no surprise that of the several commercial DE products available to growers in Australia, there is a significant difference in their efficacy against storage insect pests.

The DAF Qld. Postharvest research team in Brisbane tested the efficacy of four commercial DE products, plus lime in the laboratory in 2013 and 2014. The most significant difference between products, was their efficacy against the very common, rust red flour beetle (Tribolium castaneum), with only two products showing acceptable results. Product performance from best to worst was – Dryacide®, Permaguard®, Cut'n'dry®, Absorbacide® and AgLime®. See Figure 2.

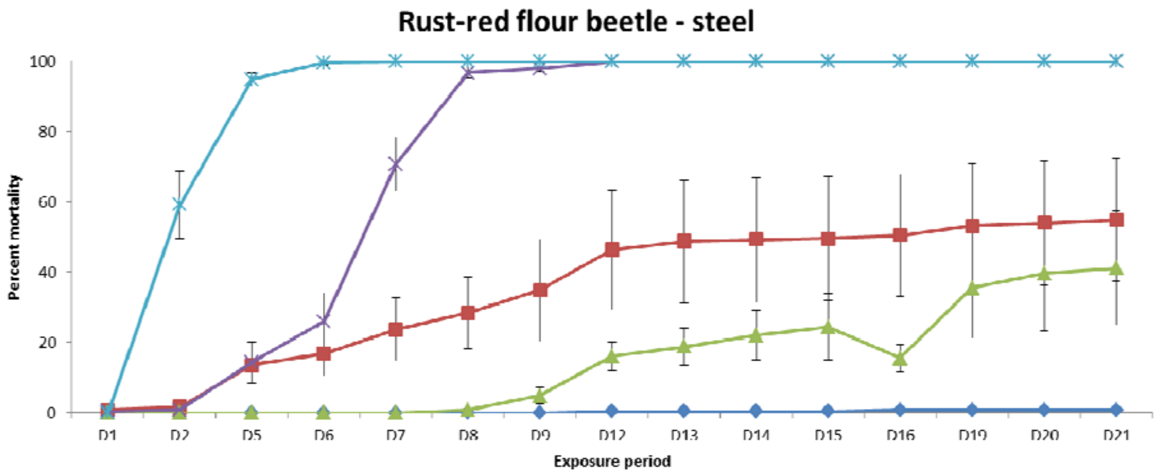

Figure 2. Efficacy of four DE products and AgLime over three weeks against Rust Red Flour beetles (P.Burrill, V.Byrne, A.Ridley 2014)

DE dust particles kill insects by absorbing some of the waxy layer covering the insect's body. Damage to this outer 'water-proofing wax layer' leads to desiccation and eventual death over a number of days. Research in the USA indicates DE's impact on the insect's body is both abrasion and desiccation.

Therefore, DE works best in low humidity conditions. Stored cereal grains, such as wheat, must be no greater than 12% moisture content, or below 60% relative humidity for DE to be effective.

Application

While the Dryacide® label allows for it's use as both a structural surface treatment and a grain treatment (1 kg DE / tonne grain), in most circumstances, the main focus for DE's use should be for structural treatment.

Grain treatment

The problem for grain treatments at the label rate of 1 kg DE / tonne of grain is that it affects grain flow characteristics and therefore handling. It also has an impact on grain 'angle of repose'. For this reason most bulk handling companies (e.g. Graincorp etc.) and other grain buyers do not accept bulk grain treated with DE. Presence of DE in grain can also impact on milling quality and there may be other specific market objections to DE dust application to bulk grain. Always check before applying it to grain. Current retail cost for DE ranges from $6 - $10 per kg., making it an expensive treatment for bulk grain.

Structural treatment – storages & grain handling equipment

DE can be applied to structures and equipment either dry or added to water to form a slurry. The rate for dry dust application (straight out of the bag) is 2 g/m², which is equivalent to 1 kg of DE over 500 m². A Blow-Vac gun is one option for application.

DE dust can also be mixed into water at 120 g dust / litre of water, applied at a rate of 5 litres per 100 m² giving an application of approx. 6 g /m² dry basis to the storage structure.

The label specifies a flat fan nozzle with at least 5 litres/minute flow rating, so an XR11015VK ceramic nozzle would be a suitable choice. The ceramic will withstand the abrasion much longer than a plastic nozzle. At 3 bar this nozzle will give you 5.9 L/min.

In summary, for all storages and equipment, physically clean &/or water wash, all grain residues and dust, then consider using a DE structural treatment to deal with any remaining pests.

For further information on DE / Dryacide®, search on www.storedgrain.com.au and www.entosol.com.au

C Profume® fumigation - when & how to use

ProFume® gas fumigant (998g/kg Sulfuryl fluoride) is currently registered in Australia for the control of insect pests in stored cereal grains, baled hay, dried fruits, nuts and various other uses as specified on the current label.

It was registered for use in Australia in 2007 by Dow AgroSciences, about the same time as the strong resistant strain of rusty grain beetle (RGB) was identified at bulk handler's depots in Australia.

In recent months (July 2015) Dow AgroSciences, has sold the Profume product business to Douglas Products LLC based in the USA. However "A-Gas Rural", the South Australian based company will continue to act as the product handling / distribution company

Key points for ProFume - Sulfuryl fluoride (SF):

- ProFume, a cylinderised gas, can only be use by approved, licensed fumigators**.** Contact "A-Gas Rural"
- Is only registered for cereal grains, - NOT for pulse or oilseeds
- Requires a gas-tight, sealable storage to maintain gas concentrations for the required fumigation time
- SF fumigations with grain temperatures below 20°C give poor insect control results
- Fumigation time (7 days) is critical to ensure control of the egg and pupae stages of storage pests

Prior to the recent (2007) appearance of strong phosphine resistant RGB all the major grain storage pests in Australia were controlled using a phosphine dose rate target that produced at least 300 ppm for 7 days with grain temperatures of 25 °C. This is typically achieved using the current label does rate in gas-tight sealable silos that meet the Australian standard AS2628.

However to control this strong phosphine resistant RGB, research has shown it would now require a concentration of 360 ppm phosphine gas for a minimum of 27 days. This may be too much to ask of many good quality sealable storages. Using ProFume (SF) is the logical choice, once strong phosphine resistant RGB has been identified in a post phosphine fumigation situation.

Fortunately, research has also shown that SF (ProFume) will control this strong resistant RGB. It is important however to be aware it will normally require 7 day fumigations at 25 °C or higher grain temperatures to provide reliable control of all the hard to kill egg stage of our major storage pests. See Figure 3.

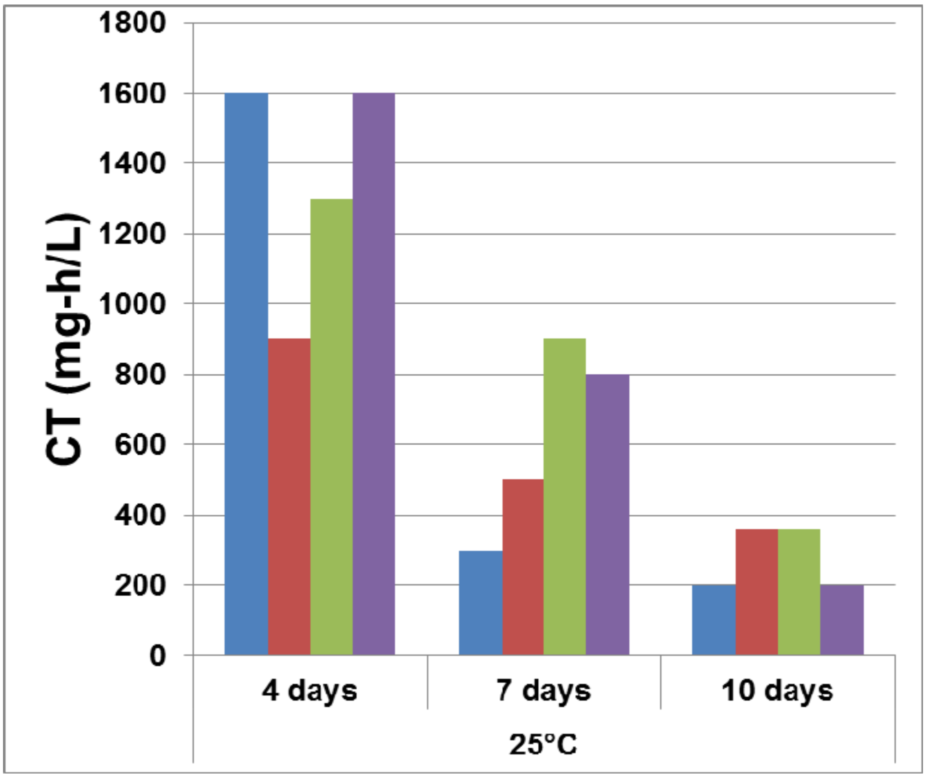

Figure 3. Sulfuryl fluoride (SF) - time and concentration required for control of four major storage pests; rust-red flour beetle (blue), rusty grain beetle (red), lesser grain borer (green), rice weevil (purple) (R.Kaur & M.Nayak 2014)

Costs

Currently the ProFume gas product costs about $31 per kg. With a standard dose of 35g/m^3, this would use 4.4 kg for a silo that can hold 100 tonne of wheat (125 m^3). So Profume product cost is about $1.40 per tonne.

To this cost, we also need to add travel and application costs required by the licensed fumigator.

This typically brings total ProFume treatment costs into the range of $4 to $7 per tonne.

Phosphine tablet product costs growers about 40c per tonne. To this add application labour costs.

ProFume and resistance management

Despite ProFume's relatively high cost, it is very valuable to the Australian grain industry for its key role in dealing with the strong phosphine resistant rusty grain beetle (RGB) (*Cryptolestes ferrugineus*).

It is important we use ProFume (SF) correctly to maintain it's efficacy in the grains industry, which includes this important function as a resistant management tool to rotate with phosphine gas.

Use of Profume in situations that result in "under-dosing" insects in poorly sealed storages, or using short fumigation exposure times, will only see insects quickly develop resistance to yet another valuable product.

D Checklist for on-farm storage – AAA score

Most producers have developed mutually beneficial business relationships with one or more grain buyers / traders/ end users. It is in the interest of growers, buyers and the industry as a whole to see 'on-farm storage facilities' well managed and as a profitable part of the farm business.

The aim of the a checklist is to assist grain producers to move towards 'best practice for their farm storages facilities'. In doing so, individual producers build a reputation as reliable suppliers of good quality, insect free grain. Over time, this builds confidence and profitability for both producer and grain buyer. For the Australian industry, there are cost savings for everyone along the value chain as grain moves to domestic & export markets.

A "Stored grain checklist" is available from the stored grain website at www.storedgrain.com.au or contact Philip Burrill on philip.burrill@daf.qld.gov.au or 0427 696 500 and he will be happy to email it to you.

With a copy of the electronic word document, grain growers and others can add or delete items to suit their own storage facilities and grain trading situations.

Acknowledgements

The author would like to thank members of the Department of Agriculture & Fisheries Qld., Postharvest grain protection team based at the EcoSciences Precinct, Brisbane. Research results presented were derived from experiments undertaken by Valerie Byrne and Raman Kaur, along with valuable input from Andrew Ridley, Greg Daglish, Pat Collins, Manoj Nayak. The author is also grateful for the continued support of GRDC and the significant contribution from growers with on-farm trials, comments and suggestions.

Contact details

Philip Burrill
Department of Agriculture and Fisheries (DAF Qld.)
Mb: 0427 696 500
Email philip.burrill@daf.qld.gov.au

® Registered trademark

The what, where and why of soil testing in the northern region

Mike Bell[1] and David Lester[2]

[1] University of Qld (Gatton)
[2] DAF (Toowoomba)

Key words

Soil testing, sampling frequency, sampling depths, crop responses

GRDC code

UQ00063, UQ00066

Take home message

Soil testing is a key component of ensuring both sustainable land management in the longer term and maximising the chance of reaching the water-limited yield potential in the coming season. The sampling strategy adopted will be determined by the reason for sampling (fertility monitoring or fertilizer diagnosis), the size and availability of the different pools nutrient in the soil (determining the appropriate laboratory test method), the mobility of the nutrients of concern in the soil profile (determining soil layers of interest) and the root activity of different rotation species in that soil type-seasonal rainfall combination.

The correct soil sampling strategy and diagnosis of potential nutrient limitations will not guarantee an economic response to applied fertilizer, as seasonal conditions and inappropriate application strategy (timing or placement) can reduce the crop nutrient requirement or limit crop recovery of the applied nutrient. However, it will ensure the best possible chance of delivering on water-limited yield potential in the coming season and represents value for money in a farm management plan.

This paper discusses current thinking on soil sampling methodology (frequency, depth intervals), analytical methods and interpretation relative to fertilizer N responsiveness for the northern grains region.

Perhaps the most compelling argument for soil testing is that if you don't understand the fertility status of the soils under management it is extremely difficult and time-consuming to then ensure the right fertilizer product, application rate, and method of application are used to maximise chances of crop recovery and an economic yield response. This is becoming increasingly important in the northern region as the native fertility levels in our once-fertile clay soils are diminished through grain removal and we become increasingly reliant on external nutrient inputs.

Northern soils and climate

We have some clear advantages in our region over other rain-fed cropping zones. Firstly, moisture stored in the soil profile during a fallow can deliver a significant proportion of our annual crop growth and yield (especially in winter cropping), so once we make a planting decision the questions about crop size (and hence nutrient demand) are more about how much *extra* growth/yield we may derive from the seasonal forecast of in-crop rainfall rather than whether we will have any crop at all. Secondly, for expensive nutrients like phosphorus (P) and potassium (K), we find these nutrients have an excellent residual value for seasons following the actual application, so we have flexibility to apply these nutrients when our cash flow and seasonal/stubble conditions suit, rather than for each crop. Clearly once we understand the soil status of these nutrients, the different crop species nutrient requirements and the rates of crop removal in harvested produce, we can effectively use nutrient budgeting (fertilizer applied - grain removal) to guide our fertility strategy.

However our heavier soil types also confer some disadvantages, and these relate to the typically mobile nutrients like nitrogen (N – our largest and most expensive nutrient input) and sulphur (S). These nutrients are less mobile in clay soils, and while that means they are less likely to be lost below the root zone by leaching, they are also slower/require higher amounts of rainfall to redistribute into subsoils where much of crop root activity (water and nutrient uptake) occurs. In the case of N, this slow movement into the profile also increases the risk window for significant losses to the atmosphere as a gas through the processes of denitrification and volatilization. These processes predominantly occur at or near the soil surface, although in the case of denitrification, can also extend to deeper layers under prolonged wet conditions. These loss pathways can result in significant losses of plant-available N and so shift the soil nutrient status out of the normal expected range, with implications for fertilizer requirement in subsequent crop seasons. The only practical way to assess the outcome of 'unusual' rainfall events/seasonal conditions for these nutrients is soil testing.

Soil testing strategies

Soils can be tested for a range of factors - to estimate how much water can be or has been stored; to identify the depth of root barriers or subsoil constraints such as boron or salinity; or the potential occurrence of a soil-borne disease. In this paper we focus on soil testing in relation to crop nutrition. This testing can be undertaken to either monitor long term fertility trends in cropped fields (i.e. is my fertilizer strategy maintaining my soil available nutrient status, and are these still appropriate to address yield limitations) or to identify the fertilizer requirement for the coming season. The field sampling strategies to address these two objectives are quite different. The first is quite challenging in trying to quantify changes in nutrient status over time, through repeated sampling at the same and at the same (or similar) reference points, to minimize background variability. The second and most commonly applied approach is trying to adequately represent the fertility status across the management unit in question, be it a yield zone, soil type or paddock..

The frequency with which this sampling should be undertaken will be related to the nutrient status of the field (are levels marginal/limiting or is there good background fertility?) and also how quickly the nutrient status can change (in response to crop uptake and removal, or to rainfall events/seasonal conditions). It is important to remember that when interpreting soil test results the values on the report are (i) only as good as the paddock sampling strategy with which they were collected, (ii) have variability associated with the laboratory analysis and detection method, and (iii) are being related to a critical range of soil test values below which a crop response is expected. In other words, normal soil test results should be used as a guide rather than a guarantee, but will still provide a very firm plank in a sensible nutrient management program. Ideally, integrating plant tissue analysis also would provide a more robust assessment of the soil fertility status.

Sampling depths will vary with the nutrient and reflect the zones in the soil profile contributing to meeting crop demands. The most common soil sampling depth for nutrient analysis has been 0 to 10 centimetres for broad-acre crops. This layer was chosen because nutrients, especially P, and plant roots in early growth stages are more concentrated within this layer. However to obtain more comprehensive soil nutrient data, sampling below 10cm should be considered for some nutrients.

Suggested sampling increments for key nutrients (and salinity/sodicity constraints) for northern cropping regions are:

- 0 to 10cm (N, P, K,S and sodicity);
- 10 to 30cm (N, P, K and S);
- 30 to 60cm (N and S, salinity/sodicity);
- 60 to 90cm (N, salinity/sodicity); and
- 90 to 120cm (optional - N, salinity/sodicity).

Deeper sampling does raise issues of logistics and cost, which should be discussed with soil test providers. However, the additional information provides a clearer insight into nutrient status in the crop root zone. Changes in level of nutrient availability or subsoil constraint are very slow so the frequency with which these need to be measured also has longer time scale, amortizing the cost out over many years.

Analytical results and testing methods

Soil test information is most useful for indicating the available amounts of macro-nutrients (those required in relatively large amounts to sustain plant growth – N, P, K, and S, calcium [Ca], magnesium [Mg] and sodium [Na]). Results for micro-nutrients (zinc, copper, manganese, boron) are also useful, but much more as a broad indicator of soil status rather than being directly linked to crop requirements and likely fertilizer response. Tissue testing for micronutrients is typically more informative for plant requirement in that regard.

Appropriate soil tests for measuring soil extractable or plant available nutrients in the northern cropping region are:

- Bicarbonate extractable P (Colwell-P), to assess easily available soil P;
- Acid extractable P (BSES-P), to assess slower release soil P reserves and the build-up of fertiliser residues;
- Exchangeable K;
- KCl-40 extractable S or MCP-S; and
- 2M KCl extractable mineral N, to provide measurement of nitrate-N and ammonium-N.

Tests for N and S provide information on nutrient supply (i.e. they can be directly linked to the quantity of nutrient available to the crop), while P and K tests indicate nutrient sufficiency/deficiency. It should be noted that N (and to a lesser extent S) demand is highly influenced by seasonal conditions, mineralisation from crop residues and soil organic matter between testing and harvest, and crop yield potential, making soil testing for N in isolation an unreliable indicator of fertiliser N requirements.

Other measurements that aid the interpretation of soil nutrient tests include:

- Soil carbon/organic matter content;
- Phosphorus buffering index (PBI);
- Soil salinity measured as electrical conductivity; and
- Chloride and other exchangeable cations (Ca, Mg and Na) including aluminium.

Further details of these analytical methods can be found in the Crop Nutrition factsheet for the northern grains region (http://grdc.com.au/Resources/Factsheets/2014/01/Soil-testing-for-crop-nutrition-North)

Frequency of testing

The frequency of soil testing in a field will be determined by the size of the available nutrient pool, the mobility of each nutrient in soil water and the rates of crop uptake and removal. The availability of nutrients which are accumulated and removed in large quantities (e.g. N), or which are subject to significant loss pathways (gaseous or leaching losses) can change quite quickly, and so will require closer attention. This may include regular soil testing, but under a string of similar climatic conditions, use of a nutrient budgeting approach combined with periodic soil testing can provide satisfactory results. However, as indicated by the problems with N availability after the La Nina years in 2010-2012, once anomalous events occur a soil test re-set is required to quantify the impact and identify the need to change the management approach.

Other nutrients taken up in large quantities but not necessarily removed in grain (e.g. K), and which are not mobile in the soil water, can change their distribution down a soil profile quite quickly, concentrating in shallow topsoil layers. Minimum or no-till management accentuates this nutrient ‘stratification’ so monitoring to detect such changes and develop a management response can be required relatively frequently in soils where (particularly subsoil) nutrient status is marginal.

Noting these exceptions, some general comments about frequency can be considered. Nutrient status in the top 10cm can typically change the fastest due to high root densities, stubble/residue return and fertilizer placement. As a result, these layers are typically sampled with greatest frequency. With the exception of mobile and dynamic nutrients like N, changes in status in deeper layers will be slower, especially in relation to immobile nutrients like P, K and micro-nutrients, and so will require less frequent testing. However an important point is that knowledge about the subsoil nutrient status of each paddock, especially in relation to slow release nutrient pools like BSES-P and limits to root activity like salinity, are essential to allow development of an effective fertilizer management program.

Relating soil test results to likely fertilizer responses

This topic was covered by Chris Guppy in some detail in the 2012 Goondiwindi Updates, and a detailed research program to improve our understanding of the critical soil test ranges below which crop response to applied fertilizer would be expected has been undertaken since then in UQ00063 (PKS in all crops) and UQ00066 (N in sorghum and canola). This work was based on the realization that most attention had been applied to wheat (N responses and the need for starter P based on the 0-10cm layer), with few guidelines for other crops. In the following section we show new information on the relationship between soil test and fertilizer N responsiveness (expressed as % maximum yield with applied N) for sorghum derived under UQ00066, and note that similar relationships have not yet been able to be developed for canola.

We also update (or in some cases simply reproduce) the indicative estimates of critical soil test ranges for P and K reported by Chris Guppy in 2012, and note that results from UQ00063 have yet to resolve the uncertainty around the ability of soil tests to predict responses to applied S – even in a supposedly responsive crop like canola.

Soil test N response for sorghum

The relationship for sorghum (Fig. 1) looks promising for all except low yielding crops, although surprisingly there is no clear indicator of different critical soil profile N contents (below which fertilizer responses are expected) for crops with different yield potentials and presumably N demands – although there are suggestions that lower yielding crops are less N limited when soil profile N at planting is <70-80 kg/ha in the top 120cm. The quantum of sorghum grain yield response to applied N (Fig. 2) increased as profile N reserves at sowing fell, with the rate of increase greater for sites and seasons where crop yield potential was high. These slopes are an indicator of the likely economic benefit of applied N.

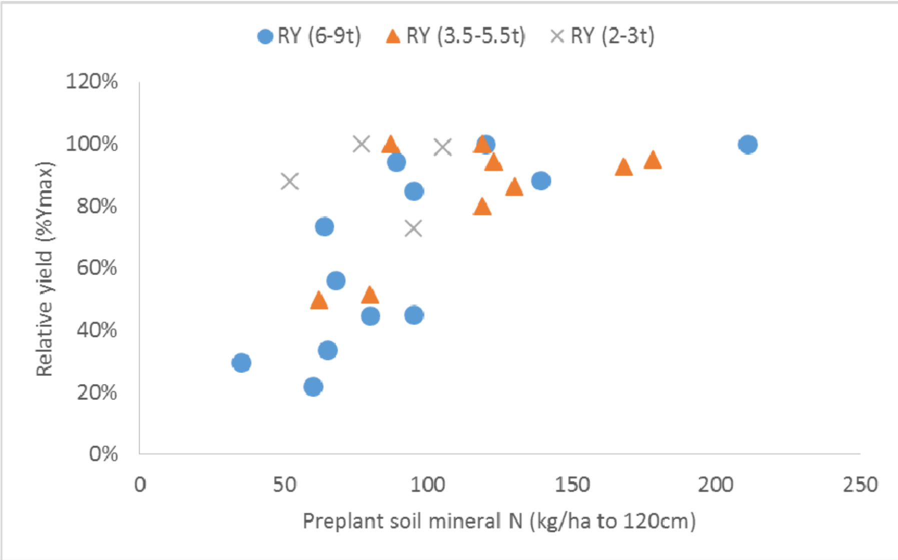

Figure 1. Relationship between relative sorghum grain yield (Y0/Ymax) and profile mineral N (sum of NH_4-N and NO_3-N) determined in soil tests taken prior to fertilizer application and crop sowing. Relationships are shown for soil profile depths of 120cm, with experiments with different seasonal yield potentials (2-3 t/ha, 3.5-5.5 t/ha and 6-9 t/ha) indicated by contrasting symbols.

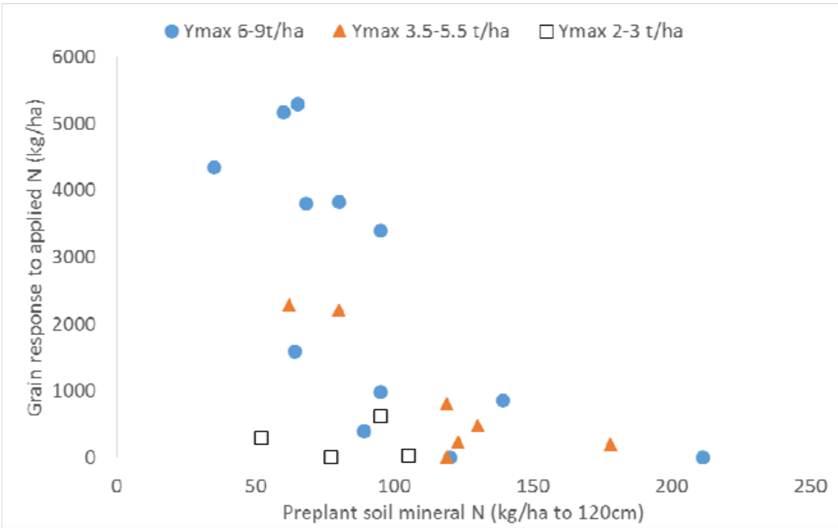

Figure 2. The quantum of sorghum grain yield response to applied N fertilizer (Ymax – Y0) plotted as a function of profile mineral N (120cm depth) at or prior to sowing. The steeper slope of the response surface in sites/seasons with a higher yield potential indicates greater returns on fertilizer N investment.

Phosphorus soil tests

The values listed below for P tests are what we currently use to determine if sites are likely to respond to P (starter P or deep bands), and it is a combination of the two distinct soil P test measurements that give the best indication of likely crop response. Colwell-P is measuring the labile, easily plant available P pool, whilst BSES-P measures not only this pool but also a pool that only releases P very slowly. The key difference is that this slow release pool will not release enough P fast enough to meet the demands of a rapidly growing crop, and so without some rapidly available Colwell P, addition of soluble P fertilizer is required.

Table 1. Generalised critical P values used to determine likely response or drivers of P availability in northern Vertosols

	Surface (0-10cm)		Subsoil (10-30cm)	
Colwell P	<25 mg/kg	Likely to get a response to starter P	<10 mg/kg	Likely to get a response to deep P placements
	>60 mg/kg	Ensure good groundcover to limit erosion risk!	>100 mg/kg	Unlikely to see P deficiency in your lifetime
BSES P	<25 mg/kg	Limited evidence of residual fertiliser accumulation	<30 mg/kg	Limited reserves of slowly available P. Consider replacement of removed P once every 5 years.
	>100 mg/kg	High residual fertiliser load	>100 mg/kg	Potential to slowly replace Colwell P reserves

There are species variations in the critical Colwell values according to species planted. For example maize and wheat require between 25-30 mg Colwell P/kg in the 0-10cm layer, while peanuts require only 12-15 mg/kg, with limited responses above that value. Although we have placed 'critical values' in the surface BSES tests in Table 1, we pay very little attention to these values. We are actually content with Colwell and PBI tests in 0-10 and 10-30, and BSES in the 10-30 only, at least once. Because BSES-P releases only slowly, movement in that value takes years, so does not need to be monitored annually.

Because P is an element that roots have to grow towards to maintain uptake, anything that limits the active extension and proliferation of roots will necessarily limit the accessibility of the P that is, at least in a soil test, considered available. Hence, soil conditions that inhibit root growth (sodicity, pH, salinity, nematode damage), necessarily increase the critical values because higher soil solution P concentrations are needed to match demand from a smaller root system. Under these circumstances we would encourage test strips be laid down to determine if remediation is economic. We remain uncertain of the responsiveness of crops to intermediate soil P values, but would expect variation based on the moisture regime the crop experiences each year.

The lower *critical* values in the subsoil for available P (and available K, below) reflect the larger soil volumes in a 10-30cm depth increment. By the time a plant root system requires nutrients from these depths, many of the yield limits such as grain number have been established in response to early P status (starter P and 0-10cm P status). What is needed by the plant then through to maturity is a long, regular arrival of nutrients from a more extensive and established root system. Plants will only rely on the nutrient status in these subsoil levels when times are hard near the surface. Surface moisture conditions through a season determine the dependence on subsoil nutrient resources, and consequently responses to deep placement. The excellent residual value we have seen from deep P applications in trials in a number of sites suggests that deep P placement followed by a season where topsoil supply dominates does not represent a waste of money. That deep P will be available to subsequent crops in the rotation.

Potassium soil tests

Potassium availability is a little more difficult to establish rules of thumbs for, but Table 2 below summarises our current thinking. Again, there are species differences in these values too. For the majority of species these values are about where we think responses are likely, however, we know that cotton requires higher K availability and critical values in cotton can be almost twice those reported in Table 2.

Table 2. Critical K values used to determine likely response or drivers of K availability in northern Vertosols

	Surface (0-10cm)		Subsoil (10-30 cm)	
CEC	ExK (cmol/kg)	High Mg (>30% CEC) or Na (>6% CEC)	ExK (cmol/kg)	High Mg (>30% CEC) or Na (>6% CEC)
<30 cmol/kg	0.2	0.4	0.1	0.2
30-60 cmol/kg	0.4	0.7	0.3	0.5
>60 cmol/kg	0.6	1.0	0.5	0.8

Considerably more work is required to improve the precision of these critical values, and to understand the mechanism behind the increase in those values where soil Na or Mg status is high. The two main mechanisms are direct competition at the root surface between these cations and K or changes in soil physical structure and aggregation that results in slower root extension and proliferation in the soil volume. It is highly likely that both are important in determining the availability of K to plants, but as yet we are only taking early steps in separating out these effects and understanding which plays a more significant role. Sorting out the importance of each of these mechanisms greatly affects how you manage them, as it will determine whether you attempt to broadcast K widely and enrich a much larger soil volume a little, or concentrate your K in multiple bands at various row spacing. The reason the critical value increases with CEC in Table 2 is because as the CEC of a soil increases, the buffer capacity of the soil for K increases along with it. In essence, the rate at which K is released from the soil to replace that taken up by a plant root is slower than the rate required by the plant root to maintain adequate K status, as the CEC increases. It is very similar to the way a high PBI in a soil increases the critical Colwell P value.

We are continuing to develop a method to estimate the slowly available reserves of K in each soil, with the tetra-phenyl borate extractable K (TBK) method still the most promising. A concerted push to develop testing methods for these slowly available pools is being undertaken by Chris Guppy (UNE) and Phil Moody (DSITI) in the next 3-4 years.

Through our current K field research, whole plant tissue K concentrations at maturity are emerging as a reasonable confirmation of soil K status.

Sulfur soil tests

Critical values for S responses in the surface are currently set at around 6 mg/kg of KCl-40 extractable S and in the subsoil, this would fall to around 4 mg/kg. However, we are currently recommending taking a deeper subsoil test for S, from 30-60cm depth. This is simply because S is far more mobile in the soil profile of heavier clay soils than either P or K, and hence, depending on rainfall, can move vertically in the soil column and be found at deeper depths. Responsiveness to S, where subsoil S is low, is also affected by soil moisture status. A dry topsoil, where organic S reserves accumulate, limits the mineralisation and release of S associated with that organic matter. Often a transient S deficiency can occur in prolonged dry periods, but is relieved with rainfall. At the very least, we are advocating monitoring S levels through the surface 60 cm.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, and the authors would like to thank them for their continued support.

Contact details

Prof Mike Bell
University of Queensland
Plant Science Building (8117A), Gatton Campus
Ph: 0754 601140
Mob: 0429 600730
Email: m.bell4@uq.edu.au