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Project Code	
Project Type	

FINAL REPORT 2016

PROJECT CODE	:	S12/02

PROJECT TITLE	Practical development of weed patch management for adoption in grains

PROJECT DURATION

Project Start date	1 July 2012					
Project End date	31 December 2015					
SAGIT Funding Request	2012/13		2013/14		2014/15	

PROJECT SUPERVISOR CONTACT DETAILS

Title:	**First Name:**	**Surname:**
Dr	Nigel	Wilhelm

Organisation:

South Australian Research and Development Institute (SARDI) (a group of the Primary Industries & Regions SA)

Mailing address:

Telephone:	**Facsimile:**	**Mobile:**	**Email:**

ADMINISTRATION CONTACT DETAILS

Title:	**First Name:**	**Surname:**
Mrs	Adrienne	Twisk

Organisation:
South Australian Research and Development Institute (SARDI) (a group of the Primary Industries & Regions SA)
Mailing address:

Telephone:	**Facsimile:**	**Mobile:**	**Email:**

PROJECT REPORT

Executive Summary

Site specific weed management (SSWM) has the potential to deliver significant improvements in weed control efficiency, through the targeted application of weed control measures only to where the weeds are located. Improvements in weed control efficiency will typically be achieved through reduced herbicide usage where herbicide is not required. SSWM has four principal components.

The impact of various herbicide strategies for grass control was assessed in two paddocks with patches of either annual ryegrass or brome grass in 2013. The impact of a second year of control was also assessed in these paddocks to study their impact on recruitment levels (reproductive capacity of weeds). The evidence was that while good control can be achieved in high density grass patches, recruitment levels in these patches still tend to be sufficiently high that the patches remain. Another brome grass site was monitored at Loxton as a low rainfall example in 2014 and an extra site at Wallaroo with rye grass was also undertaken.

High density weed patches should be targeted with high efficacy treatments over several seasons to drive weed numbers down. Herbicide savings can be made by reducing inputs into low density populations and these savings are greatest when using high cost herbicides. It is important to monitor weed populations where herbicide application has been reduced for density increase and be prepared to treat where large increases occur. Improved weed mapping systems and an annual weed surveillance program will help to ensure population increases are monitored and managed.

The poor ability of biomass sensors (such as Yara N-sensor) to adequately differentiate between crop and grassy weeds highlights the potential value of sensors able to separate crop from weeds (such as the H-Sensor SPAA which is currently being researched, funded by SAGIT).

Project Objectives
1. Improve weed management by identifying Precision Agriculture zones with the best economic return from spraying grass weed patches. 2. Increase adoption of Site Specific Weed Management (SSWM), with possible $15/ha savings, by compiling a "User's Guide to SSWM".

Overall Performance

The project achieved all milestones and successfully investigated the merits of site specific management of grassy weeds. A user guide to SSWM has been produced from the project findings and the extensive experiences of the author, Dr Sam Trengove.

Project personnel

Dr N Wilhelm	SARDI research officer	5%
Dr S Trengove	Consultant	20%
Mr S Sherriff	SARDI research officer	40%
B & D Johns	Farmers, Warnertown	
A & L Wakefield	Farmers, Urania	
S & L Nitschke	Farmers, Loxton	
S & S Paddick	Farmers, Moonta	

Despite John Heap (who submitted the initial project) leaving SARDI before the project was underway and supervision being taken over by N Wilhelm, the project has been conducted successfully and within budget, even though there have been delays in achieving the final project reports.

Finding paddocks matching the requirements for the project proved very difficult due to the paucity of comprehensive yield map histories and accurate maps of grassy weed populations. However, sufficient paddocks were located due to the extensive network of S Trengove. Another technical difficulty encountered was that current biomass sensors do not always reliably detect weed patches because they are confounded by variability in crop performance.

Key Performance Indicators (KPI)

KPI	***Achieved (Y/N)***	***If not achieved, please state reason.***
1/2012. Identify at least three paddocks with suitable grass weed infestations and define yield zones based on yield maps and grower experience.	Y	

2/2012. Determine grass weed density distribution in at three paddocks with suitable weed infestations.	Y	See brief explanations for all milestones below
3/2013. Establish experimental herbicide plots in different yield zones in two paddocks.	Y	
4/2013. Obtain weed growth and yield data for herbicide plots. Identify at least three more paddocks with suitable grass weed infestations and define yield zones based on yield maps and grower experience.	Y	
5/2014. Establish experimental herbicide plots in different yield zones in two new paddocks Establish experimental herbicide plots in different yield zones in the existing plots in the two original paddocks.	Y	
6/2014. Obtain weed growth and yield data for herbicide plots in the two new paddocks and two existing paddocks.	Y	
7/2015. Draft User's Guide written.	Y	
8/2015. Final User's Guide written.	Y	
9/2015. Collate all field data into a final analysis	Y	
10/2015. SAGIT Final Report.	Y	

Technical Information

Milestone 1/2012. Despite extensive surveying of cropping paddocks across the mid North region, only two paddocks satisfying all the criteria for our investigations have been identified. These criteria include extensive and varied populations of a grassy weed, substantial variation in land properties across the paddock (ie zones), have accurate and reliable yield mapping capability plus detailed paddock records, the manager is keen to be involved in the project and the paddock will be seeded to cereal in 2013.

Identified paddocks for trials 2013.
Warnertown, Brendon Johns. Paddock cropped to chickpeas in 2012. Brome grass patches identified using the Yara N-Sensor.

Urania, Ashley Wakefield. Paddocks cropped to chickpeas, lentils and canola in 2012. Crop Spec data assessed for identification of ryegrass patches.

Milestone 2/2012. Brome grass patches were identified and mapped using the Yara N-Sensor in the target paddock at Warnertown.

Existing Crop Spec data was assessed for paddocks at Urania for suitable distributions of ryegrass patches and zone variability. Ground truthing the chosen paddock struggled to match ryegrass density with Crop spec data; this sensor has been found to be relatively insensitive to young ryegrass on a number of occasions. Sites for differing rye-grass density were selected by ground-truthing.

Milestone 3/2013.
The paddock at Warnertown (Brendon Johns) was seeded to Clearfield wheat Kord on 17 May 2013. The planned treatments were imposed in four separate locations (Low grass/Low crop productivity, Low grass/High crop productivity. High grass/Low crop productivity, High grass/High crop productivity).

The Urania paddock (Ashley Wakefield) was seeded to Gladius wheat on 23 May 2013. The planned treatments were imposed in four separate locations. However, the factorial combination of grass density and crop productivity was only partly achieved due to poor detection of ryegrass by the crop sensor and subsequent ground-truthing.

Milestone 4/2013.
<u>Warnertown and Brome grass</u>.
Location of differing grass density and crop production was very successful in this paddock with high density brome sites having 14 or 78 plants per sq m while the low had 5-7 in the absence of chemical control. High crop production sites yielded 3.5 to nearly 4 t/ha (depending on treatments) while the low production sites were mostly less than 3.5 t/ha (see table 1 in attachment). Brome grass showed strong delayed emergence in this paddock with emerged plants increasing 5-10 fold over July.

Recent findings by Mr Trengove showed that employing a more expensive, but more efficacious herbicide treatment, in high density ryegrass patches produced a greater economic return in the year of application through increased grain yield. However, the longer term benefits over two and three years in reduced weed density were limited. The large seed bank that was carried over meant that despite improved control in one year, high density patches remained high. The question is then, what is required to drive the high density weed patches down equal to the low density areas? The results here show that recruitment per plant in the high density locations (no of heads per surviving plant) is higher than in the low density patches. This means that high density patches not only had higher numbers of survivors (even with similar control) but the survivors produced more heads per plant, than plants in low density area. The grain yield increases in the year of application from effective weed control, and hence economic returns, were also higher in these high density areas. Both these aspects support the earlier findings of Mr Trengove.

The impact of brome grass was relatively low at this site in 2013 where crop performance was generally high. The best control treatments (without crop damage) produced yield increases of less than 10% in the presence of high brome grass pressure.

The pre-seeding applications of Sakura plus Avadex caused crop damage: while the impact on establishment was minor, crop vigour was noticeably weaker in these treatments most of the year (see NDVI data in table 1) and grain yield appeared to be depressed. The low density brome + low crop productivity zone showed this effect most clearly; treatments 3 and 5 had grain yields nearly 10% lower than treatments 2 and 4 even though all controlled brome grass equally well.

Urania and Rye grass.
Due to the problems with the crop sensor, locating two types of grass density (low and high) was only partially successful in this paddock, (grass numbers relatively high in one low density location and low in one high density location). However, the site is still a very useful one. Rye grass had little impact on crop performance in 2013 at this site but recruitment levels were high in some treatments (up to 80 heads per sq m) which sets the treatments up well for 2014 studies.

Pre-seeding treatments with Sakura in this paddock also reduced crop vigour and grain yield (see NDVI and yield data for treatments 4 and 5 in table 2) at all 4 locations. Treflan on this intensively cropped farm was poorly effective at controlling rye grass (little or no reduction in rye grass emerged or number of heads produced). Recruitment in high density patches (more heads per plant) was also higher than in low density patches (as predicted from Trengove's earlier findings).

The level of recruitment per plant at both sites seemed to be more a function of grass density than crop productivity because recruitment levels were similar for both low and high production zones at both sites.

Milestone 5/2014.
The impact of 1 and 2 years of control in these two paddocks were examined in 2014 by applying the same treatments again in the 2nd year to the same plots and comparing this with a paired plot, where no control was applied in the 2nd year.

Several paddocks were surveyed for grass populations during the 2013 season in preparation for new experiments in 2014. One new site was identified at Loxton for an investigation into brome grass control in a low rainfall environment and a fourth site at Wallaroo dominated by rye-grass.

Milestone 6/2014.
Trials begun in 2013 were monitored in 2014 after the same treatments were re-applied to all plots and compared to a paired plot, where no control was applied in the 2nd year. Due to the complex nature of these comparisons, the findings from this component of the work have been incorporated into the generalized findings below.

Wallaroo and Rye grass – new site in 2014.
Rye grass patches surveyed in 2013 did not translate well into low and high density patches in the 2014 crop with all trial locations having from 200-400 plants per sq m. High levels of weed control gave 15-20% increases in grain yield regardless of weed density or crop potential. Those treatments which reduced rye grass heads per square metre late in the crop to less than 50 per sq m (Sakura and/or Boxer Gold) gave the highest yield increases in the wheat.

Loxton and Brome grass – new site in 2014.
At the low density brome site the average brome head density was 1.3 heads/m^2 and at the high density brome site the control (nil treatment) had 258 brome heads/m^2. Intervix® applied at 700 ml/ha failed to provide any significant control (Fig. 3). A herbicide resistance test of this brome showed a high level of resistance to the 'imi' herbicides.

Grain yield results at the high density brome site showed that the herbicide treatments that provided good weed control had significantly higher yield, whereas there was no yield benefit from herbicide used at the low density site. Increasing seed rate also improved yield at the high brome site, and resulted in the highest gross margins at this site.

These results indicate that the best economic and weed control outcome in this paddock would be achieved by targeting high density brome patches with trifluralin and metribuzin and higher seeding rates and using lower cost treatments (nil herbicide and a lower seeding rate) in low density patches.

Milestone 7/2015.

A draft User Guide was prepared by Sam Trengove and Stuart Sherriff and circulated to John Heap (was unable to commit time to review), Chris Preston (provided verbal comments to the project supervisor – was comfortable with the accuracy of the material but thought it a little long for farmer consumption) and Alan Mayfield. This feedback was incorporated into a second draft by end of January 2016.

Milestone 8/2015.

A final version is attached to this report, "Users guide for site specific weed management.docx".

Milestone 9/2015.

All trial data has been collated, summarized, analysed and interpreted in the attached file, "Practical devel of weed patch mgt adoption in grains_Results for submission.docx".

Milestone 10/2015.

Despite all the trials having been completed and all other milestones completed by the end of January 2016, the project supervisor only completed this final report in May 2016 due to overloads in commitments during the Jan-May period.

For detailed trial results and analyses, see the attached file, "Practical devel of weed patch mgt adoption in grains_Results for submission.docx".

Conclusions Reached &/or Discoveries Made

The impact of various herbicide strategies for grass control was assessed in two paddocks with patches of either annual ryegrass or brome grass in 2013. The impact of a second year of control was also assessed in these paddocks to study their impact on recruitment levels. The evidence was that while good control can be achieved in high density grass patches, recruitment levels in these patches still tend to be sufficiently high that the patches remain. Another brome grass site was monitored at Loxton as a low rainfall example in 2014 and an extra site at Wallaroo with rye grass was also undertaken.

The most fundamental question to be answered was "in which parts of the paddock does it make economic sense to control weeds?" Traditional wisdom suggests that control measures should be targeted to dense weed patches. Recent observations from SARDI field research suggest that this may not be correct because areas of very dense weeds may also be areas where crop potential is inherently low (and hence profits from controlling weeds is also low) . For example, there is evidence that annual ryegrass can be denser in areas which support weaker seedling cereal crop growth. However, the paddocks that were monitored in this project did not support this theory because profit increases from weed control were not closely linked to the yield potential of the crop. Because it is critical to prevent substantial recruitment for long term grassy weed management, even in areas of low crop potential, high levels of control (which often demand more expensive options) are often warranted to reduce recruitment.

Dot point summary:

- High density grassy weed patches should be targeted with high efficacy treatments over several seasons to drive weed numbers down, where weed control is the primary aim, however,
- Increasing weed control by 10% with a higher efficacy and higher cost treatment was rarely justified by the marginal yield benefit gained, even in high density weed populations.
- Significant herbicide savings can be made by reducing inputs into low density populations of grassy weeds particularly when using high cost herbicides.
- Phytotoxic herbicide effects reduced yield at low density weed sites in three of four paddocks. This indicates that a yield benefit could be gained in these zones by not applying herbicide or using a safer herbicide product.
- Different grain yield loss functions in response to weed density were established for different production zones at Warnertown and Wallaroo. As a result, different thresholds for breakeven weed control were established dependent on zone. This provides some evidence for the original hypothesis that, returns can be greater from grassy weed control, in zones of the paddock where grassy weed populations were moderate and yield potential high, compared to high density populations in low yield potential zones. However, because of the critical need to control recruitment in grassy weeds to prevent major increases in weed populations in subsequent years, investment in weed control in low yielding but high weed density zones was still worthwhile.
- It is important to monitor grassy weed populations where herbicide application has been reduced for density increase and be prepared to re-treat where significant increases occur.
- The poor ability of biomass sensors (such as Yara N-sensor) to adequately differentiate between crop and grassy weeds highlights the potential value of sensors able to separate crop from weeds (such as the H-Sensor SPAA which is currently being researched, funded by SAGIT).
- Improved weed mapping systems and an annual weed surveillance program will help to ensure population increases are monitored and managed.

Intellectual Property

None of the information generated in this project is deemed to have any potential for commercialization.

Application / Communication of Results

Preliminary results were presented to the independent consultants' annual planning meeting in February 2015.

Field sites were visited by local farmer groups as part of their spring crop tours in 2013 and 2014.

Major extension messages were developed after the second year of control results and the second set of paddocks have been analysed. Project outcomes were presented by Sam Trengove at the GRDC Adviser Updates in Adelaide, Wagga Wagga and Ballarat in early 2015.

A Ground Cover article, "New Tool tested for improving herbicide efficiency," was published in Issue 116, May-June 2015.

The findings regarding specific site management of weeds are summarized in the user guide prepared as part of the project (see attached).

POSSIBLE FUTURE WORK

Given the uniqueness of crop potential, seasonal stresses, weed types and patchiness and severity of weed densities in every paddock, the theory of improved cost effectiveness of weed control with targeted herbicide applications is hard to put into practice such that the full theoretical benefits of such an approach can be realised. The need to consider recruitment of weed species, and not just protection of crop potential in the year of application, further complicates the approach.

Given the building occurrence of herbicide resistance in weed populations and the difficulty in mapping weed patches reliably with current technology, we believe the industry is well served by current investigations into new generation technology (such as the SAGIT project on the H sensor) and alternative control strategies to herbicides (such as the current GRDC project, "Over dependence on agrichemicals.....".

AUTHORISATION	
Name:	Professor Alan Tilbrook
Position:	Research Chief, Livestock & Farming Systems
Signature:	
Date:	

SAGIT Project

Project code: S12/02

Project Title: Practical development of weed patch management for adoption in grains

Protocol 1: Field trials assessing the economic benefit of site specific weed management for annual ryegrass and brome grass

PROJECT MANAGER - Dr N. Wilhelm, SARDI, Waite

PROJECT CO-ORDINATOR – S. Trengove, Trengove Consulting

RESEARCH OFFICER - S. Sherriff, SARDI, Clare

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2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate mL or g/ha	Cumulative herbicide	Site HRLY	HRHY	LRLY	LRHY
Nil	0	Nil	0	0	1283 a..	1865 a..	1456 a...	1689 a..
Trifluralin IBS	1700	Nil	0	11	1281 a..	1801 a..	1304 ab..	1715 a..
Trifluralin IBS	1700	Trifluralin IBS	1700	22	1324 a..	1855 a..	1307 ab..	1663 a..
Boxer Gold IBS	2500	Nil	0	39	1256 a..	1848 a..	1293 ab..	1697 a..
Boxer Gold IBS	2500	Boxer Gold IBS	2500	78	1280 a..	1813 a..	1349 ab..	1627 ab.
Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	147	1004 ..c	1678 .b.	944 ...d	1512 ..c
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	115	1115 .bc	1646 .bc	1105 ..cd	1483 ..c
Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	77	1205 ab.	1701 .b.	1250 .bc.	1558 .bc
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	154	1083 .bc	1568 ..c	1116 ..c.	1567 .bc

Site	Depth	Colwell P	PBI	Colwell K	Organic Carbon	Soil N	Sulphur	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	CEC	ESP (sodicity)	Bo
		mg/Kg		mg/Kg	%	kg/ha	kg/ha	dS/m	pH	pH	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%	
HBLY	0-10	22	36	182	0.39			0.08	8.2	8.8	9.38	0.63	0.47	0.06	10.5	0.6	
HBHY		23	34	241	0.41			0.08	8.1	8.7	8.85	0.68	0.62	0.02	10.2	0.2	
LBLY		24	66	265	0.37			0.07	8.2	8.8	9.75	0.76	0.68	0.02	11.2	0.2	
LBHY		30	34	251	0.4			0.06	8.2	8.8	8.22	0.66	0.64	0.02	9.5	0.2	
HBLY	0-30					23.4	5.85	0.07	8.2	8.9	9.19	1.03	0.33	0.04	10.6	0.4	
HBHY						42.9	7.41	0.09	8.1	8.9	14.19	2.22	0.55	0.1	17.1	0.6	
LBLY						27.3	7.8	0.08	8.1	8.9	11.66	2.23	0.5	0.2	14.6	1.4	
LBHY						27.3	7.41	0.08	8.1	8.9	11.53	1.27	0.55	0.04	13.4	0.3	
HBLY	30-60					19.5	4.29	0.07	8.3	9.1	8.1	2.09	0.26	0.08	10.5	0.8	
HBHY						23.4	9.36	0.15	8.3	9.4	10.72	4.6	0.39	1.02	16.7	6.1	
LBLY						15.6	9.75	0.17	8.3	9.6	9.95	4.33	0.39	1.75	16.4	10.7	
LBHY						15.6	8.19	0.07	8.2	9.1	12.32	2.68	0.27	0.12	15.4	0.8	

Summary

The impact of various herbicide strategies for grass control was assessed in two paddocks with patches of either annual ryegrass or brome grass in 2013. The impact of a second year of control was also assessed in these paddocks to study their impact on recruitment levels. The evidence was that while good control can be achieved in high density grass patches, recruitment levels in these patches still tend to be sufficiently high that the patches remain. Another brome grass site was monitored at Loxton as a low rainfall example in 2014 and an extra site at Wallaroo with rye grass was also undertaken.

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Dot point summary:

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moderate and yield potential high, compared to high density populations in low yield potential zones. However, because of the critical need to control recruitment in grassy weeds to prevent major increases in weed populations in subsequent years, investment in weed control in low yielding but high weed density zones was still worthwhile.

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1. Introduction

Annual grass weeds (e.g. annual ryegrass, brome grass, wild oats and barley grass) are a major constraint to SA grain production. Weed control costs are a significant component of production costs. Current commercial practice is to apply herbicides uniformly to whole paddocks. Careful and effective application of weed control to only certain parts of the paddock where control is profitable has the potential to reduce production costs.

An increasing number of SA growers now have GPS guidance and boom sprayer section control that is suitable for site specific weed management. Despite these technical advances in SSWM most growers are still hesitant to experiment because the economic benefits have not been adequately assessed. This project aimed to determine paddock zones to which weed control expenditure is best targeted.

2. Brome grass control in wheat at Warnertown – 2013/2014

2.1 Methods

A paddock (paddock 20) near Warnertown on the property of Brendon and Denise Johns was cropped to chickpeas in 2012. On 17 July 2012 the paddock was mapped with the Yara N-Sensor and a map of NDVI produced (Figure 2.1.a). With the crop being relatively even this map was related to the variability in weed density, with brome grass being the weed of most significance, however there were also small areas of barley grass and wild oats. This paddock has yield data back to 2006 (Figure 2.1.c-h), the average cereal yield data has been calculated from the cereal yield maps for 2006, 2007, 2008, 2010 and 2011 (Figure 2.1.b).

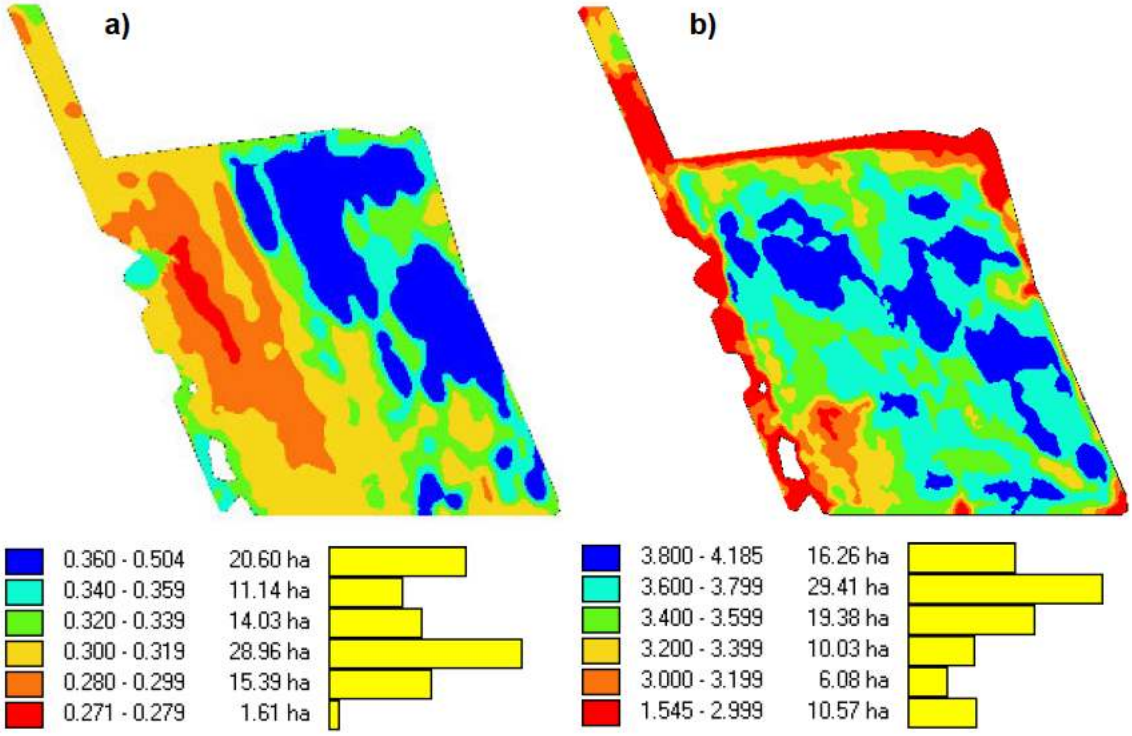

Figure 2.1.a) NDVI map of paddock 20 collected 17th July 2012 showing variable weed growth in chickpeas, b) average cereal yield for paddock 20 based on years 2006, 2007, 2008, 2010 and 2011.

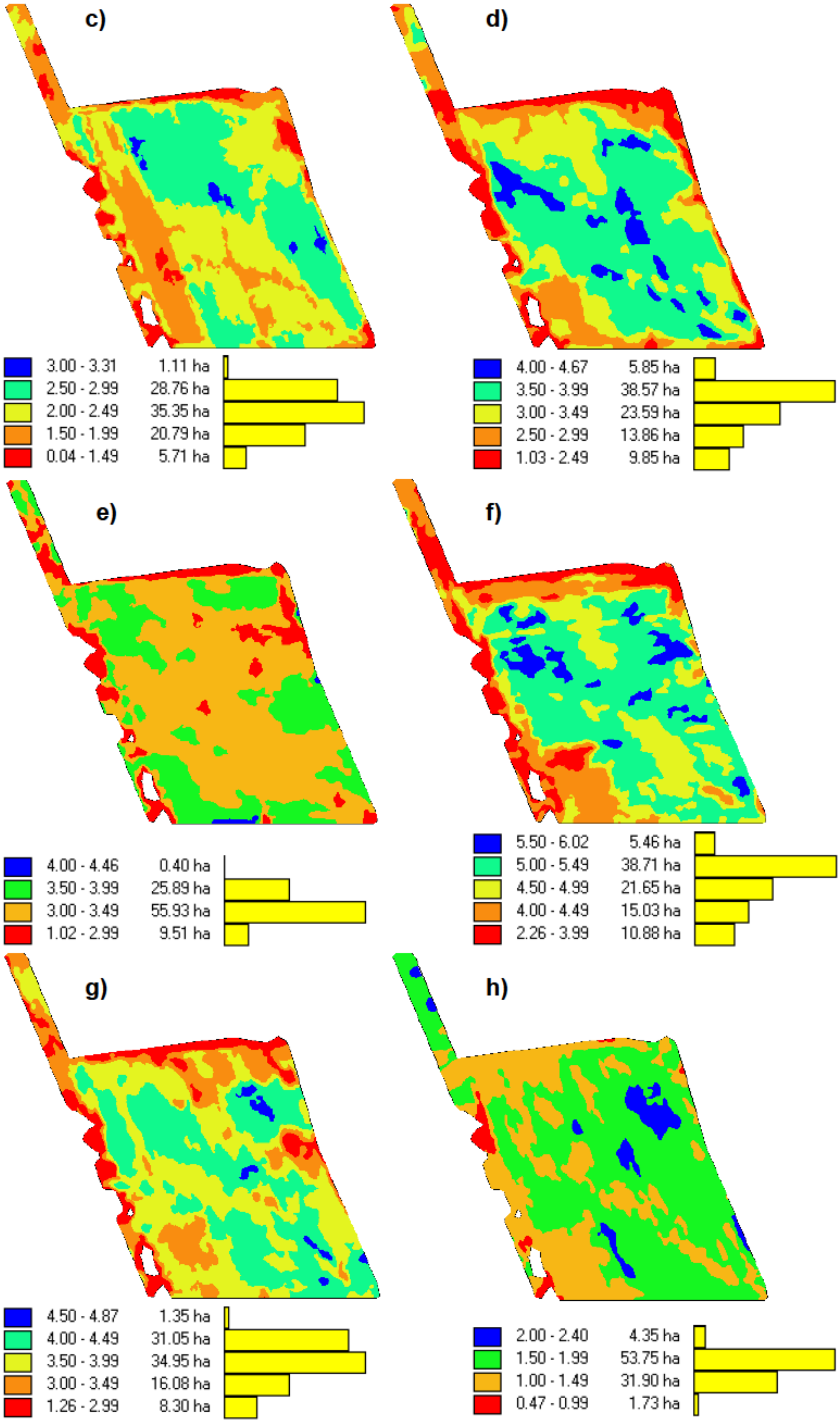

Figure 2.1.c) Wheat yield map 2006, d) barley yield map 2007, e) barley yield map 2008, f) wheat yield map 2010, g) barley yield map 2011, h) chickpea yield map 2012.

The average cereal yield map data (Figure 2.1.b) and the NDVI data from 2012 (Figure 2.1.a) were used to identify four regions. These regions were a factorial of high and low historical yield and high and low NDVI, where NDVI was used as a surrogate for brome grass density (Figure 2.1.i-l). Median values were used as thresholds, where the median cereal yield was 3.58 t/ha and median NDVI was 0.32. One site was selected in each of these zones as the location for a small plot trial to assess the efficacy of brome grass control and the yield response this generated within each zone. At each of these sites soil tests were taken and segmented to 0-10cm, 0-30cm and 30-60cm.

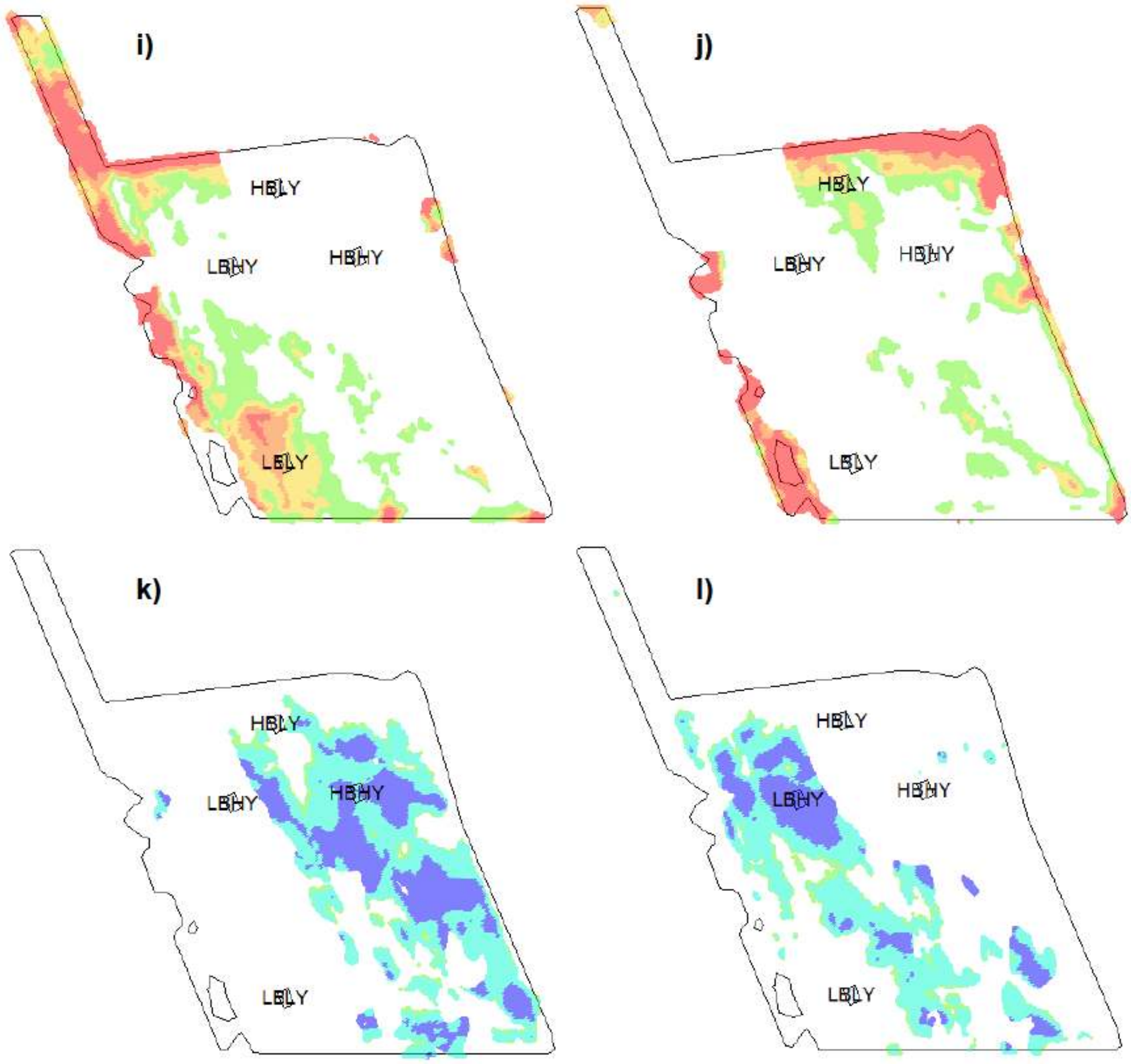

Figure 2.1.i) Low historical yield and low NDVI, j) low historical yield and high NDVI, k) high historical yield and high NDVI, and l) high historical yield and low NDVI. For each zone resultant trial site locations are shown.

The following acronyms are used in reference to each site

- HBLY - high brome and low yield
- HBHY - high brome and high yield
- LBLY - low brome and low yield
- LBHY - low brome and high yield

At each site a ten treatment trial was implemented. The ten treatments were a factorial of five herbicide treatments and two seasons (Table 2.1.a). The herbicide treatments were selected with the aim of achieving a range of brome grass control from 0-100%. The trial design was a randomised complete block design with four replicates. Prior to the trial period the 2012 crop was chickpeas, where selective group A herbicide application is expected to have provided close to 100% brome grass control. In 2013 the trial was sown on 17 May with Kord CL wheat with the SARDI New Variety Agronomy Clare trial seeder with knife points and press wheels on 225 mm row spacing. The plot dimensions were 12m * 1.4m on 1.8m centers. In 2014 the trial was inter row sown on 13/05/14 with the same seeding equipment and again with Kord CL wheat. In both years 100kg DAP/ha treated with flutriafol was applied with the seed.

Table 2.1.a: Herbicide treatment list.

Treatment	2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Total herbicide cost ($/ha)
1A	Nil	0	Nil	0	0
1B	Nil	0	Intervix	500	20
2A	Crusader	500	Nil	0	35
2B	Crusader	500	Crusader	500	70
3A	Sakura + Avadex Xtra	118 + 2000	Nil	0	58
3B	Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	116
4A	Intervix	500	Nil	0	20
4B	Intervix	500	Intervix	500	40
5A	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	78
5B	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	156

The Sakura and Avadex Xtra treatments were applied immediately prior to sowing in both years. Post emergent treatments in 2013 were applied 25 June and in 2014 the Crusader was applied 16 June and Intervix was applied 7 July. The 2013 measurements were as follows; wheat and brome grass plant counts were conducted on 25 June, further brome grass counts on 29 July, Greenseeker measurements on 21 August, brome grass head counts on 17 October and harvested on 7 November. Grain quality, including test weight, protein, and screenings was also measured. Insecticides, fungicides and post emergent nitrogen were applied when necessary in both years.

The 2014 measurements were as follows; wheat and brome plant counts recorded on 19 June, further brome plant counts and wild oat plant counts on 21 August, Greenseeker measurements on 28 July, brome grass and wild oat head counts on 2 October and the trials were harvested on 17 November. Grain quality, including test weight, protein, and screenings was also measured.

For simplicity Kord CL Plus wheat was used in these trials. However where non Clearfield treatments were applied the use of Kord CL wheat will negatively affect the yield and gross margin of those treatments relative to the highest yielding conventional wheat, such as Mace. Analysis of National Variety Trial (NVT) data for South Australia from 2010 - 2014 indicates that on average Mace wheat yields 9.6% higher than Kord CL. Gross margin analysis has been conducted using the Kord CL yields measured in these trials and also calculated with yields adjusted to Mace yields where non Clearfield treatments were imposed. An APW wheat price of $270/t was used in this analysis.

Partial budget sensitivity analysis was calculated over a two year period assessing the sensitivity to herbicide price, herbicide efficacy, brome grass head density and the wheat yield loss functions for different zones established in figure 2.2.a.

Brome grass plant and head counts were transformed by calculating the log of the count plus one. This was performed to improve the distribution of residuals for the data. All data were analysed by ANOVA in the software package Genstat.

2.2 Results

Table 2.2.a) soil test results from each trial site.

Paddock site	Sample ID	Depth	DGT P	Colwell P	PBI	Soil N	Sulphur	Organic Carbon	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Exc. Calcium	Exc. Magnesiu	Exc. Potassiu	Exc. Sodium	ESP (sodicity)	Boron Hot CaCl2
			µg/L	mg/kg		kg/ha	kg/ha	%	dS/m	pH	pH	meq/100g	meq/100g	meq/100g	meq/100g	%	mg/kg
High brome/High yield	ST 237T	0-10	164	53	59			2.16	0.14	6.5	6.9	12.5	3.2	1.2	0.19	1.1	
Low brome/High yield	ST 239T	0-10	89	33	50			1.34	0.15	7.6	8.2	12.8	1.6	1.2	0.1	0.6	
High Brome/Low yield	ST 238T	0-10	35	22	88			1.79	0.18	7.9	8.5	20.5	2.2	1.2	0.24	1	
Low brome/Low yield	ST 240T	0-10	36	26	81			1.88	0.26	7.8	8.3	18.9	1.8	1.3	0.25	1.1	
High brome/High yield	ST237AH	0-30				35	18		0.12	7.6	8.5	18.2	3.7	0.8	0.27	1.2	1.13
Low brome/High yield	ST239AH	0-30				31	12		0.13	7.6	8.6	15.1	1.8	0.9	0.11	0.6	0.96
High Brome/Low yield	ST238AH	0-30				35	23		0.16	7.7	8.7	18.8	2.8	0.7	0.27	1.2	1.47
Low brome/Low yield	ST240AH	0-30				43	16		0.14	7.7	8.7	18	2.2	0.8	0.21	1	1.25
High brome/High yield	ST237BH	30-60				12	12		0.12	8.1	9.1	15.4	4.1	0.4	0.58	2.8	2.26
Low brome/High yield	ST239BH	30-60				12	14		0.1	8.1	9	13	2.6	0.4	0.21	1.3	1.29
High Brome/Low yield	ST238BH	30-60				20	14		0.16	8.1	9.1	14.5	5	0.4	1.05	5	2.84
Low brome/Low yield	ST240BH	30-60				27	14		0.15	8.1	9	13.7	4.4	0.4	0.85	4.4	1.75

Comments: No obvious constraints are present in any of these soils that explain the differences in yield performance. The lower yielding sites are more sodic at depth, but not highly sodic, boron levels are all less than 5. All sites are low in salinity at all depths and all sites have increasing pH with depth. The low yielding sites are lower in P, which is contrary to many paddocks where the lower yielding sites are generally higher in P due to less removal over time. Sufficient fertiliser P was supplied to meet the crops' requirements.

2013

Comparing brome grass density in the nil treatments between 17 May (Table 2.2.b), 25 June (Table 2.2.d) and 29 July (Table 2.2.e) shows that the majority of the brome grass did not emerge until July, in fact only 13% of the population present on 29 July had emerged by 25 June. Only low populations of brome were present at sowing (Table 2.2.b). This supports earlier work by Sam Kleemann, who demonstrated increased dormancy expression in brome using seed sourced from another paddock on the Johns property in 2011. Interestingly, there were similar pre sowing brome grass densities at all sites (Table 2.2.b), yet as the season progressed the differences between sites classified as high brome and low brome become more significant, when the brome grass plant and head counts are compared between sites in the nil treatment (Table 2.2.d, e & g). Of interest, both high brome sites have brome grass heads/plant greater than 1 in the nil treatment, whereas the low brome sites have brome grass heads/plant less than 1 (Table 2.2.h). This suggests that the plants at the high brome sites would have set more seed and this may help explain why these sites have higher brome densities.

The Sakura and Avadex Xtra treatment applied at sowing reduced early brome grass numbers (Table 2.2.d) and also provided control of the brome emerging into July (Table 2.2.e). Brome control with Crusader was between 45-83%, whereas Intervix achieved 71-84% control and 83-95% when used in conjunction with Sakura and Avadex Xtra (Table 2.2.e). Brome grass head counts indicated that control was better than suggested by the plant counts (Table 2.2.g), where the poorest control with Crusader at site HBLY was still 89% reduction in head number compared to the nil treatment. The Intervix and Sakura + Avadex Xtra + Intervix treatments provided close to 100% control of brome grass heads.

Sakura + Avadex Xtra lowered wheat plant numbers by 12% when averaged across all sites (Table 2.2.c). This phytotoxic effect on the crop was also observed in the Greenseeker data (Table 2.2.f), where the Sakura + Avadex Xtra treatments had lower NDVI. On average across all sites the difference between the nil and Sakura + Avadex Xtra was 0.06, however this ranges from 0.10 at site HBLY to 0.03 at site HBHY. The increased difference at site HBLY may also reflect the better brome grass control achieved with Sakura + Avadex Xtra at this site where brome grass density was much higher than all other sites. When the Sakura + Avadex Xtra treatments are compared to Intervix at 500ml/ha, the NDVI difference averaged 0.04 lower across all sites. This comparison eliminates the effect of large differences in brome grass control on the NDVI and clearly shows the phytotoxic impact of Sakura + Avadex Xtra on Kord CL in that year.

Grain yield data shows that the sites conformed to the yield zoning where the high yield sites averaged over 3.5 t/ha with good grass control and the low yield sites averaged less than 3.0 t/ha (Table 2.2.i). At the high brome sites, grain yield of the Crusader and Intervix treatments was significantly greater than the nil, indicating a yield benefit derived from weed control. Despite good to excellent brome grass control with Sakura + Avadex Xtra and Sakura + Avadex Xtra + Intervix there were no significant yield benefits from the control at HBLY and HBHY. At the low brome sites there was little weed competition, so the herbicide effect was observed in the absence of weed competition. Treatments including Sakura + Avadex Xtra yielded less than the nil at the LBLY site, whereas Crusader and Intervix treatments increased yield. The effects observed in wheat plant establishment (Table 2.2.c) and NDVI (Table 2.2.f) are supportive of these yield effects, indicating that the herbicides phytotoxic effect may have reduced yield. All yields were similar at the LBHY site.

Grain quality was not affected by brome grass density, or herbicide treatment in 2013 (Table 2.2.j).

Table 2.2.b) brome grass counts (plants/m^2) for each site at sowing (17 May 2013).

Treatment	Site			
	HBLY	HBHY	LBLY	LBHY
Nil	2.14	2.67	2.33	3.33

Table 2.2.c) wheat plant density (plants/m^2) for selected treatments applied at sowing, letters denote differences between treatments at 95% probability. Counted 25 June 2013.

Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		163 a	149 a	158 a	149 a
Sakura + Avadex Xtra	118 + 2000	146 a	133 a	136 a	134 b
LSD (0.05)		ns	ns	ns	4

Table 2.2.d) brome grass density (plants/m^2) 25 June 2013 for selected treatments applied at sowing, letters denote differences between treatments at 95% probability from transformed data.

Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		8.2 a.	2.5 a.	0.4 a	2.4 a.
Sakura + Avadex Xtra	118 + 2000	1.9 b.	0.5 b.	0.1 a	0.5 b.

Table 2.2.e) brome grass density (plants/m^2) counted 29 July 2013, letters denote differences between treatments at 95% probability from transformed data.

Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		78.3 a...	13.8 a.	4.8 a	7.1 a..
Crusader	500	43.4 ab..	4.6 .b	0.8 a	3.5 .b.
Sakura + Avadex Xtra	118 + 2000	13.6 ..c.	3.6 .b	0.8 a	1.0 .bc
Intervix	500	22.5 .bc.	2.6 .b	0.8 a	1.8 .bc
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	3.8 ...d	2.0 .b	0.8 a	0.5 ..c

Table 2.2.f) Greenseeker NDVI measured 21 August 2013, letters denote differences between treatments at 95% probability.

2013 Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		0.75 a..	0.81 a..	0.69 ab	0.82 a.
Crusader	500	0.74 a..	0.79 ab.	0.72 a.	0.80 ab
Sakura + Avadex Xtra	118 + 2000	0.67 .bc	0.79 ab.	0.65 .b	0.76 .b
Intervix	500	0.72 ab.	0.77 .bc	0.72 a.	0.80 ab
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	0.66 ..c	0.76 ..c	0.65 .b	0.78 ab

Table 2.2.g) brome grass head density (heads/m^2) counted 16 October 2013, letters denote differences between treatments at 95% probability from transformed data.

Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		86.2 a....	27.9 a..	2.9 a	5.4 a.
Crusader	500	9.9 .b...	0.2 ..c	0.0 a	0.4 .b
Sakura + Avadex Xtra	118 + 2000	6.3 ..c..	2.3 .b.	0.0 a	0.5 .b
Intervix	500	0.6 ...d.	0.2 ..c	0.0 a	0.0 .b
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	0.0 ....e	0.1 ..c	0.0 a	0.1 .b

Table 2.2.h) brome grass heads/plant. Calculated from plant counts on 29 July 2013 and head counts 16 October 2013.

Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		1.1	2.1	0.6	0.8
Crusader	500	0.2	0.8	0.0	0.1
Sakura + Avadex Xtra	118 + 2000	0.5	0.7	0.0	0.4
Intervix	500	0.0	0.1	0.0	0.0
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	0.0	0.1	0.0	0.2

Table 2.2.i) wheat grain yield (t/ha) in 2013, letters denote differences between treatments at 95% probability.

2013 Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		2.85 a.	3.33 a.	3.15 .b.	3.92 a.
Crusader	500	3.13 .b	3.47 .b	3.27 ..c	3.95 a.
Sakura + Avadex Xtra	118 + 2000	2.83 a.	3.40 a.	3.03 a..	3.83 a.
Intervix	500	3.07 .b	3.55 .b	3.29 ..c	3.99 a.
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	2.83 a.	3.45 a.	2.99 a..	3.82 a.

Table 2.2.j) wheat grain quality averaged across treatment in 2013 (no significant difference was identified between treatments).

Quality measurement	Site			
	HBLY	HBHY	LBLY	LBHY
Protein (%)	11.5	11.0	11.6	11.5
Screenings (% < 2.0mm)	3.3	3.7	2.8	3.0
Test Weight (kg/hl)	79.0	80.0	81.8	79.4

2014

Similar to 2013 wheat density was slightly reduced in the IBS Sakura + Avadex Xtra treatments compared to the nil (table 2.2.k), however in 2014 this difference was not significant. Brome grass emergence generally followed the same pattern as in 2013 in that higher levels of brome were identified in later counts (21 August, table 2.2.m) compared to the first count on 16 June 2014 (table 2.2.l). However, in the nil treatments at three of the four sites brome grass density was very high at all sampling times.

All herbicide treatments applied in 2013 lowered brome plant and head density compared to the control in 2014 at all sites (table 2.2.l, table 2.2.m, and table 2.2.n). Treatments that provided the greatest brome control in 2013 had the lowest brome density in 2014 and this is most evident at the high brome sites (figure 2.2.b). At the HBLY site the application of herbicide again in 2014 further reduced brome head density compared with a single herbicide application in 2013. The reduction in brome grass head density in 2014 as a result of the first or second application of Sakura + Avadex Xtra was 87% and 85%, respectively (table 2.2.n). This was the lowest efficacy treatment at this site. Repeated application of high efficacy treatments reduced brome head density in 2014 to densities approaching zero. At the HBHY site there was a similar trend. The reduction in brome grass head number in 2014 as a result of the first or second application of Sakura + Avadex Xtra was 83% and 85%, respectively (table 2.2.n). This was the lowest efficacy treatment at this site. However, the other herbicide treatments did not show a significant difference in response to the second herbicide application in 2014. At the low brome density sites there was a reduction in brome density from all treatments relative to the control, however there was no significant difference between any of the herbicide treatments including after the 2014 treatments were applied.

Where Intervix was applied in 2014 to the nil treatment from 2013 the brome head density was reduced significantly at all sites. However, at the HBLY site brome head control was significantly poorer (93%) than where herbicides were applied repeatedly.

The Greenseeker data collected 28 July 2014 was driven mainly by brome grass density between sites (table 2.2.p) and this data supports the head counts that were performed 2 months later and shows greater variation between treatments than the plant count on 21 August 2014.

The control (nil herbicide in 2013 and 2014) produced the lowest grain yield at all four sites, although this difference was not significant at the LBHY site (table 2.2.q). At HBLY all herbicide treatments yielded significantly higher than the control, but there were no differences between herbicide treatments. At HBHY, Sakura + Avadex Xtra + Intervix applied twice and Intervix applied twice generated the highest yields, though not significantly higher than all other treatments. At LBLY Sakura + Avadex Xtra + Intervix and Sakura + Avadex Xtra applied only in 2013 generated the highest yields, though not significantly higher than all other treatments (table 2.2.q). Sites with high brome grass density had the largest yield responses to weed control. However, the yield loss per brome grass head was greatest at the LBHY site, with 8.2 kg/ha yield lost per brome head. At the HBHY site it was 6.9 kg/ha yield lost per brome head and at the HBLY it was 2.4 kg/ha per brome head (figure 2.2.a).

In 2014 there were no phytotoxic herbicide effects identified.

Gross margin analysis indicates that in a scenario where Kord CL Plus wheat is grown Intervix applied in the first season only is the highest grossing treatment at three of four sites (HBHY, LBLY and LBHY), however this is not significantly greater than Intervix applied twice and several other treatments including Crusader applied in the first season (table 2.2.s). At the fourth site (HBLY) Crusader applied in the first season only was the most profitable treatment, though not significantly greater than Intervix applied once or twice or Crusader applied twice. However, when the opportunity cost of growing a lower yielding wheat variety is considered the highest profit making treatment at all sites is Crusader applied in the first season only. This is not significantly greater than Crusader applied twice at three of four sites though (HBLY, HBHY and LBHY) (table 2.2.s).

Table 2.2.k) wheat plant density (plants/m^2) for selected treatments applied at sowing, letters denote differences between treatments at 95% probability. Counted 16 June 2014.

2013 Treatment	Rate (mL or g)	Site			
		HBLY	HBHY	LBLY	LBHY
Nil		141 a	152 a	163 a	140 a
Sakura + Avadex Xtra	118 + 2000	129 a	142 a	155 a	153 a

Table 2.2.l) brome grass density (plants/m^2) for selected treatments from 2013 and treatments applied at sowing 2014, letters denote differences between treatments at 95% probability from transformed data. Counted 16 June 2014.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site			
				HBLY	HBHY	LBLY	LBHY
Nil	0	Nil	0	250.4 a...	76.9 a...	14.8 a.	16.1 a.
Crusader	500	Nil	0	9.5 .bc.	0.4 ..cd	0.0 .b	1.1 .b
Sakura + Avadex Xtra	118 + 2000	Nil	0	21.6 .b..	14.5 .b..	0.0 .b	0.4 .b
Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	6.4 ..cd	3.8 .bc.	0.0 .b	0.4 .b
Intervix	500	Nil	0	3.0 ...d	0.4 ..cd	0.0 .b	0.4 .b
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	3.0 ..cd	0.9 ...d	0.0 .b	0.0 .b

Table 2.2.m) brome grass density (plants/m^2) counted 21 August 2014, letters denote differences between treatments at 95% probability from transformed data.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HBLY	HBHY	LBLY	LBHY
Nil	0	Nil	0	163.1 a....	71.2 a..	10.9 a.	29.3 a.
Nil	0	Intervix	500	76.8 a....	38.6 a..	9.6 a.	20.7 a.
Crusader	500	Nil	0	9.6 ..c..	1.3 ..c	2.0 .b	2.5 .b
Crusader	500	Crusader	500	4.5 ...d.	2.8 ..c	2.0 .b	1.3 .b
Sakura + Avadex Xtra	118 + 2000	Nil	0	21.5 .b...	8.8 .b.	1.3 .b	2.3 .b
Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	6.1 ..cd.	8.1 .b.	0.3 .b	1.5 .b
Intervix	500	Nil	0	2.8 ...d.	2.5 .bc	0.5 .b	4.0 .b
Intervix	500	Intervix	500	3.5 ...d.	2.0 ..c	0.3 .b	4.0 .b
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	4.0 ...d.	3.0 .bc	2.0 .b	1.3 .b
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	1.0 ....e	3.0 .bc	1.0 .b	1.5 .b

Table 2.2.n) brome grass head density (heads/m^2) counted 2 October 2014, letters denote differences between treatments at 95% probability from transformed data. Letters appear out of order for HBLY and HBHY due to data transformation, see appendix 2 and 3 for raw data.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HBLY	HBHY	LBLY	LBHY
Nil	0	Nil	0	233.1 a....	74.0 a...	13.7 a.	22.7 a.
Nil	0	Intervix	500	16.1 ..c..	1.4 ...d	0.0 .b	2.9 .b
Crusader	500	Nil	0	12.4 .bc..	1.1 ..cd	0.1 .b	1.0 .b
Crusader	500	Crusader	500	1.0 ...de	0.0 ...d	0.0 .b	0.0 .b
Sakura + Avadex Xtra	118 + 2000	Nil	0	31.0 .b...	12.6 .b..	0.2 .b	2.3 .b
Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	4.5 ..c..	3.8 ..c.	0.0 .b	0.5 .b
Intervix	500	Nil	0	6.3 ..c..	0.5 ...d	0.1 .b	0.5 .b
Intervix	500	Intervix	500	0.0 ....e	0.1 ...d	0.0 .b	1.9 .b
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	3.7 ..cd.	0.4 ...d	0.1 .b	1.1 .b
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	0.1 ....e	0.6 ...d	0.0 .b	0.0 .b

Table 2.2.o) Greenseeker NDVI measured 28 July 2014, letters denote differences between treatments at 95% probability.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HBLY	HBHY	LBLY	LBHY
Nil	0	Nil	0	0.62 a..	0.74 a...	0.54 a...	0.66 a.
Nil	0	Intervix	500	0.51 .b.	0.59 ..cd	0.50 ..c.	0.59 a.
Crusader	500	Nil	0	0.48 .bc	0.63 .bc.	0.53 ab..	0.62 a.
Crusader	500	Crusader	500	0.45 .bc	0.59 ..cd	0.49 ..c.	0.63 a.
Sakura + Avadex Xtra	118 + 2000	Nil	0	0.51 .b.	0.67 ab..	0.51 .bc.	0.62 a.
Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	0.43 ..c	0.60 .bcd	0.51 .bc.	0.61 a.
Intervix	500	Nil	0	0.47 .bc	0.56 ...d	0.50 ..c.	0.62 a.
Intervix	500	Intervix	500	0.43 ..c	0.59 ..cd	0.49 ..c.	0.62 a.
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	0.46 .bc	0.62 .bcd	0.50 ..c.	0.60 a.
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	0.42 ..c	0.57 ..cd	0.46 ...d	0.60 a.

Table 2.2.p) brome grass heads/plant. Calculated from plant counts on 21 August 2014 and head counts 2 October 2014.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HBLY	HBHY	LBLY	LBHY
Nil	0	Nil	0	1.4	1.0	1.3	0.8
Nil	0	Intervix	500	0.2	0.0	0.0	0.1
Crusader	500	Nil	0	1.3	0.2	0.0	0.4
Crusader	500	Crusader	500	0.2	0.0	0.0	0.0
Sakura + Avadex Xtra	118 + 2000	Nil	0	1.4	1.4	0.2	1.0
Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	0.7	0.5	0.0	0.3
Intervix	500	Nil	0	2.3	0.2	0.2	0.1
Intervix	500	Intervix	500	0.0	0.1	0.0	0.5
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	0.9	0.1	0.0	0.8
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	0.1	0.2	0.0	0.0

Table 2.2.q) wheat grain yield in 2014, letters denote differences between treatments at 95% probability.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HBLY	HBHY	LBLY	LBHY
Nil	0	Nil	0	1.83 .b	2.54 ...d	2.43 ...d	3.44 a
Nil	0	Intervix	500	2.32 a.	3.15 abc.	2.61 ab..	3.61 a
Crusader	500	Nil	0	2.45 a.	3.14 abc.	2.56 abc.	3.58 a
Crusader	500	Crusader	500	2.47 a.	2.99 ..c.	2.50 ..cd	3.61 a
Sakura + Avadex Xtra	118 + 2000	Nil	0	2.37 a.	3.07 .bc.	2.63 a...	3.52 a
Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	2.40 a.	3.22 ab..	2.59 abc.	3.64 a
Intervix	500	Nil	0	2.39 a.	3.25 ab..	2.53 .bcd	3.71 a
Intervix	500	Intervix	500	2.44 a.	3.32 a...	2.57 abc.	3.64 a
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	2.50 a.	3.28 ab..	2.64 a...	3.67 a
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	2.38 a.	3.34 a...	2.56 abc.	3.65 a

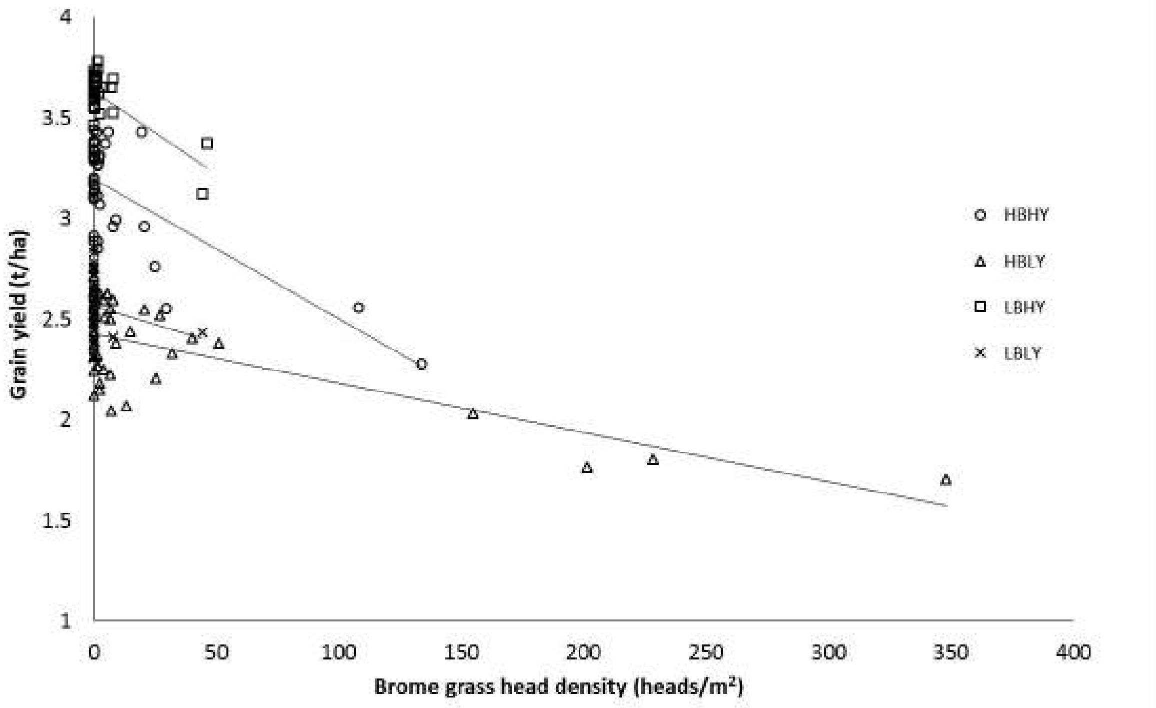

Figure 2.2.a) wheat grain yield in 2014 in response to brome grass head density. HBHY, y = -0.0069x + 3.19, R^2 = 0.429. HBLY, y = -0.0024x + 2.43, R^2 = 0.514, LBHY, y = -0.0082x + 3.63, R^2 = 0.336. LBLY, y = -0.0037x + 2.57, R^2 = 0.032.

Table 2.2.r) 2014 grain quality parameters bulked across reps

Site	2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Protein %	Test Weight kg/hl	Screenings % < 2.0mm
HBLY	Nil	0	Nil	0	12.4	77.3	2.9
	Nil	0	Intervix	500	11.2	80.2	2.5
	Crusader	500	Nil	0	12.1	79.3	2.7
	Crusader	500	Crusader	500	12	79.6	2.5
	Sakura + Avadex Xtra	118 + 2000	Nil	0	12.4	79.3	2.8
	Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	12.3	79.1	2.3
	Intervix	500	Nil	0	11.3	80	2.3
	Intervix	500	Intervix	500	12	78.7	2.6
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	12.1	79.6	2.2
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 200 + 500	11.9	79.1	2.9
HBHY	Nil	0	Nil	0	12.8	77.1	3.8
	Nil	0	Intervix	500	9.8	80	3.1
	Crusader	500	Nil	0	11.1	78.5	3.8
	Crusader	500	Crusader	500	10.4	79	3.6
	Sakura + Avadex Xtra	118 + 2000	Nil	0	12.2	78.3	3.6
	Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	10.8	79.2	3.4
	Intervix	500	Nil	0	10	80.4	2.6
	Intervix	500	Intervix	500	10.9	79.5	2.8
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	11.1	80.2	2.8
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 200 + 500	10	80.1	2.8
LBLY	Nil	0	Nil	0	12	81.1	2.5
	Nil	0	Intervix	500	12.2	80.7	3
	Crusader	500	Nil	0	12.1	80.3	2.8
	Crusader	500	Crusader	500	12.1	80.1	3
	Sakura + Avadex Xtra	118 + 2000	Nil	0	12.4	78.8	2.4
	Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	12	79.6	2.8
	Intervix	500	Nil	0	11.6	80.6	2.8
	Intervix	500	Intervix	500	11.8	80.2	2.6
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	11.8	80.8	2.5
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 200 + 500	11.8	81.4	2.7
LBHY	Nil	0	Nil	0	13.3	77.1	3.8
	Nil	0	Intervix	500	10.4	79.8	2.7
	Crusader	500	Nil	0	11.4	79.6	3.3
	Crusader	500	Crusader	500	12.4	77.6	3.5
	Sakura + Avadex Xtra	118 + 2000	Nil	0	12.2	76.5	3.7
	Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	11.4	78.3	3.2
	Intervix	500	Nil	0	10.3	79.8	2.6
	Intervix	500	Intervix	500	11.8	77.3	3
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	10	80	3.1
	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 200 + 500	10.8	76.4	3.4

Table 2.2.s) Cumulative gross margins ($/ha) calculated for each treatment over two seasons. Kord indicates gross margin calculated from measured treatment yields in these trials. Mace or Kord indicates where non Clearfield treatment was applied yield (increased by 9.6%) and gross margin adjusted to reflect returns from Mace wheat. Calculations based on APW wheat price of $270/t and all other variable costs being fixed at $292/ha/yr.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Cumulative herbicide cost ($/ha)	HBLY Kord	HBLY Mace or Kord	HBHY Kord	HBHY Mace or Kord	LBLY Kord	LBLY Mace or Kord	LBHY Kord	LBHY Mace or Kord
Nil	0	Nil	0	0	680 ....ef	801 ...d.	964 ...d	1112 ...d	912 .bc..	1055 .b..	1380 .bc.	1569 ab..
Nil	0	Intervix	500	20	789 .bcd..	863 ..cd.	1181 abc.	1270 abc.	961 ab...	1043 .b..	1452 ab..	1556 ab..
Crusader	500	Nil	0	35	890 a.....	1035 a....	1160 abc.	1331 a...	960 ab...	1112 a...	1412 abc.	1607 a...
Crusader	500	Crusader	500	70	858 abc...	1003 ab...	1091 ..c.	1259 abc.	898 ..c..	1047 .b..	1387 abc.	1583 a...
Sakura + Avadex Xtra	118 + 2000	Nil	0	58	773 ..cde.	908 .bc..	1091 ..c.	1257 abc.	886 ..c..	1033 .b..	1337 ..cd	1526 abc.
Sakura + Avadex Xtra	118 + 2000	Sakura + Avadex Xtra	118 + 2000	116	700 ...def	834 ..cd.	1097 ..c.	1270 abc.	816 ...d.	962 ..c.	1352 .bcd	1549 ab..
Intervix	500	Nil	0	20	866 abc...	928 .bc..	1237 a...	1322 ab..	971 a....	1037 .b..	1487 a...	1583 a...
Intervix	500	Intervix	500	40	869 ab....	869 ..cd.	1225 ab..	1225 .bc.	954 ab...	954 ..c.	1423 abc.	1423 ..c.
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Nil	0	78	785 .bcd..	849 ..cd.	1137 .bc.	1222 ..c.	865 ..cd.	934 ..c.	1367 .bcd	1463 .bc.
Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	Sakura + Avadex Xtra + Intervix	118 + 2000 + 500	156	673 .....f	674 ....e	1110 ..c.	1110 ...d	753 ....e	753 ...d	1269 ...d	1269 ...d

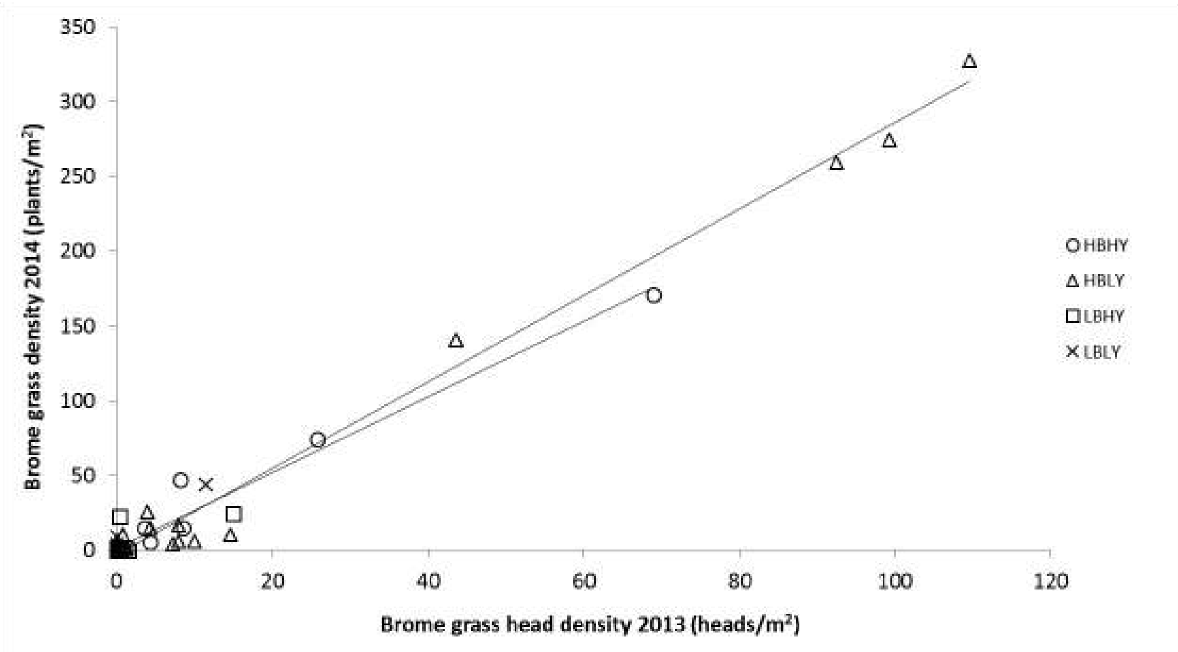

Figure 2.2.b) Brome grass plant density 2014 in response to brome grass head density 2013. HBHY, y = 2.53x + 1.27, R^2 = 0.97. HBLY, y = 2.89x - 2.89, R^2 = 0.99.

Partial budget sensitivity analysis

Weed control effects on gross margin are sensitive to herbicide price, herbicide efficacy, grain price, weed density and crop yield loss associated with the weed in question. To obtain a positive return from brome grass control at HBLY brome grass head density needed to be greater than 30 heads/m^2 for herbicides that cost $20/ha or more. This is in contrast with the high yield sites HBHY and LBHY where brome grass control produced a positive return at densities as low as 10 heads/m^2, depending on herbicide cost and efficacy (table 2.2.t, table 2.2.u and table 2.2.v). This is calculated from yield responses over two years.

In the presence of weeds, where two herbicide products are equivalent in price the product with the highest efficacy always generates the highest return. Where two herbicide products provide equivalent efficacy and the cost differs, the product with the lowest cost always generates the highest return. Crusader provided 90% efficacy on average over two seasons at a cost of $35/ha/year. For this herbicide at HBLY, HBHY and LBHY the threshold density for a positive return is 30, 10 and 9 brome heads/m^2, respectively.

Table 2.2.t) Partial budget sensitivity over two wheat cropping seasons in response to herbicide price, herbicide efficacy and brome grass head density at HBLY, where wheat yield (y) in response to brome head density (x) is, y = -0.0024x + 2.43. Grey shading highlights positive a return.

Brome head density	Efficacy = 70%					Efficacy = 100%				
(heads/m^2)	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha
1	-19	-34	-49	-64	-79	-19	-34	-49	-64	-79
10	-11	-26	-41	-56	-71	-7	-22	-37	-52	-67
30	7	-8	-23	-38	-53	19	4	-11	-26	-41
50	25	10	-5	-20	-35	45	30	15	0	-15
100	71	56	41	26	11	110	95	80	65	50
300	252	237	222	207	192	369	354	339	324	309

Table 2.2.u) Partial budget sensitivity over two wheat cropping seasons in response to herbicide price, herbicide efficacy and brome grass head density at HBHY, where wheat yield (y) in response to brome head density (x) is, y = -0.0069x + 3.19. Grey shading highlights positive return.

Brome head density	Efficacy = 70%					Efficacy = 100%				
(heads/m^2)	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha
1	-17	-32	-47	-62	-77	-16	-31	-46	-61	-76
10	6	-9	-24	-39	-54	17	2	-13	-28	-43
30	58	43	28	13	-2	92	77	62	47	32
50	110	95	80	65	50	166	151	136	121	106
100	241	226	211	196	181	353	338	323	308	293
300	762	747	732	717	702	1098	1083	1068	1053	1038

Table 2.2.v) Partial budget sensitivity over two wheat cropping seasons in response to herbicide price, herbicide efficacy and brome grass head density at LBHY, where wheat yield (y) in response to brome head density (x) is, y = -0.0082x + 3.63. Grey shading highlights positive return.

Brome head density	Efficacy = 70%					Efficacy = 100%				
(heads/m^2)	\$20/ha	\$35/ha	\$50/ha	\$65/ha	\$80/ha	\$20/ha	\$35/ha	\$50/ha	\$65/ha	\$80/ha
1	-17	-32	-47	-62	-77	-16	-31	-46	-61	-76
10	11	-4	-19	-34	-49	24	9	-6	-21	-36
30	73	58	43	28	13	113	98	83	68	53
50	135	120	105	90	75	201	186	171	156	141
100	290	275	260	245	230	423	408	393	378	363
300	910	895	880	865	850	1308	1293	1278	1263	1248

2.3 Discussion

Brome grass control decisions based on the best economic outcome in this paddock for the 2013 and 2014 seasons, would have been to grow the highest yielding available wheat variety and a uniform application of Crusader at 500ml/ha to the whole paddock in 2013 and no herbicide application in 2014, regardless of brome grass density (table 2.2.s). However, where brome grass population control alone is considered, a case for site specific management can be made in this paddock (table 2.2.n). At the low brome sites all herbicide treatments provided equivalent control, therefore the highest gross margin treatment of Crusader applied in 2013 would be the treatment of choice. At the HBHY site treatments including Intervix and Crusader provided higher efficacy, though there was no significant difference between one or two years application. Therefore, the highest gross margin treatment of Crusader applied in 2013 would again be the treatment of choice. At the HBLY site treatments including Intervix and Crusader provided higher efficacy and treatments with consecutive years of application were significantly better than treatments with application in 2013 only. Of these treatments Crusader applied in consecutive years had the highest gross margin. Therefore, based on optimising weed control whilst also optimising gross margin the best treatment would have been to treat the entire paddock with a uniform application of Crusader in 2013 and then treat only the highest density patches with Crusader again in 2014. This does not consider the long term management of herbicide resistance.

The relationship between brome grass head density and grain yield loss varied between zones (figure 2.2.a). In particular, yield loss in response to brome grass was higher in the high yield zones compared with HBLY. It is assumed that all zones received the same rainfall, sunlight and all zones received the same fertiliser inputs yet the low yield zones consistently yielded less. This indicates a lower water use efficiency and a less efficient use of other resources. The resources made available for crop use through removal of brome grass competition are also used less efficiently. Yield increased by 2.4kg/ha for each brome grass head removed at HBLY, whereas yield increased by 6.9 and 8.2kg/ha at HBHY and LBHY, respectively. This has implications for the economics of weed control in each of these zones and explains why consecutive years of weed control did not produce the best economic outcome at HBLY, despite providing significantly better weed control. The reduction in brome grass head density from the second herbicide application did not generate a yield response large enough to cover the additional herbicide cost. This is highlighted in the sensitivity analysis where brome grass densities of 30 heads/m^2 or more are needed to generate a positive return, even from a lower cost herbicide (table 2.2.t).

The economic benefit of site specific weed management cannot exceed the cost of the herbicide used, unless the herbicide has a phytotoxic effect on the crop that affects yield. The ability to target herbicide treatments site specifically may be the impetus for growers to use more expensive and more efficacious herbicide treatments on targeted areas that they would not consider using on a whole paddock basis. This should lead to better weed control outcomes, higher overall grain yields and higher gross income. However, all of these benefits could be accrued by using the high cost and high efficacy treatment across the whole paddock, therefore the economic benefit should only be calculated on the herbicide saving in the regions where the herbicide is not applied.

Sakura + Avadex Xtra is a treatment that had phytotoxic effects on the crop, reducing grain yields in 2013 (table 2.2.i). At $58/ha it is the most expensive herbicide mixture used in the trial, but provided the lowest efficacy ranging from 70-87% (table 2.2.n). Due to these three factors this treatment performed poorly in terms of gross margins. However, in a more complex scenario where brome grass exists in a paddock in a mixed population with ryegrass, Sakura + Avadex Xtra is the only treatment used in this trial that would be expected to have high efficacy on ryegrass. Therefore in this scenario the use of Sakura + Avadex Xtra to target both weeds may be warranted. The use of this herbicide mix is also warranted when considering herbicide resistance management.

3. Ryegrass control in wheat at Urania - 2013/2014

3.1 Methods

Four paddocks on the property of Ashley and Louise Wakefield near Urania are now farmed as one paddock (paddock 218CDEF, Figure 3.1.a). Recent cropping history for the four paddocks is the same, however historically they have been farmed separately and as such have different yield map histories. In 2012 the paddock was cropped to canola and in July 2012 the paddock was mapped with a Topcon Crop Spec sensor and a map of Crop Spec index S1 was produced (Figure 3.1.b). It was expected that the image was indicative of where ryegrass patches were present in the paddock, however on inspection of the paddock in autumn 2013 the Crop Spec S1 was poorly correlated with ryegrass density, based on ryegrass residue in the stubble. Therefore, sites for high and low ryegrass density were identified based on the levels of ryegrass residue observed in the stubble.

Several other data layers that show variation in soils have also been mapped. These include gamma radiometrics total count (Figure 3.1.c), dual EM38 deep (Figure 3.1.d) and dual EM38 shallow (Figure 3.1.e). Several years of yield maps are available for each paddock. The mean of the cereal yield maps is shown in Figure 3.1.f, however they cannot be compared between paddocks due to different cropping histories and some yield maps being excluded due to errors in the mapping process. Paddock 218C is excluded due to insufficient quality yield maps. However, comparison of the mean cereal yield map with the gamma radiometrics total count indicates that there is a consistent relationship across paddocks, where average cereal yield increases with gamma total count value (Figure 3.1.g). Given this consistent relationship, both the mean cereal yield maps and the gamma radiometric total count maps were used to identify sites of differing yield potential.

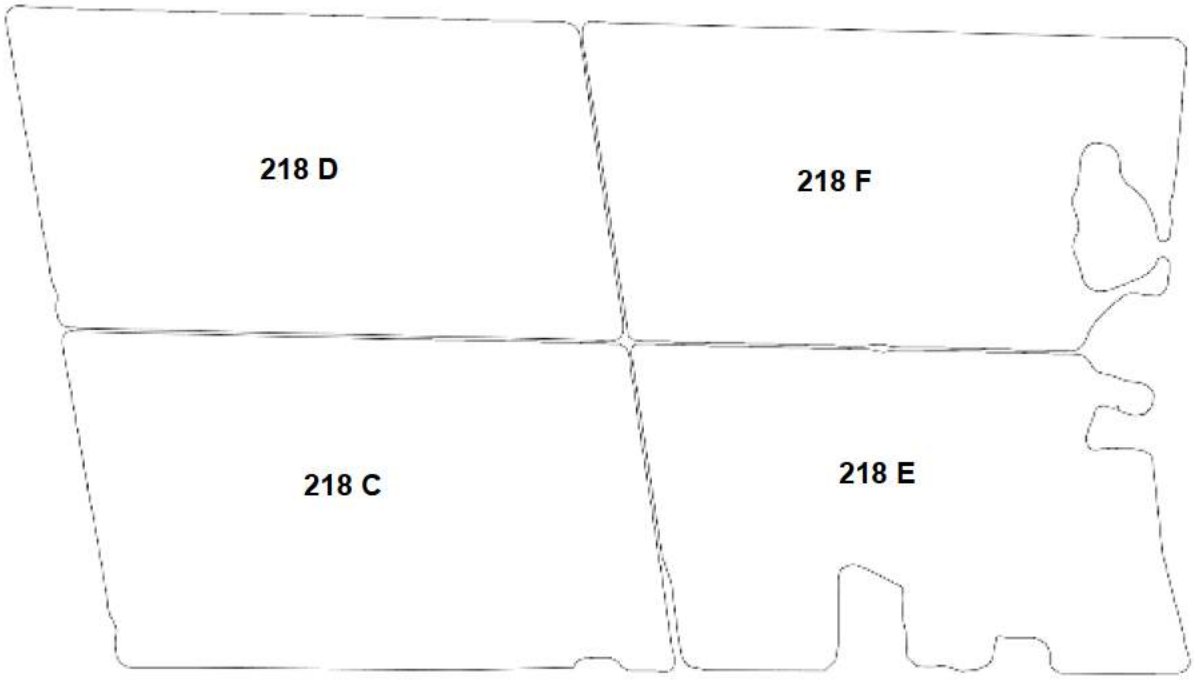

Figure 3.1.a) the original layout of paddocks 218 C, D, E & F used in this study.

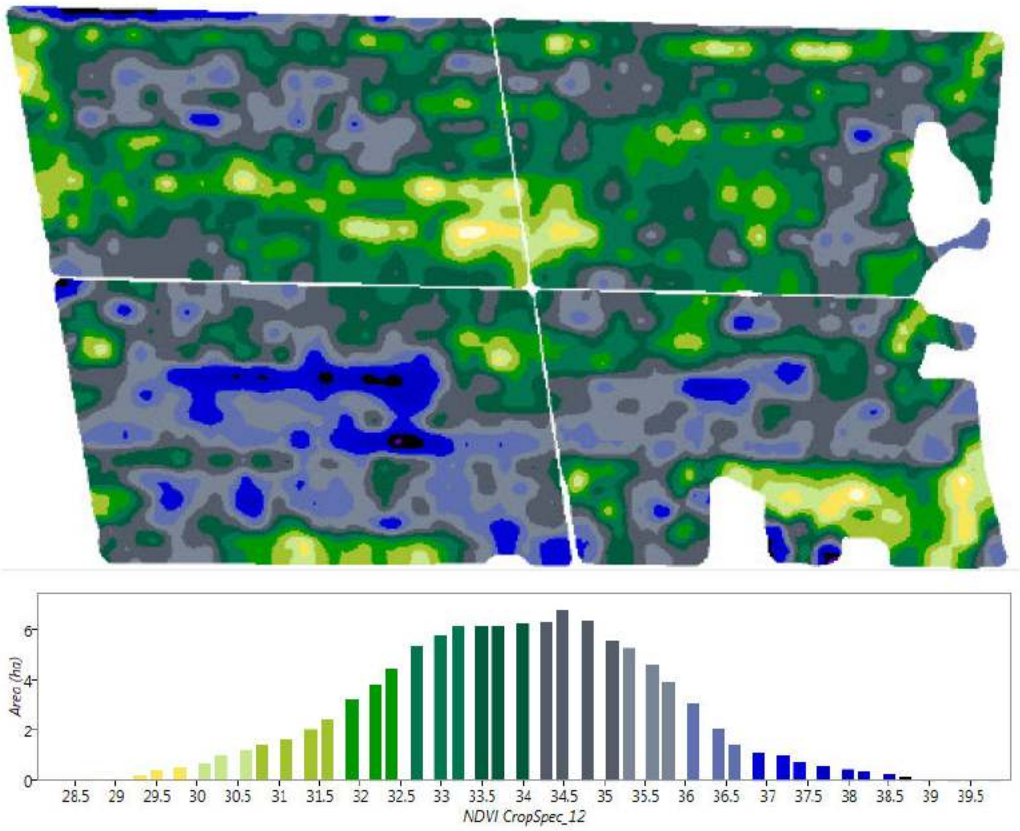

Figure 3.1.b) Crop Spec index S1 mapped in July 2012.

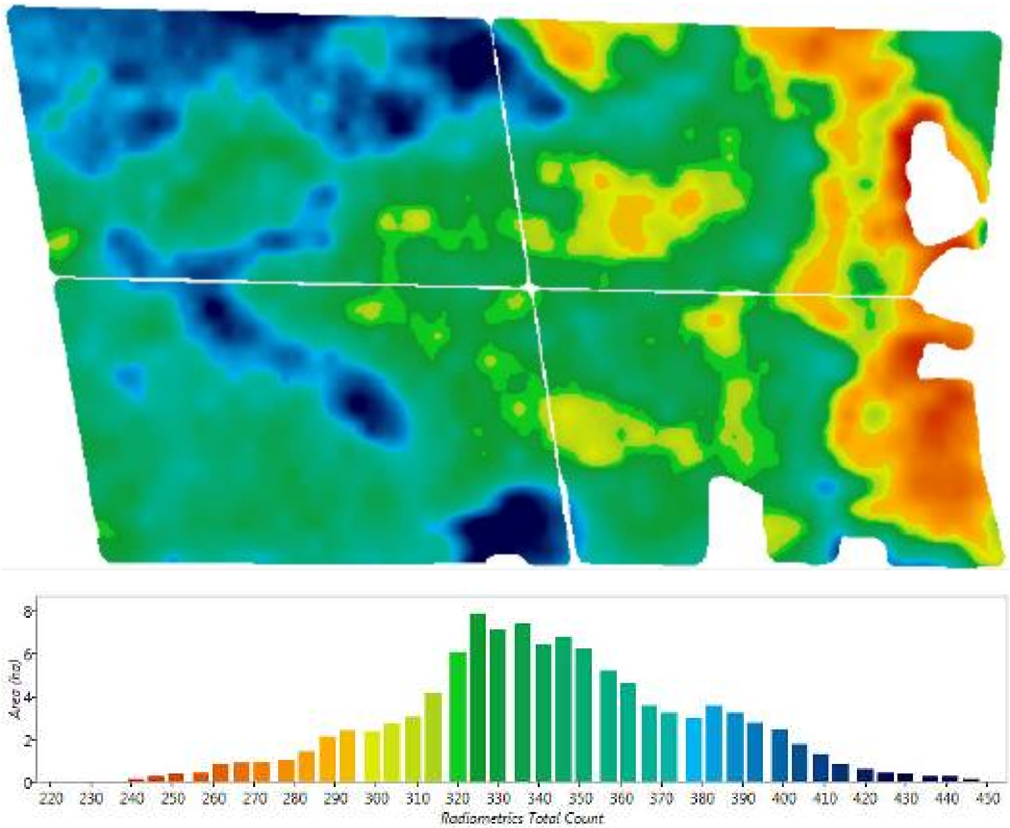

Figure 3.1.c) Gamma Radiometrics total count.

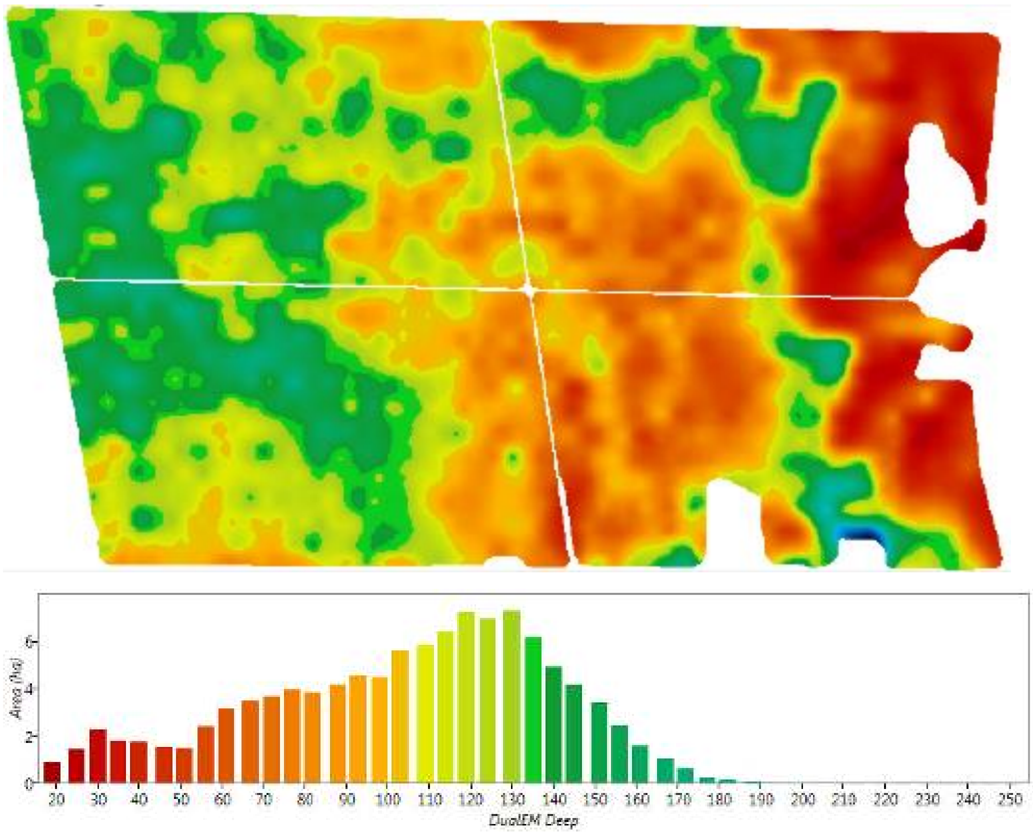

Figure 3.1.d) Dual EM deep.

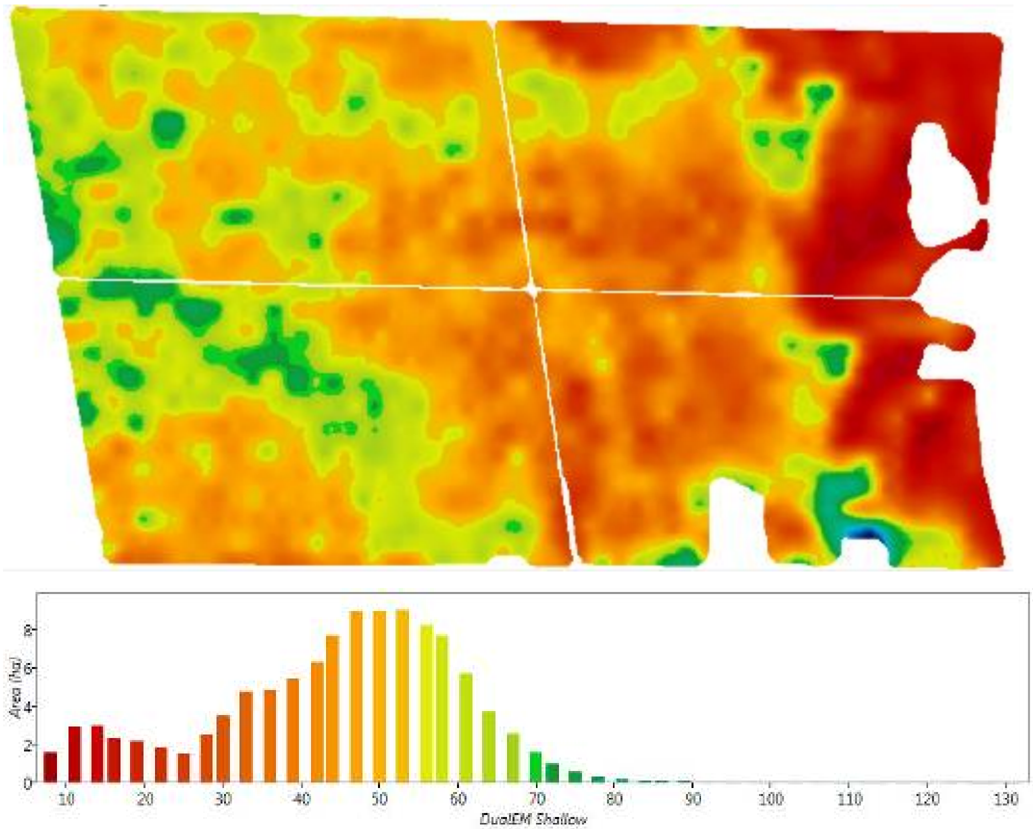

Figure 3.1.e) Dual EM shallow.

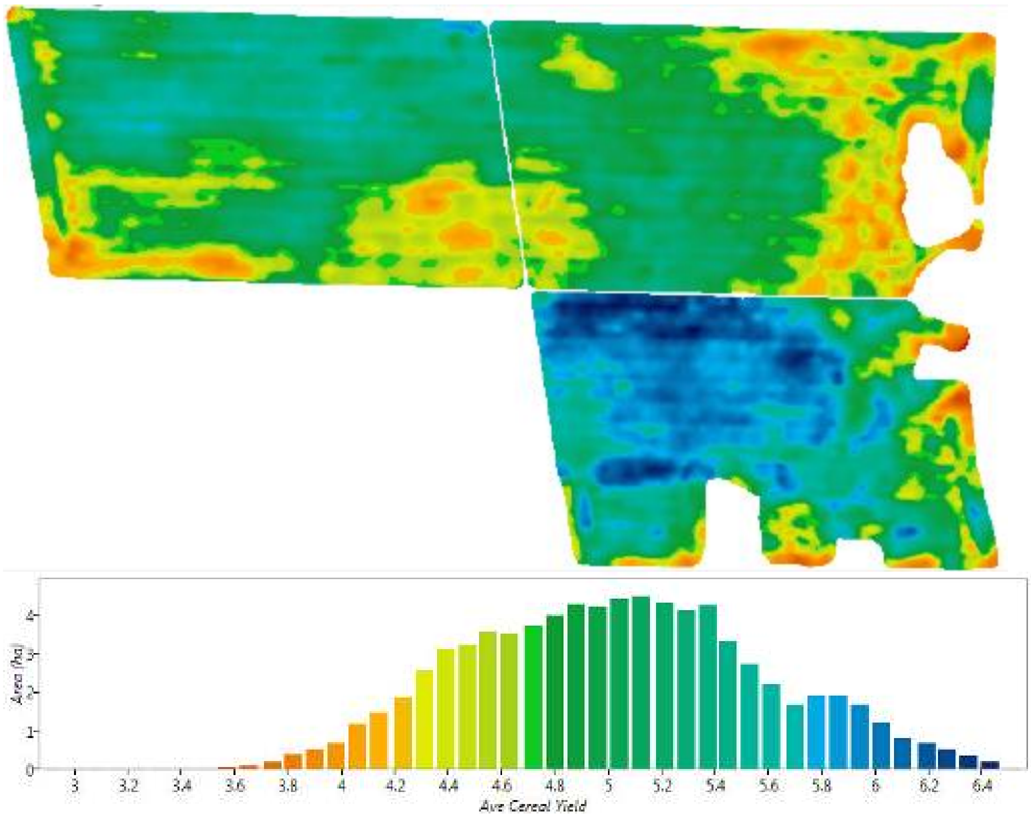

Figure 3.1.f) Average cereal yield in 218 D, E & F, not all the same years and crops have been used, so differences within paddocks are valid, but between paddocks is not.

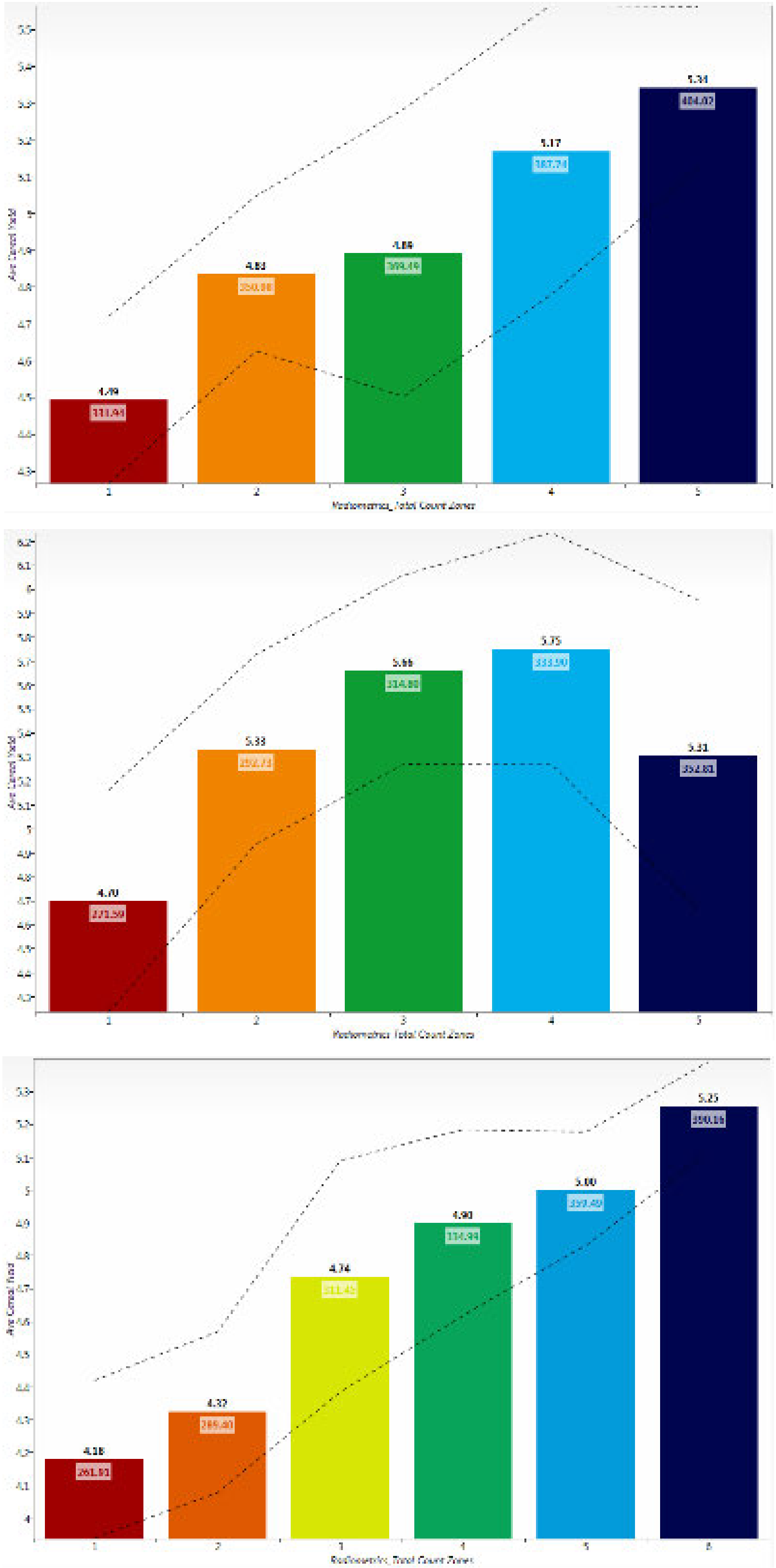

Figure 3.1.g) The relationship between gamma radiometrics total count and mean cereal yield in 218 D (top), 218 E (middle) and 218 F (bottom). Dotted line represents ±1 standard deviation in yield.

The mean cereal yield data, gamma radiometrics total count data and the observation of ryegrass residues in the canola stubble were used to identify four trial sites. These sites were a factorial of high and low historical yield and high and low ryegrass density. One site was selected in each of these zones as the location for a small plot trial to assess the efficacy of ryegrass control and the yield response this generated within each zone (figure 3.1.h).

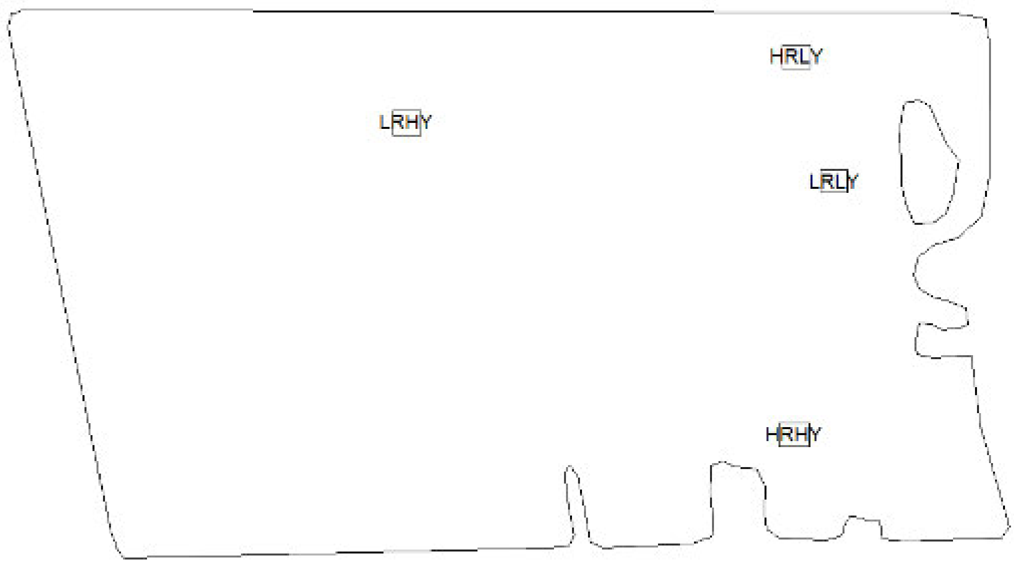

Figure 3.1.h) Trial site locations in paddock 218CDEF.

The following acronyms are used in reference to each site

- HRLY - high ryegrass density and low yield
- HRHY - high ryegrass density and high yield
- LRLY - low ryegrass density and low yield
- LRHY - low ryegrass density and high yield

At each site a ten treatment trial was implemented (Table 3.1.a). The herbicide treatments were selected with the aim of achieving a range of ryegrass control from 0-100%. The trial design was a randomised complete block design with four replicates. Prior to the trial period the 2012 crop was canola, where selective Group A herbicide application and desiccation with glyphosate is expected to have provided close to 100% ryegrass control. In 2013 the trial was sown on 23 May with Gladius wheat using the SARDI Clare trial seeder with knife points and press wheels on 225 mm row spacing, the plot dimensions were 12m * 1.4m on 1.8m centers. In 2014 the trial was inter-row sown with Espada wheat 21 May and the same seeding equipment was used. In both years 100kg DAP/ha treated with flutriafol was applied with the seed.

Table 3.1.a: Urania ryegrass control herbicide treatment list.

Treatment	2013 Treatment Herbicide and timing	Rate (mL or g/ha)	2014 Treatment Herbicide and timing	Rate (mL or g/ha)	Total herbicide cost ($/ha)
1A1B	Nil	0	Nil	0	0
2A	Trifluralin IBS	1700	Nil	0	11
2B	Trifluralin IBS	1700	Trifluralin IBS	1700	22
3A	Boxer Gold IBS	2500	Nil	0	39
3B	Boxer Gold IBS	2500	Boxer Gold IBS	2500	78
4A	Sakura IBS + Boxer Gold Post	118 + 2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	147
4B	Sakura IBS + Boxer Gold Post	118 + 2500	Sakura IBS	118	115
5A	Sakura IBS + Boxer Gold Post	118 + 2500	Nil	0	77
5B	Sakura IBS + Boxer Gold Post	118 + 2500	Sakura IBS + Boxer Gold Post	118 + 2500	154

The incorporated by sowing (IBS) treatments were applied immediately prior to sowing in both years, the post emergent Boxer Gold treatments in 2013 were applied on 5 June and in 2014 they were applied 19 June. In 2013 wheat and ryegrass plant counts were conducted on 16 July, Greenseeker measurements on 9 August, ryegrass head counts on 16 October. The 2013 trials were harvested for wheat grain yield on 13 December and grain quality was measured including test weight, protein and screenings. In 2014 wheat plant counts were conducted 19 June, ryegrass plant counts and Greenseeker measurements were conducted on 29 July, and ryegrass head counts on 22 October. The trials were harvested for wheat grain yield 26 November and grain quality was tested as in 2013.

Ryegrass plant and head counts were transformed by calculating the log of the count plus one. This was performed to improve the distribution of residuals for the data. All data were analysed by ANOVA in the software package Genstat.

3.2 Results

Soil test results for samples collected prior to sowing 2013

Paddock site	Depth	Colwell P	PBI	Colwell K	Organic Carbon	Soil N	Sulphur	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	CEC	ESP (sodicity)	Boron Hot (CaCl2)
		mg/Kg		mg/Kg	%	kg/ha	kg/ha	dS/m	pH	pH	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%	mg/kg
HRLY	0-10	29	188	631	2.25			0.22	7.8	8.6	22.8	3.7	1.6	0.2	28.4	0.8	
HRHY		32	173	824	2.31			0.20	7.8	8.5	24.8	3.7	2.2	0.3	31.1	0.9	
LRLY		40	151	819	2.94			0.22	7.7	8.3	26.4	2.5	2.0	0.3	31.2	0.9	
LRHY		29	186	1176	2.51			0.29	7.7	8.3	29.6	4.8	2.9	0.5	37.8	1.3	
HRLY	0-30					90	50	0.20	7.9	8.6	20.2	4.4	1.2	0.4	26.2	1.4	3.70
HRHY						51	80	0.36	8	9	19.1	6.0	1.5	2.7	29.3	9.1	10.64
LRLY						66	43	0.18	7.7	8.3	27.4	2.5	1.0	0.3	31.2	1.0	2.73
LRHY						70	57	0.29	7.8	8.6	27.4	6.4	1.5	1.2	36.4	3.4	6.26
HRLY	30-60					59	76	0.20	8.3	9.1	12.6	7.8	0.5	0.9	21.8	4.0	8.13
HRHY						16	143	0.66	8.4	9.4	8.9	9.0	0.8	5.0	23.8	21.2	21.15
LRLY		Maximum soil depth, 30cm															
LRHY						27	65	0.71	8.3	9.3	12.7	12.6	0.9	7.7	34.0	22.7	23.92

Comments: while not apparent in the soil chemistry results, the main soil constraint at the low yielding sites was soil depth due to the presence of shallow rock. This is evident from LRLY, where the probe could not reach the 30-60cm depth.

2013

How well did the sites fit their description?

Ryegrass density did not match the description at the HRHY and LRLY site in that the densities recorded on 16 July 2013 were 4 plants/m^2 and 21 plants/m^2 in the nil treatments, respectively (Table 3.2.c). This highlights the difficulty in acquiring an accurate map for weed management. The grain yield matched the site description at all sites. This meant that instead of a combination of yield and ryegrass density producing 4 different sites in effect there were two HRLY and two LRHY sites, though the high density sites were not extreme. For the purpose of this report the sites will be referred to as their original ID's.

Low levels of ryegrass were present prior to sowing in 2013 at three of the four sites with an average density of 2.4 plants/m^2 (table 3.2.a). The exception was the HRLY site with a density of 11.7 plants/m^2.

Wheat plant establishment was not affected by herbicide treatment at any site (table 3.2.b) with average densities ranging from 133 plants/m^2 to 152 plants/m^2. However reduced plant vigor was noticed in the Sakura + Boxer Gold treatment at all sites and this is supported by reduced NDVI recorded 9 August 2013. The NDVI differences may have been inflated at some sites by the differences in ryegrass density but it also occurs at the low density sites where there was little difference in ryegrass population (table 3.2.d).

Effect of herbicide treatments on ryegrass population

Ryegrass control with trifluralin was poor and not significantly better than nil at any site (Table 3.2.c). This was not unexpected as some trifluralin resistance was known to exist in this paddock. Boxer Gold IBS significantly reduced the ryegrass density as recorded on 16 July 2013 at the HRLY and HRHY sites by 65% and 25%, respectively. However at the LRLY and LRHY sites ryegrass control with Boxer Gold was not significantly better than nil. As expected the Sakura IBS + Boxer Gold Post treatment produced the lowest ryegrass densities which were significantly lower than all other treatments at all sites.

Ryegrass head density was generally more affected by herbicide treatment than ryegrass plant density, however trifluralin did not significantly reduce head density at any site (table 3.2.e). Boxergold IBS significantly reduced ryegrass head density at all sites with control ranging from 40% to 85% and the Sakura IBS + Boxer Gold Post treatment produced 89% to 95% control and was significantly better than the Boxer Gold IBS treatment at every site.

Grain yield was affected more by phytotoxic effects of herbicide treatments than ryegrass density (table 3.2.f). Boxer Gold IBS treatment was the highest yielding treatment at each site, though it was never significantly greater than the control. At three of the four sites the Sakura IBS + Boxer Gold Post treatment was the lowest yielding treatment, and yielded significantly less than the Boxer Gold IBS treatment despite providing better weed control.

Aspects of wheat grain quality including test weight and screenings were affected at some sites (table 3.3.g). Protein was not significantly different within the same site.

Table 3.2.a) Pre sowing ryegrass density (plants/m^2) at each site, 18 May 2013.

Treatment	Site			
	HRLY	HRHY	LRLY	LRHY
Nil	11.7	3.3	2.7	1.2

Table 3.2.b) Wheat plant counts (plants/m^2), 16 July 2013. Letters denote differences between treatments at 95% probability.

2013 Herbicide	Rate	Site			
	(mL or g)	HRLY	HRHY	LRLY	LRHY
Nil	0	130 a	157 a	153 a	159 a
Trifluralin IBS	1700	136 a	135 a	149 a	150 a
Boxer Gold IBS	2500	134 a	128 a	155 a	154 a
Sakura IBS + Boxer Gold Post	118 + 2000	132 a	138 a	139 a	144 a

Table 3.2.c) Ryegrass plant density (plants/m^2) at each site, 16 July 2013. Letters denote differences between treatments at 95% probability from transformed data.

2013 Herbicide	Rate	Site			
	(mL or g)	HRLY	HRHY	LRLY	LRHY
Nil	0	31.4 a..	4.1 a..	21.1 a.	4.1 a.
Trifluralin IBS	1700	24.5 a..	4.1 a..	18.4 a.	5.5 a.
Boxer Gold IBS	2500	11.1 .b.	3.4 .b.	11.6 a.	3.2 a.
Sakura IBS + Boxer Gold Post	118 + 2000	2.0 ..c	3.0 ..c	2.3 .b	0.7 .b

Table 3.2.d) Greenseeker NDVI measured 9 August 2013. Letters denote differences between treatments at 95% probability.

2013 Herbicide	Rate	Site			
	(mL or g)	HRLY	HRHY	LRLY	LRHY
Nil	0	0.51 a...	0.63 a.	0.63 a.	0.60 a.
Trifluralin IBS	1700	0.48 .b..	0.60 a.	0.61 a.	0.57 a.
Boxer Gold IBS	2500	0.44 ..c.	0.60 a.	0.59 a.	0.57 a.
Sakura IBS + Boxer Gold Post	118 + 2000	0.33 ...d	0.43 .b	0.46 .b	0.44 .b

Table 3.2.e) Ryegrass head density (heads/m^2), 16 October 2013. Letters denote differences between treatments at 95% probability from transformed data.

2013 Herbicide	Rate (mL or g)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	75.0 a..	20.5 a..	66.9 a..	9.3 a..
Trifluralin IBS	1700	63.5 a..	11.6 a..	83.1 a..	7.1 a..
Boxer Gold IBS	2500	19.2 .b.	3.2 .b.	39.9 .b.	3.9 .b.
Sakura IBS + Boxer Gold Post	118 + 2000	5.0 ..c	1.0 ..c	6.0 ..c	1.0 ..c

Table 3.2.f) 2013 Grain yield (t/ha). Letters denote differences between treatments at 95% probability.

2013 Herbicide	Rate (mL or g)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	3.89 a.	5.28 ab..	4.22 ab.	4.79 a.
Trifluralin IBS	1700	3.95 a..	5.16 .b.	3.88 .bc	4.81 a.
Boxer Gold IBS	2500	4.03 a..	5.30 a...	4.32 a..	4.84 a.
Sakura IBS + Boxer Gold Post	118 + 2000	3.67 .b	4.96 ..c	3.90 .bc	4.61 .b

Table 3.2.g) 2013 Grain quality including protein, test weight and screenings (<2.0mm). Letters denote different levels of significance within the same site LSD 0.05.

Site	2013 Herbicide	Rate (mL or g)	Protein %	Test Weight kg/hL	Screenings % < 2.0mm
HRLY	Nil	0	12.1 a	75.3 ..c	2.6 a
	Trifluralin IBS	1700	11.7 a	77.0 ab.	2.3 a
	Boxer Gold IBS	2500	12.0 a	76.5 .b.	2.3 a
	Sakura IBS + Boxer Gold Post	118 + 2000	11.9 a	77.4 ab.	2.5 a
	LSD (0.05)		ns	1.0	ns
HRHY	Nil	0	11.5 a	77.1 ..c	1.5 a
	Trifluralin IBS	1700	11.5 a	77.4 .bc	1.6 a
	Boxer Gold IBS	2500	11.3 a	77.6 .bc	1.6 a
	Sakura IBS + Boxer Gold Post	118 + 2000	11.7 a	78.1 ab.	1.8 a
	LSD (0.05)		ns	0.7	ns
LRLY	Nil	0	12.4 a	73.0 a	2.8 ..c
	Trifluralin IBS	1700	12.9 a	72.2 a	3.1 .bc
	Boxer Gold IBS	2500	12.7 a	73.7 a	2.9 .bc
	Sakura IBS + Boxer Gold Post	118 + 2000	12.9 a	74.5 a	3.6 ab.
	LSD (0.05)		ns	ns	0.6
LRHY	Nil	0	11.9 a	76.3 ab	2.4 ab
	Trifluralin IBS	1700	11.8 a	76.7 ab	2.3 ab
	Boxer Gold IBS	2500	12.0 a	76.0 .b	2.2 .b
	Sakura IBS + Boxer Gold Post	118 + 2000	11.8 a	77.0 a.	2.6 a.
	LSD (0.05)		ns	0.9	0.4

2014

Wheat population

In 2014 wheat plant density was similar for all herbicide treatments (table 3.2.h). However it was noted that vigor was reduced in plots that were treated with Sakura in 2014. The Greenseeker NDVI measurements support this, whereby comparing the treatments 2013 Sakura + Boxer Gold followed by 2014 Nil, and 2013 Sakura + Boxer Gold followed by 2014 Sakura, the average NDVI value across all four sites was reduced from 0.55 to 0.47 respectively (table 3.2.j). It is unlikely that ryegrass plant density had much effect on these values, as the numbers were low in these treatments, particularly at HRHY where ryegrass density was below 3 plants/m^2.

Ryegrass population

Two years of trifluralin application did not significantly reduce ryegrass plant density compared to the nil at any site (table 3.2.i). Sakura + Boxer Gold applied only in 2013 had significantly lower ryegrass density than the control at 3 of 4 sites in 2014, whereas Boxer Gold applied only in 2013 had significantly lower ryegrass density at 2 of 4 sites. Boxer Gold applied in consecutive seasons compared to only in 2013 significantly reduced ryegrass plant numbers at 1 site only (LRLY). At the higher density sites (HRLY & LRLY) following Sakura IBS + Boxer Gold post in 2013 with another herbicide treatment in 2014 significantly reduced ryegrass density compared with following with no herbicide in 2014.

Ryegrass head numbers

Trifluralin did not significantly reduce head number compared to the nil with either one or two years of application (table 3.2.k). One application of Boxer Gold in 2013 followed by Nil in 2014 maintained significantly lower head numbers than two years of nil at only one site (HRLY). One application of Sakura IBS + Boxer Gold Post in 2013 followed by Nil in 2014 maintained significantly lower head numbers in 2014 than two years of nil at three of the four sites.

In contrast to plant density, consecutive applications of Boxer Gold in 2013 and 2014 significantly reduced ryegrass head number compared with Boxer Gold applied in 2013 only, at all sites. Likewise, Sakura IBS + Boxer Gold post applied in 2013 and followed in 2014 with another herbicide reduced ryegrass head number relative to Sakura IBS + Boxer Gold post applied in 2013 only, though these differences were only significant at higher density ryegrass sites (LRLY, HRLY).

Ryegrass head density in 2013 was positively correlated with ryegrass head density in 2014 at all sites (figure 3.2.a). The slope of these linear regressions was less than 0.4 for all sites, indicating lower ryegrass head densities in 2014 than 2013, even though none of the plots used in generating this regression received a herbicide treatment in 2014.

Grain yield and quality

Grain yield was not responsive to herbicide treatment at 3 of the 4 sites in 2014 (table 3.2.l). At the HRHY site where ryegrass levels were low treatments with Sakura applied in 2014 were the lowest yielding treatments. Grain quality testing was conducted on samples bulked across the 4 replicates (table 3.2.m). The most significant factor affecting these results appeared to be site.

Gross margin analysis

No treatments generated a gross margin better than the control over the two seasons (table 3.2.n). Sakura + Boxer Gold reduced yields in 2013, therefore given its high cost these treatments generated the lowest gross margins at all sites, despite providing the best weed control. Boxer Gold applied either once or in consecutive seasons generated gross margins equivalent to the control.

Table 3.2.h) Wheat plant density of selected treatments (plants/m^2), 19 June 2014. Letters denote differences between treatments at 95% probability.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	Nil	0	97 a	108 a	123 a	123 a
Trifluralin IBS	1700	Trifluralin IBS	1700	104 a	118 a	114 a	119 a
Boxer Gold IBS	2500	Boxer Gold IBS	2500	98 a	101 a	108 a	129 a
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	106 a	105 a	113 a	132 a

Table 3.2.i) Ryegrass plant density (plants/m^2), 29 July 2014. Letters denote differences between treatments at 95% probability from transformed data.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	Nil	0	56.7 a..	10.3 a...	48.5 a...	4.4 .bc...
Trifluralin IBS	1700	Nil	0	63.3 a..	11.4 a...	45.1 a...	6.1 ab....
Trifluralin IBS	1700	Trifluralin IBS	1700	42.8 a..	6.4 ab..	28.8 a...	9.9 a.....
Boxer Gold IBS	2500	Nil	0	23.5 .b.	1.5 .bcd	21.6 ab..	1.9 ..cde.
Boxer Gold IBS	2500	Boxer Gold IBS	2500	14.0 .b.	2.3 .bc.	4.5 ..c.	1.5 ...def
Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	6.8 ..c	0.0 ...d	3.0 ..c.	0.4 .....f
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	4.2 ..c	1.5 .bcd	0.8 ...d	1.5 ...def
Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	12.9 .b.	3.0 .bc.	11.7 .b..	3.4 .bcd..
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	4.9 ..c	0.8 ..cd	0.8 ...d	0.8 ....ef

Table 3.2.j) Greenseeker NDVI measured 29 July 2014. Letters denote differences between treatments at 95% probability. *F pr value = 0.064

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	Nil	0	0.41 ab.*	0.54 ab..	0.61 ab..	0.60 a
Trifluralin IBS	1700	Nil	0	0.43 a..*	0.53 ab..	0.61 ab..	0.59 a
Trifluralin IBS	1700	Trifluralin IBS	1700	0.42 ab.*	0.57 ab..	0.54 ..cd	0.56 a
Boxer Gold IBS	2500	Nil	0	0.42 ab.*	0.57 a...	0.60 ab..	0.60 a
Boxer Gold IBS	2500	Boxer Gold IBS	2500	0.39 abc*	0.52 .bc.	0.57 .bc.	0.60 a
Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	0.42 ab.*	0.53 abc.	0.64 a...	0.59 a
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	0.36 ..c*	0.47 ...d	0.52 ..cd	0.55 a
Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	0.43 a..*	0.55 ab..	0.61 ab..	0.62 a
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	0.38 .bc*	0.48 ..cd	0.50 ...d	0.57 a

Table 3.2.k) Ryegrass head density (heads/m^2), 22 October 2014. Letters denote differences between treatments at 95% probability from transformed data.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	Nil	0	31.6 ab...	7.4 ab...	32.1 ab.	4.5 ab...
Trifluralin IBS	1700	Nil	0	38.1 a....	11.6 a....	32.1 a..	7.1 a....
Trifluralin IBS	1700	Trifluralin IBS	1700	33.1 a....	9.9 a....	22 ab.	6 a....
Boxer Gold IBS	2500	Nil	0	18.7 .b...	3.7 .bc..	21.4 ab.	4.8 a....
Boxer Gold IBS	2500	Boxer Gold IBS	2500	8.1 ..c..	0.8 ...de	11.5 .b.	1.3 ..cd.
Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	1.7 ...d.	0.2 ....e	1 ..c	0.4 ...de
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	0.6 ...de	0.5 ....e	0.8 ..c	1.1 ..cd.
Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	10.7 ..c..	2.4 ..cd.	13.5 ab.	2.1 .bc..
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	0.1 ....e	0.4 ....e	0.5 ..c	0 ....e

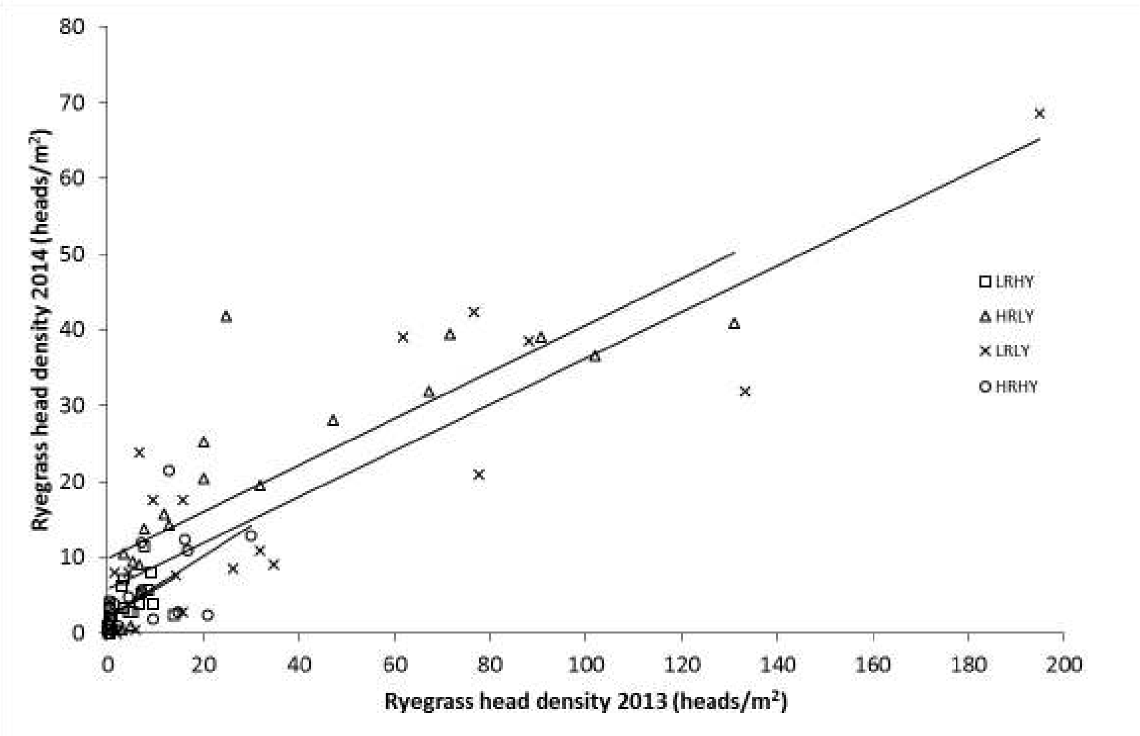

Figure 3.2.a) Ryegrass head density in 2014 in response to ryegrass head density in 2013. Treatments used to generate data were 1A, 2A, 3A and 5A, which did not receive herbicide treatment in 2014. LRHY, y = 0.38x + 2.018, R^2 = 0.26. HRLY, y = 0.31x + 9.83, R^2 = 0.68. LRLY, y = 0.31x + 5.80, R^2 = 0.77. HRHY, y = 0.4x + 2.17, R^2 = 0.36.

Table 3.2.l) 2014 grain yield (t/ha). Letters denote differences between treatments at 95% probability. *F pr value = 0.09

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	Nil	0	3.02 a	3.79 abc*	3.06 a	3.63 a
Trifluralin IBS	1700	Nil	0	3.06 a	3.75 .bc*	2.87 a	3.71 a
Trifluralin IBS	1700	Trifluralin IBS	1700	3.13 a	3.93 a..*	3.28 a	3.62 a
Boxer Gold IBS	2500	Nil	0	3.01 a	3.86 abc*	3.08 a	3.72 a
Boxer Gold IBS	2500	Boxer Gold IBS	2500	3.08 a	3.84 abc*	2.97 a	3.68 a
Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	2.96 a	3.85 abc*	2.98 a	3.65 a
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	2.98 a	3.68 ..c*	2.76 a	3.57 a
Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	3.15 a	3.88 ab.*	3.25 a	3.7 a
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	3.04 a	3.68 ..c*	3.22 a	3.77 a

Table 3.2.m) 2014 Grain quality, samples bulked across replicates

Site	2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate (mL or g/ha)	Protein %	Test Weight kg/hl	Screenings % < 2.0mm
LRHY	Nil	0	Nil	0	13.0	78.8	2.9
	Trifluralin IBS	1700	Nil	0	12.4	79.7	2.7
	Trifluralin IBS	1700	Trifluralin IBS	1700	12.9	77.8	2.8
	Boxer Gold IBS	2500	Nil	0	12.8	80.3	3.5
	Boxer Gold IBS	2500	Boxer Gold IBS	2500	12.5	77.7	3.0
	Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	12.9	78.1	2.9
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	13.1	71.9	3.1
	Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	12.7	78.5	2.6
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	12.8	78.6	3.1
HRLY	Nil	0	Nil	0	12.3	78.9	3.0
	Trifluralin IBS	1700	Nil	0	12.2	78.6	3.5
	Trifluralin IBS	1700	Trifluralin IBS	1700	12.1	79.8	3.1
	Boxer Gold IBS	2500	Nil	0	12.2	78.9	3.1
	Boxer Gold IBS	2500	Boxer Gold IBS	2500	11.8	79.0	2.7
	Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	12.1	78.9	2.9
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	12.1	78.4	3.3
	Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	11.9	80.3	2.9
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	12.2	79.1	2.9
LRLY	Nil	0	Nil	0	12.6	77.9	3.8
	Trifluralin IBS	1700	Nil	0	13.0	76.7	4.0
	Trifluralin IBS	1700	Trifluralin IBS	1700	12.4	78.7	3.4
	Boxer Gold IBS	2500	Nil	0	13.2	77.9	4.4
	Boxer Gold IBS	2500	Boxer Gold IBS	2500	13.3	76.8	3.7
	Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	13.6	76.9	4.2
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	13.2	77.6	4.0
	Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	13.6	77.1	4.8
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	14.3	75.0	5.6
HRHY	Nil	0	Nil	0	11.7	79.6	3.3
	Trifluralin IBS	1700	Nil	0	11.3	79.8	3.2
	Trifluralin IBS	1700	Trifluralin IBS	1700	11.1	79.7	3.3
	Boxer Gold IBS	2500	Nil	0	12.1	80.0	3.4
	Boxer Gold IBS	2500	Boxer Gold IBS	2500	11.8	79.3	3.2
	Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	10.7	80.6	2.9
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	11.2	79.7	3.3
	Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	11.2	79.2	3.6
	Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	11.9	79.5	3.2

Table 3.2.n) Cumulative gross margins ($/ha) calculated for each treatment over two seasons. Calculations based on a fixed wheat price of $270/t and all other variable costs being fixed at $292/ha/yr. Letters denote differences between treatments at 95% probability.

2013 Treatment Herbicide	Rate (mL or g/ha)	2014 Treatment Herbicide	Rate mL or g/ha	Cumulative herbicide	Site HRLY	HRHY	LRLY	LRHY
Nil	0	Nil	0	0	1283 a..	1865 a..	1456 a...	1689 a..
Trifluralin IBS	1700	Nil	0	11	1281 a..	1801 a..	1304 ab..	1715 a..
Trifluralin IBS	1700	Trifluralin IBS	1700	22	1324 a..	1855 a..	1307 ab..	1663 a..
Boxer Gold IBS	2500	Nil	0	39	1256 a..	1848 a..	1293 ab..	1697 a..
Boxer Gold IBS	2500	Boxer Gold IBS	2500	78	1280 a..	1813 a..	1349 ab..	1627 ab.
Sakura IBS + Boxer Gold Post	118 +2500	Boxer Gold IBS + Boxer Gold Post	2500 + 2000	147	1004 ..c	1678 .b.	944 ...d	1512 ..c
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS	118	115	1115 .bc	1646 .bc	1105 ..cd	1483 ..c
Sakura IBS + Boxer Gold Post	118 +2500	Nil	0	77	1205 ab.	1701 .b.	1250 .bc.	1558 .bc
Sakura IBS + Boxer Gold Post	118 +2500	Sakura IBS + Boxer Gold Post	118 +2500	154	1083 .bc	1568 ..c	1116 ..c.	1567 .bc

3.3 Discussion

Control of ryegrass did not generate a positive yield response, and in fact the highest efficacy treatment reduced yield in 2013 due to phytotoxic effects on the crop (table 3.2.f, table 3.2.l). Ryegrass density varied between sites, however ryegrass head density declined between 2013 and 2014 even in the absence of any weed control (table 3.2.e, table 3.2.k, and figure 3.2.a). This was not expected. No sites had very high densities with 83 and 38 heads/m^2 being the highest density treatments in 2013 and 2014, respectively (table 3.2.e, table 3.2.k). Results from trials at Wallaroo indicate that yield decline in response to ryegrass heads can be in the order of 1.7-2.5 kg/ha per ryegrass head/m^2 (figure 5.2.c). Using these figures as a guide for Urania indicates yield loss in the highest density scenario could be in the order of 141-208 kg/ha and 54-80 kg/ha in 2013 and 2014, respectively. Given these small potential yield gains, and that the highest efficacy treatment in 2013 had a phytotoxic effect on the crop it is not surprising there was no significant yield response generated from ryegrass control.

Nil herbicide applied in both seasons was the equal highest gross margin at all sites (table 3.2.n). Boxer Gold applied in both 2013 and 2014 was the highest efficacy treatment at all sites that generated a gross margin equivalent to that of the control. With a view to maintaining a low seed bank into the future whilst maximising gross margin in 2013 and 2014 the use of Boxer Gold in both seasons across the whole paddock was the most appropriate strategy.

4. Brome grass control in barley at Loxton – 2014

4.1 Methods

Trials conducted at Steve and Lisa Nitschke's property in 2014 aimed to assess strategies for site specific management of brome, including different herbicide options and seed rates in Scope CL barley. In 2013 Kord CL wheat was grown in the House paddock and mapped using a Yara N-Sensor to determine the variability in brome density (figure 4.1.a). This was moderately successful, where higher NDVI correlated with higher brome grass density. The paddock had yield map data for seasons 2008-2011, which was four consecutive seasons of wheat (figure 4.1.c-f). This yield data was used to calculate the mean cereal yield map (figure 4.1.b). The mean cereal yield map and 2013 NDVI were used to target trial sites in 2014, where sites were targeted to high and low brome grass density and high and low yield potential.

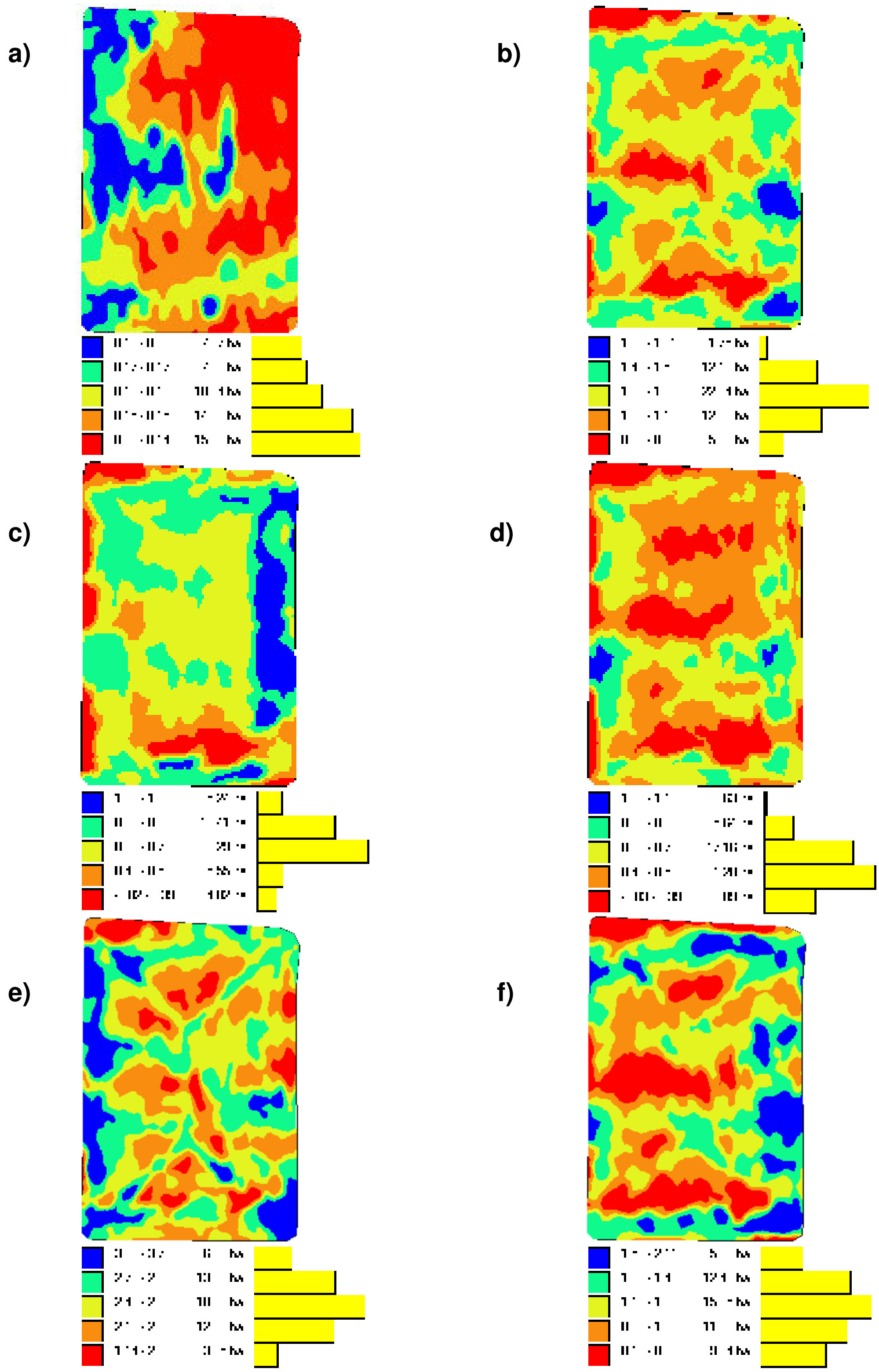

Figure 4.1.a) NDVI map of House paddock collected 29 May 2013 showing variable weed growth in wheat, b) average cereal yield for House paddock based on years 2008, 2009, 2010 and 2011, c) wheat yield map 2008, d) wheat yield map 2009, e) wheat yield map 2010, f) wheat yield map 2011.

The average cereal yield map data (figure 4.1.b) and the NDVI data from 2013 (figure 4.1.a) were used to identify four regions. These regions were a factorial of high and low historical yield and high and low NDVI, where NDVI was used as a surrogate for brome grass density (Figure 4.1.g-j). Median values were used as thresholds, where the median cereal yield was 1.2 t/ha and median NDVI was 0.16. One site was selected in each of these zones as the location for a small plot trial to assess the efficacy of brome grass control and the yield response this generated within each zone. At each of these sites soil tests were taken and segmented to 0-10cm, 0-30cm and 30-60cm.

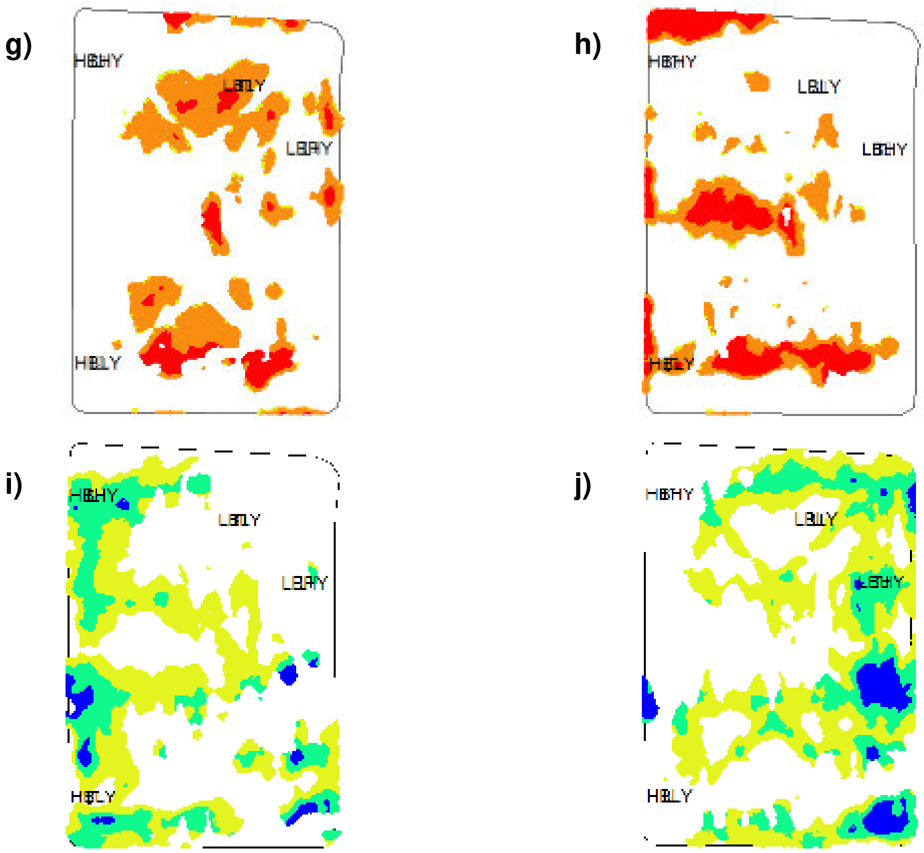

Figure 4.1.g) Low historical yield and low NDVI, h) low historical yield and high NDVI, i) high historical yield and high NDVI, and j) high historical yield and low NDVI. For each zone resultant trial site locations are shown.

The following acronyms are used in reference to each site

- HBLY - high brome and low yield
- HBHY - high brome and high yield
- LBLY - low brome and low yield
- LBHY - low brome and high yield

At each site a six treatment trial was established. The trials were set up as randomised complete block designs with four replicates. Two seeding rates were used, a standard target rate of 120 barley plants/m^2 and a high rate of 250 plants/m^2. Herbicide treatments included the use of trifluralin, metribuzin, Sakura, Avadex Xtra and Intervix. Sakura is not registered for use in barley due to potential for crop damage, for this reason the rate was reduced from the label rate of 118g/ha to 80g/ha. A Nil treatment was included at both seeding rates. The complete list of seeding rate and herbicide treatment combinations is shown in table 4.1.a.

The trials were sown with Scope CL Barley, using SARDI New Variety Agronomy Clare seeding equipment on 225mm row spacing, knife points and press wheels on 225mm row spacing. The plot dimensions were 12m * 1.4m sown on 1.8m centers.
The trials were sown 6 May 2014 with 60kg DAP/ha treated with flutriafol, this was applied with the seed. The incorporated by sowing treatments (IBS) herbicides were applied immediately prior to sowing and Intervix treatments were applied 25 June 2014. 50 L/ha UAN (42% N w/v) was applied 25 June and sulphate of ammonia was applied at 50 kg/ha on 6 August.

Barley establishment, brome grass plant and head count, NDVI and grain yield and quality assessments were made throughout the season and are displayed in chronological order in tables 4.2.a through 4.2.i. The trials were harvested on 17 November 2014.

Table 4.1.a Loxton brome grass control treatment list 2014.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)
120	Nil	0
120	trifluralin + metribuzin	2000 + 120
120	Sakura + Avadex Xtra	80 + 2000
120	Intervix	700
250	Nil	0
250	trifluralin + metribuzin	2000 + 120

4.2 Results

Soil test results for samples collected 15 April 2014

Site	Depth	Colwell P	PBI	Colwell K	Organic Carbon	Soil N	Sulphur	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	CEC	ESP (sodicity)	Bo
		mg/Kg		mg/Kg	%	kg/ha	kg/ha	dS/m	pH	pH	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%	
HBLY	0-10	22	36	182	0.39			0.08	8.2	8.8	9.38	0.63	0.47	0.06	10.5	0.6	
HBHY		23	34	241	0.41			0.08	8.1	8.7	8.85	0.68	0.62	0.02	10.2	0.2	
LBLY		24	66	265	0.37			0.07	8.2	8.8	9.75	0.76	0.68	0.02	11.2	0.2	
LBHY		30	34	251	0.4			0.06	8.2	8.8	8.22	0.66	0.64	0.02	9.5	0.2	
HBLY	0-30					23.4	5.85	0.07	8.2	8.9	9.19	1.03	0.33	0.04	10.6	0.4	
HBHY						42.9	7.41	0.09	8.1	8.9	14.19	2.22	0.55	0.1	17.1	0.6	
LBLY						27.3	7.8	0.08	8.1	8.9	11.66	2.23	0.5	0.2	14.6	1.4	
LBHY						27.3	7.41	0.08	8.1	8.9	11.53	1.27	0.55	0.04	13.4	0.3	
HBLY	30-60					19.5	4.29	0.07	8.3	9.1	8.1	2.09	0.26	0.08	10.5	0.8	
HBHY						23.4	9.36	0.15	8.3	9.4	10.72	4.6	0.39	1.02	16.7	6.1	
LBLY						15.6	9.75	0.17	8.3	9.6	9.95	4.33	0.39	1.75	16.4	10.7	
LBHY						15.6	8.19	0.07	8.2	9.1	12.32	2.68	0.27	0.12	15.4	0.8	

Comments: this paddock has low levels of soil nutrition and organic carbon. HBLY was located on a weak sand dune and had the lowest sulphur and potassium levels. The LBLY site was located on a heavier textured swale and has subsoil sodicity between 30 and 60cm.

Do the sites match the descriptions?

In both of the high brome sites, brome grass population was higher than the low brome sites. Both of the high yield potential sights produced higher grain yields than the low yield potential sites.

Barley plant numbers

Barley establishment averaged 94% of seed sown (120 seeds/m^2) in the standard seed rate and 87% establishment in the high seeding rate treatment of 250 seeds/m^2. Plant densities in the standard treatment were significantly reduced at the HBLY and LBLY site by the trifluralin + metribuzin treatment. A reduction in plant numbers in the high density treatment with trifluralin + metribuzin was also recorded at the same sites, however this was not significant.

Brome grass plant and head density

A large proportion of brome grass emergence occurred after the first count on 25 June 2014. At the two HB sites the nil treatments averaged 55% of total brome grass (counted 5 August 2014) emerged at the first count (25 June 2014) compared with the treated plots with an average of 35%. This result shows that the pre-emergent herbicides are having a greater effect earlier in the season, which is not surprising. At the LB sites numbers were very low with the nil at the LBLY site producing only 4 plants/m^2 and only a single plant being found at the entire LBHY site.

At the HB sites both trifluralin + metribuzin and Sakura + Avadex Xtra provided adequate to good control (72-91%), with Sakura + Avadex Xtra providing significantly higher control than trifluralin + metribuzin at HBHY (table 4.2.c, table 4.2.d). Increasing seed rate for increased competition did not have any significant effect on brome grass plant density. Similar differences were observed in brome grass head density at the end of the season. At the HB sites there is a trend toward lower brome grass head density where seed rate is increased, however this effect is not significant (table 4.2.f, table 4.2.g). Intervix provided no brome grass control at any site.

Greenseeker data

Greenseeker data from 5 August at HBLY follows a similar trend to brome grass plant density, where treatments with high densities had higher NDVI and treatments with better control and reduced numbers had lower NDVI (table 4.2.e). Interestingly though, the effect of increased crop seed rate was not detected in a similar manner, at any of the sites.

Grain yield and quality results

Increasing seed rate to target 250 seeds/m^2 was the most significant factor affecting yield, at all sites regardless of brome grass density (table 4.2.h). At HBLY the use of pre-emergent herbicide treatments significantly increased yield compared with the control. The combination of increased seed rate with trifluralin + metribuzin produced the highest yield at HBLY, though not significantly greater than increased seed rate without herbicide. At the LB sites the use of pre-emergent herbicide reduced yield when used with low seed rate. However where high seed rate was used in combination with trifluralin + metribuzin there was no yield penalty. At HBHY there is no effect of herbicide treatment on yield, despite the pre-emergent herbicide treatments significantly reducing brome grass density. Grain quality results indicated that each site would have satisfied the criteria for malting grade.

Gross margin analysis

High seeding density (250 seeds/m^2) with or without trifluralin + metribuzin generated the highest gross margin at all sites (table 4.2.j). However, at the three sites with the lowest brome densities (HBHY, LBLY & LBHY) these are not significantly different to the low seed density with nil herbicide. At the HB sites return on investment (ROI) was positive for the high seed rate treatment with or without trifluralin and metribuzin, whereas at the LB sites the ROI declined with higher seed rate and was negative where used with trifluralin + metribuzin (table 4.2.k).

Table 4.2.a) Barley plant density (plants/m^2), 6 June 2014. Letters denote differences between treatments at 95% probability from transformed data.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	116 .bc.	115 .b	120 .b.	105 .b
120	trifluralin + metribuzin	2000 + 120	97 ...d	114 .b	99 ..c	109 .b
120	Sakura + Avadex Xtra	80 + 2000	108 ..cd	124 .b	101 .bc	119 .b
120	Intervix	700	129 .b..	118 .b	105 .bc	125 .b
250	Nil	0	239 a...	230 a.	220 a..	215 a.
250	trifluralin + metribuzin	2000 + 120	213 a...	226 a.	199 a..	203 a.

Table 4.2.b) Brome plant density (plants/m^2), 25 June 2014 for selected treatments. Letters denote differences between treatments at 95% probability from transformed data.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	136.7 a..	97.0 a..	3.8 a	0.0 *
120	trifluralin + metribuzin	2000 + 120	18.9 .bc	8.7 .b.	1.1 a	0.0 *
120	Sakura + Avadex Xtra	80 + 2000	18.2 .bc	6.1 .b.	0.8 a	0.0 *
120	Intervix	700	- -	- -	- -	- -
250	Nil	0	141.3 a..	89.4 a..	3.0 a	0.0 *
250	trifluralin + metribuzin	2000 + 120	9.8 ..c	10.2 .b.	1.9 a	0.0 *

Table 4.2.c) Brome plant density (plants/m^2), 5 August 2014. Letters denote differences between treatments at 95% probability from transformed data.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	412.0 a.	127.3 a..	2.5 a	0.0 a
120	trifluralin + metribuzin	2000 + 120	42.0 .b	35.1 .b.	0.0 a	0.0 a
120	Sakura + Avadex Xtra	80 + 2000	38.0 .b	16.2 ..c	0.8 a	0.0 a
120	Intervix	700	417.0 a.	101.3 a..	1.5 a	0.0 a
250	Nil	0	367.0 a.	128.3 a..	0.8 a	0.3 a
250	trifluralin + metribuzin	2000 + 120	71.0 .b	25.3 .bc	0.3 a	0.0 a

Table 4.2.d) Brome grass control (%), 5 August 2014. Letters denote differences between treatments at 95% probability.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	0 a.	0 a..	0 a	0 *
120	trifluralin + metribuzin	2000 + 120	90 .b	72 .b.	100 a	0 *
120	Sakura + Avadex Xtra	80 + 2000	91 .b	87 ..c	70 a	0 *
120	Intervix	700	0 a.	20 a..	40 a	0 *
250	Nil	0	11 a.	0 a..	70 a	0 *
250	trifluralin + metribuzin	2000 + 120	83 .b	80 .bc	90 a	0 *

Table 4.2.e) Greenseeker NDVI 5 August 2014. Letters denote differences between treatments at 95% probability.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g/ha)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	0.45 a..	0.48 a	0.34 .b	0.45 a.
120	trifluralin + metribuzin	2000 + 120	0.37 .bc	0.45 a	0.34 .b	0.42 .b
120	Sakura + Avadex Xtra	80 + 2000	0.34 ..c	0.43 a	0.32 .b	0.40 .b
120	Intervix	700	0.45 a..	0.49 a	0.39 a.	0.46 a.
250	Nil	0	0.40 .b.	0.44 a	0.31 .b	0.42 .b
250	trifluralin + metribuzin	2000 + 120	0.34 ..c	0.43 a	0.31 .b	0.40 .b

Table 4.2.f) Brome grass head density (plants/m^2), 1 October 2014. Letters denote differences between treatments at 95% probability from transformed data. *F pr value = 0.093

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	257.6 a.	67.9 a..	3.2 a.*	0.0 a
120	trifluralin + metribuzin	2000 + 120	31.1 .b	20.7 .b.	1.1 ab*	0.0 a
120	Sakura + Avadex Xtra	80 + 2000	20.7 .b	7.4 ..c	0.2 .b*	0.0 a
120	Intervix	700	231.7 a.	75.2 a..	1.6 ab*	0.4 a
250	Nil	0	196.5 a.	60.1 a..	1.2 ab*	0.0 a
250	trifluralin + metribuzin	2000 + 120	22.5 .b	9.8 .bc	0.7 .b*	0.0 a

Table 4.2.g) Brome grass head control (%), 1 October 2014. - = no brome grass present in nil treatments.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	0	0	0	-
120	trifluralin + metribuzin	2000 + 120	88	70	67	-
120	Sakura + Avadex Xtra	80 + 2000	92	89	93	-
120	Intervix	700	10	-11	52	-
250	Nil	0	24	11	63	-
250	trifluralin + metribuzin	2000 + 120	91	86	78	-

Table 4.2.h) 2014 Grain yield (t/ha). Letters denote differences between treatments at 95% probability.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g/ha)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	1.46 ...d	2.14 .b	2.09 ab.	2.39 .b.
120	trifluralin + metribuzin	2000 + 120	1.67 .bc.	2.12 .b	1.93 .bc	2.27 ..c
120	Sakura + Avadex Xtra	80 + 2000	1.69 .bc.	2.18 .b	1.91 ..c	2.19 ..c
120	Intervix	700	1.57 ..cd	2.22 ab	2.17 a..	2.39 .b.
250	Nil	0	1.80 ab..	2.33 a.	2.21 a..	2.51 a..
250	trifluralin + metribuzin	2000 + 120	1.85 a...	2.36 a.	2.17 a..	2.47 ab.

Table 4.2.i) Grain Quality 2014 bulked across replicates. All treatments conform to malt quality parameters.

Site	Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g)	Grain Quality bulked across reps Protein %	Test Wt kg/hL	Screenings % <2.2mm	Retention % >2.5mm
HBLY	120	Nil	0	10	67.2	1.0	91.6
	120	trifluralin + metribuzin	2000 + 120	10.3	67.3	1.4	90.4
	120	Sakura + Avadex Xtra	80 + 2000	10.2	67.9	1.0	92.3
	120	Intervix	700	9.8	66.2	1.5	91.3
	250	Nil	0	10.1	70	0.9	89.8
	250	trifluralin + metribuzin	2000 + 120	9.9	69.2	1.2	92.0
HBHY	120	Nil	0	9.2	66.7	0.7	91.0
	120	trifluralin + metribuzin	2000 + 120	9.8	67	1.1	89.4
	120	Sakura + Avadex Xtra	80 + 2000	9.4	67	0.9	92.4
	120	Intervix	700	9	67.2	1.1	91.7
	250	Nil	0	9.3	67.7	0.8	91.8
	250	trifluralin + metribuzin	2000 + 120	9.6	67.1	1.0	91.1
LBLY	120	Nil	0	9.3	67.2	1.2	91.9
	120	trifluralin + metribuzin	2000 + 120	9.3	67.6	1.0	93.6
	120	Sakura + Avadex Xtra	80 + 2000	9.5	68.6	1.1	93.8
	120	Intervix	700	9	66.9	1.0	91.8
	250	Nil	0	9	67.7	1.0	91.6
	250	trifluralin + metribuzin	2000 + 120	9	69.7	1.3	92.3
LBHY	120	Nil	0	9	69.3	1.4	92.7
	120	trifluralin + metribuzin	2000 + 120	9.3	68.7	1.4	92.3
	120	Sakura + Avadex Xtra	80 + 2000	9.2	68.6	1.3	93.6
	120	Intervix	700	8.9	69.6	1.4	92.0
	250	Nil	0	8.8	68.9	1.5	92.4
	250	trifluralin + metribuzin	2000 + 120	8.9	68.3	1.0	93.2

Table 4.2.j) Gross margins ($/ha) calculated for each treatment in 2014. Calculations based on barley price of $240/t and all other variable costs are fixed at $215/ha. Letters denote differences between treatments at 95% probability.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g/ha)	Treatment cost ($/ha)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	0	136 ..c	299 abc.	287 a.	358 a...
120	trifluralin + metribuzin	2000 + 120	15	172 ab.	279 ..cd	234 .b	314 ..c.
120	Sakura + Avadex Xtra	80 + 2000	46	144 .bc	261 ...d	197 .b	266 ...d
120	Intervix	700	28	133 ..c	291 .bcd	278 a.	330 .bc.
250	Nil	0	17	200 a..	328 a...	299 a.	371 a...
250	trifluralin + metribuzin	2000 + 120	32	196 a..	320 ab..	273 a.	346 ab..

Table 4.2.k) Return on investment (%) for each treatment relative to the low seed rate and nil herbicide treatment.

Seeding Density seeds/m²	2014 Herbicide	Rate (mL or g/ha)	Treatment cost ($/ha)	Site HBLY	HBHY	LBLY	LBHY
120	Nil	0	0	-	-	-	-
120	trifluralin + metribuzin	2000 + 120	15	241	-132	-354	-292
120	Sakura + Avadex Xtra	80 + 2000	46	19	-82	-195	-200
120	Intervix	700	28	-9	-30	-32	-100
250	Nil	0	17	378	169	69	81
250	trifluralin + metribuzin	2000 + 120	32	188	67	-43	-36

4.3 Discussion

Brome grass control strategies for this paddock based on maximising gross margin and weed control would suggest that the high input treatment of high seed rate with trifluralin + metribuzin will be the best strategy at all sites (table 4.2.f, table 4.2.j). However, at the LB sites while the high input treatment delivered the equal highest gross margin this required high cost, reducing the return on investment and increasing risk (table 4.2.k). At these sites there was little benefit in weed control from the high input treatment, too. Therefore, a lower risk option that maximises gross margin while maintaining weed control was to apply the high input treatment to the HB sites and the low seed density nil herbicide treatment to the LB sites.

Trifluralin + metribuzin and Sakura + Avadex Xtra reduced yield at the LB sites in the low seed rate treatments indicating a phytotoxic herbicide effect that reduced yield in the absence of brome competition (table 4.2.h). While this effect is not apparent at the higher seed rate the potential for herbicide phytotoxicity is another reason to not apply herbicide to the LB sites. No phytotoxic yield effect is observed at the HB sites, however the yield response to brome control with those herbicides at the HB sites was small and smaller than expected given the level of brome control achieved (table 4.2.f, table 4.2.h).

The use of Intervix in these trials provided no brome grass control, reflecting the high level of brome grass resistance to imidazolinone herbicides in this paddock. The failure of Intervix reflects a significant cost for three reasons

1. The high cost of the herbicide ($28/ha) that didn't work,
2. The blow out in weed numbers from poor control, resulting in reduced yield at HBLY and leading to increased crop competition and control costs in future years,
3. The lost production from growing a Clearfield variety that generally has a yield penalty relative to the highest yielding conventional varieties. Long term analysis on NVT data indicates Compass yields 14.5% higher than Scope on average across SA.

These costs highlight the importance of herbicide resistance testing to ensure these products work.

5. Ryegrass control in wheat at Wallaroo – 2014

5.1 Methods

Trials conducted at Stephen and Shane Paddick's property in 2014 aimed to assess strategies for site specific management of ryegrass in Mace wheat in 2014. In 2013 lentils were grown in paddock J1 and mapping using a Yara N-Sensor was conducted to determine the variability in ryegrass density (figure 5.1.a), where higher NDVI correlated with higher ryegrass density. The paddock had yield map data for seasons 2009-2013, which was wheat, field peas, wheat, barley and lentils in those seasons, respectively. The field pea yield map was affected by snails clogging the grain flow sensor and has not been presented (figure 5.1.c-f). The cereal yield data was used to calculate the mean cereal yield map (figure 5.1.b). The mean cereal yield map and 2013 NDVI were used to target trial sites in 2014, where sites were targeted to high and low ryegrass density and high and low yield potential.

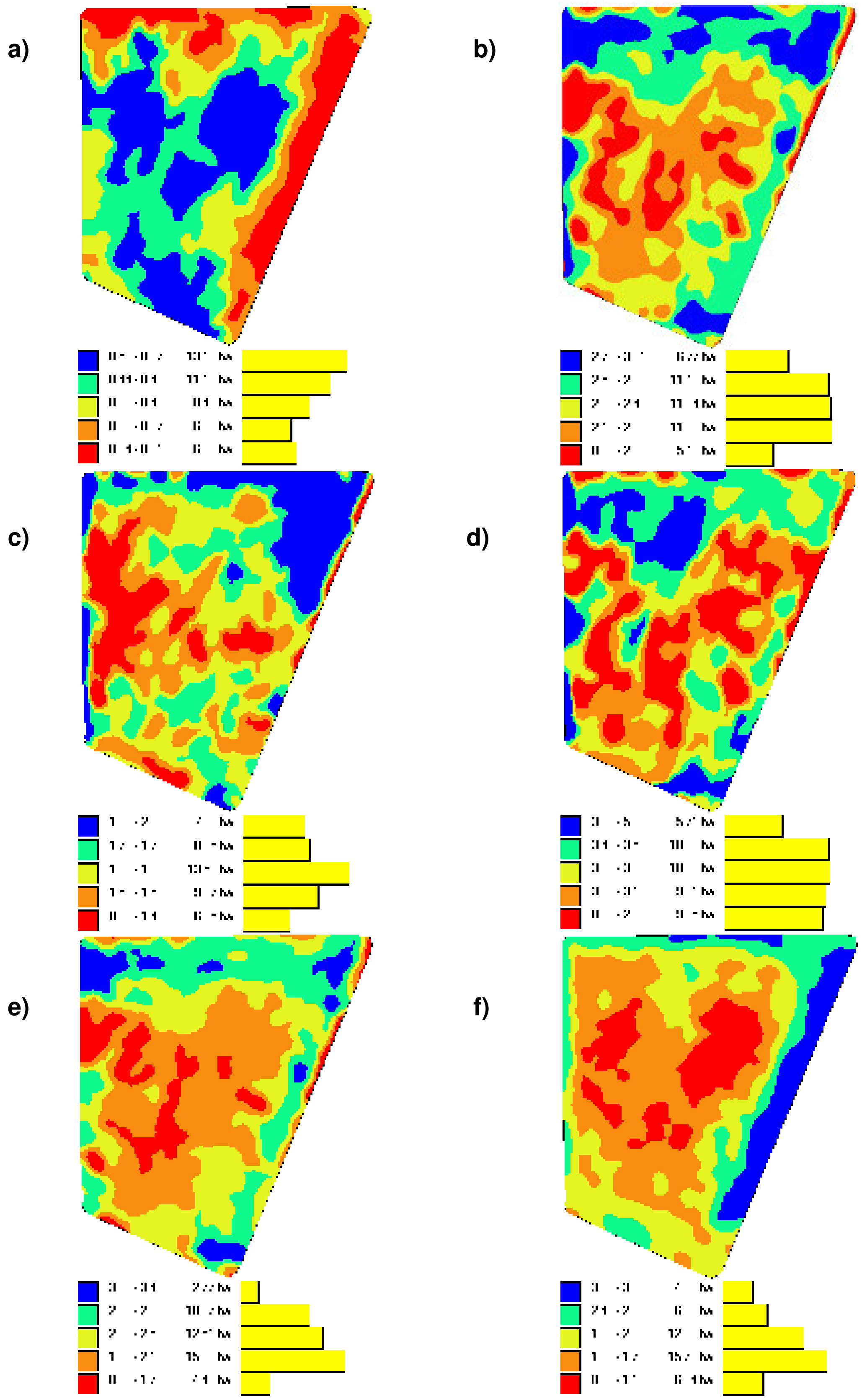

Figure 5.1.a) NDVI map of paddock J1 collected 10 June 2013 showing variable weed growth in lentils, b) average cereal yield for paddock J1 based on years 2009, 2011 and 2012, c) wheat yield map 2009, d) wheat yield map 2011, e) barley yield map 2012, and f) lentil yield map 2013.

The average cereal yield map data (figure 5.1.b) and the NDVI data from 2013 (figure 4.1.a) were used to identify four regions. These regions were a factorial of high and low historical yield and high and low NDVI, where NDVI was used as a surrogate for ryegrass density (Figure 5.1.g-j). Median values were used as thresholds, where the median cereal yield was 2.4 t/ha and median NDVI was 0.44. One site was selected in each of these zones as the location for a small plot trial to assess the efficacy of ryegrass control and the yield response this generated within each zone. At each of these sites soil tests were taken and segmented to 0-10cm, 0-30cm and 30-60cm.

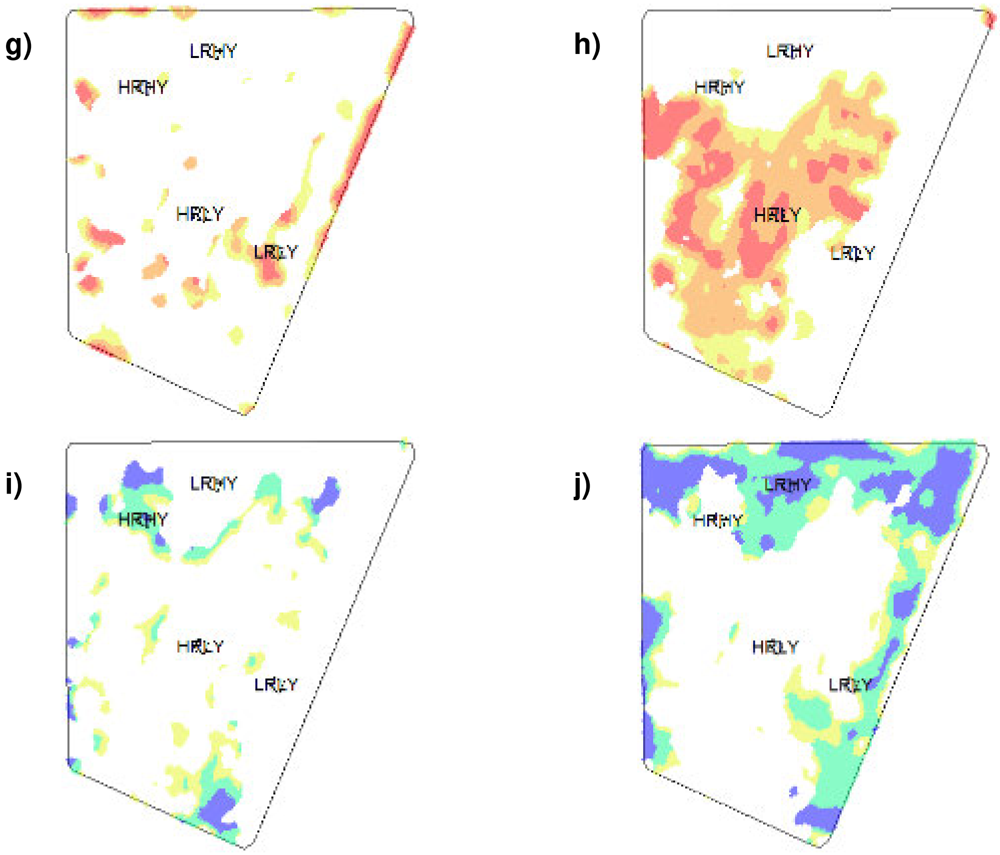

Figure 5.1.g) Low historical yield and low NDVI, h) low historical yield and high NDVI, i) high historical yield and high NDVI, and j) high historical yield and low NDVI. For each zone resultant trial site locations are shown.

The following acronyms are used in reference to each site

- HRLY - high ryegrass and low yield
- HRHY - high ryegrass and high yield
- LRLY - low ryegrass and low yield
- LRHY - low ryegrass and high yield

At each site a six treatment trial was established. The trials were set up as randomised complete block designs with four replicates. Herbicides included in this trial were trifluralin, Avadex Xtra, Boxer Gold and Sakura. A complete treatment list including rates and timings is shown in table 5.1.a. The trials were sown to Mace wheat on 20 May 2014 using the SARDI New Variety Agronomy Clare seeding equipment with knife points and press wheels on 225mm row spacing, 100kg DAP/ha treated with flutriafol was applied with the seed. The plot dimensions were 12m * 1.4m sown on 1.8m centers. The incorporated by sowing (IBS) treatments were applied immediately prior to sowing and the post emergent Boxer Gold treatments were applied on 18 June 2014 when the wheat was at the 2 – 3 leaf growth stage and the ryegrass was up to 3 leaf. Assessments of wheat plant density, ryegrass plant and head density, Greenseeker NDVI, grain yield and quality were made throughout the season and are displayed in chronological order in tables 5.2.a through 5.2.g.

Table 5.1.a) Herbicide treatment list

Herbicide	Rate mL or g/ha	Cost $/ha
Nil	0	0
Trifluralin (IBS)	1700	11
Trifluralin (IBS) + Avadex Xtra(IBS)	1700 + 2000	31
Boxer Gold (IBS)	2500	39
Sakura (IBS)	118	38
Sakura (IBS) + Boxer Gold (Post em)	118 + 2500	77

5.2 Results

Soil test results from samples collected prior to sowing 2014

Site	Depth	Colwell P	PBI	Colwell K	Organic Carbon	Soil N	Sulphur	Conductivity	pH Level (CaCl2)	pH Level (H2O)	Exc. Calcium	Exc. Magnesium	Exc. Potassium	Exc. Sodium	CEC	ESP (sodicity)	Boron Hot CaCl2
		mg/Kg		mg/Kg	%	kg/ha	kg/ha	dS/m	pH	pH	meq/100g	meq/100g	meq/100g	meq/100g	meq/100g	%	mg/Kg
HRLY	0-10	33	155	675	2.32			0.43	7.7	8.4	23.02	3.9	1.85	2.03	30.8	6.6	
HRHY		31	124	779	1.94			0.25	7.8	8.4	24.76	3.43	2.27	1.13	31.6	3.6	
LRLY		54	143	662	2.25			0.31	7.6	8.3	22.55	2.47	1.73	1.18	27.9	4.2	
LRHY		43	132	606	1.56			0.20	7.9	8.5	20.76	2.36	1.68	0.32	25.1	1.3	
HRLY	0-30					218.4	127.53	0.40	8.1	8.9	21.45	5.2	1.39	3.62	31.7	11.4	6.36
HRHY						81.9	76.05	0.28	8	8.9	22.06	4.65	1.26	2.45	30.4	8.1	4.5
LRLY						117	154.83	0.38	8	8.9	18.79	3.48	0.88	2.63	25.8	10.2	7.56
LRHY						78	20.28	0.17	8	8.7	19.92	2.75	1	0.58	24.3	2.4	2.67
HRLY	30-60					35.1	707.46	0.92	8.4	9.5	12.39	5.36	0.47	7.39	25.6	28.9	20.17
HRHY						19.5	546.39	0.76	8.3	9.5	12.63	4.98	0.41	6.4	24.4	26.2	16.53
LRLY						50.7	517.14	0.78	8.3	9.5	12.65	4.58	0.36	6.54	24.1	27.1	17.62
LRHY						39	114.66	0.29	8.3	9.5	12.89	4.96	0.53	3.27	21.7	15.1	10.15

Comments: sites identified as having low yield potential had higher sodicity and boron levels and at shallower depths.

Do the sites match the descriptions?

No. All sites were found to have high ryegrass density and all sites yielded similarly in 2014 (table 5.2.c, table 5.2.e).

Ryegrass control

A wide range in ryegrass control was achieved with the herbicide treatments, increasing from a low of 37% control with trifluralin at LRHY up to a high of 95% control with Sakura + Boxer Gold at HRHY (table 5.2.c). In general across all sites the herbicide efficacy was in order Sakura + Boxer Gold > Sakura > Boxer Gold > trifluralin + Avadex Xtra > trifluralin. A similar trend is observed in ryegrass head density (table 5.2.d) and this also reflects the order of herbicide cost (table 5.1.a). Greenseeker NDVI data also reflects this same trend (table 5.2.b), where the NDVI was responsive to increase in ryegrass density (figure 5.2.a), except at LRLY where treatments with trifluralin reduced wheat plant density (table 5.2.a) and also reduced Greenseeker NDVI values. Greenseeker NDVI values increased by 0.02-0.04 units per 100 ryegrass plants/m^2, depending on site (figure 5.2.a). This response appears to be subject to the background NDVI of the crop, where the higher the NDVI of the crop in the absence of ryegrass (i.e. where $x = 0$) the lower the slope in response to increasing ryegrass density. This is related to the NDVI being asymptotic in response to green leaf area as it approaches its maximum value of 1. Therefore the Greenseeker NDVI response to increased ryegrass density is less where the background NDVI of the crop is higher.

Grain yield results

Significant grain yield responses were observed at all sites in response to ryegrass control, with the highest efficacy treatments generating the highest yields (table 5.2.e, figure 5.2.b, and figure 5.2.c). Grain yield declined by between 1.1-1.6kg/ha per ryegrass plant/m^2, depending on site (figure 5.2.b), or between 1.7-2.5kg/ha per ryegrass head/m^2, depending on site (figure 5.2.c). While the ryegrass control achieved with Sakura + Boxer Gold was significantly better than either Sakura or Boxer Gold on their own, the increase in control was small such that the grain yield of Sakura + Boxer Gold treatments was not significantly better than Sakura at any site and only significantly better than Boxer Gold at LRLY and LRHY.

Gross margin analysis

Sakura applied on its own achieved the highest or equal highest gross margin at all sites (table 5.2.g). Boxer Gold produced equivalent gross margins at three sites and the application of Sakura + Boxer Gold produced equivalent gross margins at LRLY and HRHY.

Table 5.2.a) Wheat plant density (plants/m^2) 18 June 2014 for selected treatments. Letters denote differences between treatments at 95% probability.

2014 Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	124 a	122 a.	114 ab.*	124 a
Trifluralin	1700	124 a	111 .b	88 ..c*	120 a
Trifluralin + Avadex	1700 + 2000	122 a	129 a.	90 .bc*	115 a
Boxergold	2500	127 a	129 a.	118 a..*	125 a
Sakura	118	127 a	133 a.	108 abc*	107 a

*F pr value = 0.071

Table 5.2.b) Greenseeker NDVI 28 July 2014. Letters denote differences between treatments at 95% probability.

2014 Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	0.81 a..	0.83 a...	0.65 a...	0.66 a...
Trifluralin	1700	0.77 .b.	0.80 ab..	0.53 ..cd	0.60 .b..
Trifluralin + Avadex Xtra	1700 + 2000	0.70 ..c	0.77 .bc.	0.50 ...d	0.54 ..c.
Boxer Gold	2500	0.70 ..c	0.77 ..cd	0.55 .bc.	0.55 ..c.
Sakura	118	0.70 ..c	0.77 .bc.	0.58 .b..	0.52 ..cd
Sakura + Boxer Gold	118 + 2500	0.68 ..c	0.73 ...d	0.54 .bcd	0.50 ...d

Table 5.2.c) Ryegrass plant density (plants/m^2) 20 August 2014. Letters denote differences between treatments at 95% probability from transformed data.

2014 Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	474 a....	379 a....	244 a..	378 a...
Trifluralin	1700	277 .b...	223 .b...	111 .b.	240 ab..
Trifluralin + Avadex Xtra	1700 + 2000	130 ..c..	131 ..c..	45 ..c	154 .b..
Boxer Gold	2500	80 ...d.	102 ..c..	68 .b.	190 .b..
Sakura	118	89 ..cd.	59 ...d.	108 .b.	83 ..c.
Sakura + Boxer Gold	118 + 2500	30 ....e	19 ....e	34 ..c	46 ...d

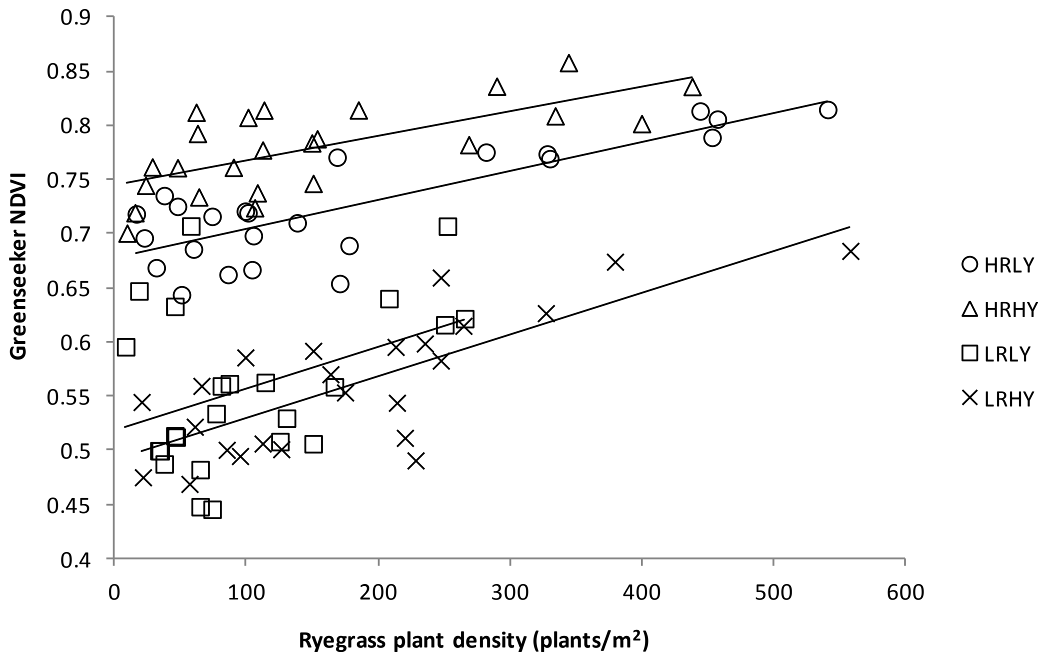

Figure 5.2.a) Greenseeker NDVI in response to ryegrass plant density. HRLY, y = 0.0003x + 0.678, R^2 = 0.67. HRHY, y = 0.0002x + 0.745, R^2 = 0.48, LRLY, y = 0.0004x + 0.518, R^2 = 0.16. LRHY, y = 0.0002x + 0.491, R^2 = 0.59.

Table 5.2.d) Ryegrass head density (heads/m^2) 2 October 2014. Letters denote differences between treatments at 95% probability from transformed data.

2014 Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	247 a...	210 a.....	237 a....	220 a..
Trifluralin	1700	134 a...	141 .b....	124 .b...	148 a..
Trifluralin + Avadex Xtra	1700 + 2000	64 .b..	68 ..c...	58 ...de	64 .b.
Boxer Gold	2500	30 ..cd	45 ...d..	76 ..cd.	67 .b.
Sakura	118	37 .bc.	25 ....e.	90 .bc..	49 .b.
Sakura + Boxer Gold	118 + 2500	16 ...d	10 .....f	34 ....e	25 ..c

Table 5.2.e) Grain yield (t/ha) harvested 24 November 2014. Letters denote differences between treatments at 95% probability.

2014 Herbicide	Rate (mL or g/ha)	Site HRLY	HRHY	LRLY	LRHY
Nil	0	2.56 ...d	2.57 ..c	2.52 ...d	2.60 ...d
Trifluralin	1700	2.66 ..cd	2.58 ..c	2.54 ..cd	2.80 ..c.
Trifluralin + Avadex Xtra	1700 + 2000	2.79 .bc.	2.75 .b.	2.71 .bc.	2.99 .b..
Boxer Gold	2500	2.98 a...	2.93 a..	2.71 .bcd	2.97 .b..
Sakura	118	2.98 a...	2.92 a..	2.77 ab..	3.14 a...
Sakura + Boxer Gold	118 + 2500	2.89 ab..	2.97 a..	2.96 a...	3.12 a...

Table 5.2.f) Grain quality bulked across replicates

Site	2014 Herbicide	Rate mL/g	Protein %	Grain Quality Test Weight kg/hL	Screenings % < 2.0mm
HRLY	Nil	0	11.3	78	9.3
	Trifluralin	1700	11.8	78.6	11
	Trifluralin + Avadex Xtra	1700 + 2000	11.1	79.2	10.5
	Boxer Gold	2500	11.2	79.5	9.4
	Sakura	118	11.5	80.3	8.9
	Sakura + Boxer Gold	118 + 2500	11.4	80.7	9.2
HRHY	Nil	0	11	78.9	12.1
	Trifluralin	1700	10.8	79.4	11.6
	Trifluralin + Avadex Xtra	1700 + 2000	11.2	80.2	10.3
	Boxer Gold	2500	10.6	80.6	8.9
	Sakura	118	10.6	80	8.6
	Sakura + Boxer Gold	118 + 2500	11.2	79.5	7.3
LRLY	Nil	0	11.8	79.1	8.2
	Trifluralin	1700	11.4	80.1	8.7
	Trifluralin + Avadex Xtra	1700 + 2000	12	78.9	9.7
	Boxer Gold	2500	11.4	80.8	8.1
	Sakura	118	11.4	80.6	8.2
	Sakura + Boxer Gold	118 + 2500	11.6	79.5	7.3
LRHY	Nil	0	10.2	81.1	6.9
	Trifluralin	1700	10.3	81.2	7.8
	Trifluralin + Avadex Xtra	1700 + 2000	10	80.3	7.5
	Boxer Gold	2500	10.3	81.8	8
	Sakura	118	10.4	81.1	7.1
	Sakura + Boxer Gold	118 + 2500	10.5	80.2	8.2

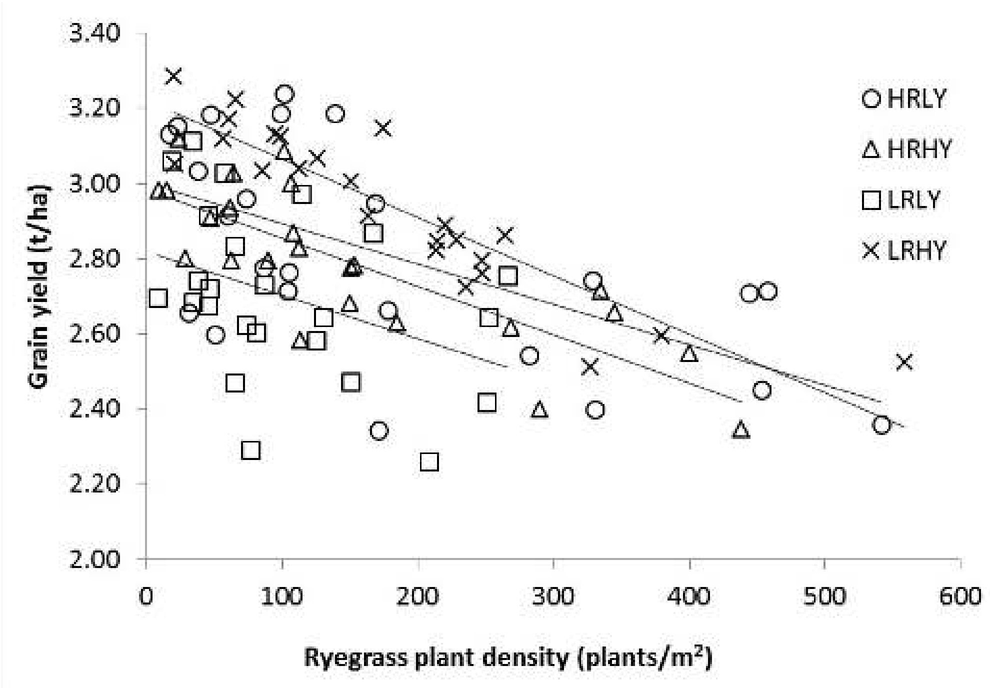

Figure 5.2.b) Wheat grain yield in response to ryegrass plant density. HRLY, y = -0.0011x + 3.00, R^2 = 0.38. HRHY, y = -0.0013x + 2.98, R^2 = 0.63, LRLY, y = -0.0012x + 2.82, R^2 = 0.16. LRHY, y = -0.0016x + 3.22, R^2 = 0.81.

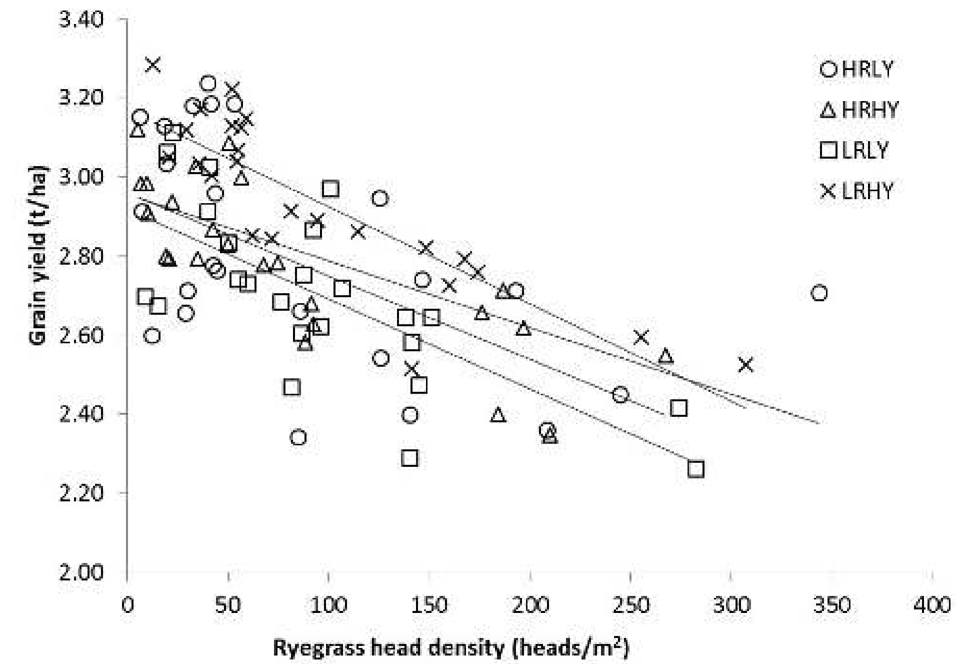

Figure 5.2.c) Wheat grain yield in response to ryegrass head density. HRLY, y = -0.0017x + 2.96, R^2 = 0.27. HRHY, y = -0.0021x + 2.96, R^2 = 0.63, LRLY, y = -0.0023x + 2.92, R^2 = 0.51. LRHY, y = -0.0025x + 3.17, R^2 = 0.74.

Table 5.2.g) Gross margins ($/ha) calculated for each treatment in 2014. Calculations based on wheat price of $270/t and all other variable costs being fixed at $292/ha. Letters denote differences between treatments at 95% probability.

2014 Herbicide	Rate	Herbicide cost	Site			
	(mL or g/ha)	$/ha	HRLY	HRHY	LRLY	LRHY
Nil	0	0	399 .b	401 .bc	388 a	410 ..c
Trifluralin	1700	11	415 .b	394 ..c	382 a	453 .b.
Trifluralin + Avadex Xtra	1700 + 2000	31	430 .b	420 .bc	409 a	484 .b.
Boxer Gold	2500	39	473 a.	459 a..	400 a	472 .b.
Sakura	118	38	473 a.	458 a..	418 a	518 a..
Sakura + Boxer Gold	118 + 2500	77	410 .b	433 ab.	430 a	474 .b.

Partial budget sensitivity analysis

Weed control effects on gross margin are sensitive to herbicide price, herbicide efficacy, grain price, weed density and crop yield loss associated with the weed in question. Sensitivity analysis below has used yield loss figures from HRLY (table 5.2.h) and LRHY (table 5.2.i) as these sites showed the extremes in yield loss in response to ryegrass head density. To produce a positive return from ryegrass control in 2014 at HRLY ryegrass head density needed to be greater than 50 heads/m^2 for herbicides that cost $20/ha or more and have an efficacy of 90% (table 5.2.h). For lower efficacy herbicides the ryegrass density threshold increases for generating a positive return on investment (ROI). At LRHY the grain yield loss in response to ryegrass heads was higher, at 2.5kg/ha per ryegrass head/m^2, compared with 1.7kg/ha per ryegrass head/m^2 at HRLY. At LRHY the ROI for any given combination of herbicide cost, efficacy and weed density was higher and the threshold ryegrass head density where breakeven occurs was lower (table 5.2.i).

Across all sites Sakura averaged 78% efficacy and Sakura + Boxer Gold averaged 91% efficacy at a cost of $38/ha and $77/ha, respectively. Therefore, at HRLY the threshold ryegrass density to break even with Sakura was 107 heads/m^2, whereas Sakura + Boxer Gold was 185 heads/m^2. Ryegrass densities in excess of 664 heads/m^2 were needed before Sakura + Boxer Gold produced a gross margin greater than that of Sakura alone. At LRHY the threshold ryegrass density to break even with Sakura was 73 heads/m^2, whereas Sakura + Boxer Gold was 126 heads/m^2. Ryegrass densities in excess of 445 heads/m^2 before Sakura + Boxer Gold produced a gross margin greater than that of Sakura alone.

Table 5.2.h) Partial budget sensitivity($/ha) over one wheat cropping season in response to herbicide price, herbicide efficacy and ryegrass head density at HRLY, where wheat yield (y) in response to ryegrass head density (x) is, y = -0.0017x + 2.96. Grey shading highlights positive return.

Ryegrass head density	Efficacy = 50%					Efficacy = 70%					Efficacy = 90%				
(heads/m^2)	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha
1	-20	-35	-50	-65	-80	-20	-35	-50	-65	-80	-20	-35	-50	-65	-80
10	-18	-33	-48	-63	-78	-17	-32	-47	-62	-77	-16	-31	-46	-61	-76
30	-13	-28	-43	-58	-73	-10	-25	-40	-55	-70	-8	-23	-38	-53	-68
50	-9	-24	-39	-54	-69	-4	-19	-34	-49	-64	1	-14	-29	-44	-59
100	3	-12	-27	-42	-57	12	-3	-18	-33	-48	21	6	-9	-24	-39
300	49	34	19	4	-11	76	61	46	31	16	104	89	74	59	44

Table 5.2.i) Partial budget sensitivity($/ha) over one wheat cropping season in response to herbicide price, herbicide efficacy and ryegrass head density at LRHY, where wheat yield (y) in response to ryegrass head density (x) is, y = -0.0025x + 3.17. Grey shading highlights positive return.

Ryegrass head density	Efficacy = 50%					Efficacy = 70%					Efficacy = 90%				
(heads/m^2)	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha
1	-20	-35	-50	-65	-80	-20	-35	-50	-65	-80	-19	-34	-49	-64	-79
10	-17	-32	-47	-62	-77	-15	-30	-45	-60	-75	-14	-29	-44	-59	-74
30	-10	-25	-40	-55	-70	-6	-21	-36	-51	-66	-2	-17	-32	-47	-62
50	-3	-18	-33	-48	-63	4	-11	-26	-41	-56	10	-5	-20	-35	-50
100	14	-1	-16	-31	-46	27	12	-3	-18	-33	41	26	11	-4	-19
300	81	66	51	36	21	122	107	92	77	62	162	147	132	117	102

5.3 Discussion

Yield loss in response to ryegrass head density ranged from 1.7kg/ha per ryegrass head/m^2 at HRLY up to 2.5kg/ha per ryegrass head/m^2 at LRHY (figure 5.2.c). A similar yield loss figure that fits within this range was found by Trengove in a ryegrass trial in wheat near Tarlee in 2008, where yield loss was 2.1kg/ha per ryegrass head/m^2.

While the ryegrass control achieved with Sakura + Boxer Gold (average 91%) was significantly better than either Sakura (average 78%) or Boxer Gold (average 76%) on its own, the increase in control was small such that the grain yield of Sakura + Boxer Gold treatments was not significantly better than Sakura at any site and only significantly better than Boxer Gold at LRLY and LRHY. For this reason, and due to the high cost of Sakura + Boxer Gold, Sakura applied on its own achieved the highest or equal highest gross margin at all sites (table 5.2.g). Boxer Gold produced equivalent gross margins at three sites and the application of Sakura + Boxer Gold produced equivalent gross margins at LRLY and HRHY.

The sensitivity analysis shows that high ryegrass densities were required before control with herbicide generated a positive return (table 5.2.h, table 5.2.i). For herbicide such as Sakura that cost \$38/ha and provided on average 78% control a ryegrass density of 107 heads/m^2 or 73 heads/m^2 was required to generate a positive ROI at HRLY and LRHY, respectively. To break even with a higher cost and higher efficacy herbicide treatment like Sakura + Boxer Gold required a ryegrass density of 185 heads/m^2 or 126 heads/m^2 at HRLY and LRHY, respectively. This is based on the yield response in the year of application and does not consider the longer term effects. These thresholds are higher than the authors consider would be acceptable to growers. No case for site specific weed management can be made in this paddock given that all sites had similar high ryegrass densities. However, in a paddock with greater variability in ryegrass density, i.e. densities ranging from 10-200 ryegrass heads/m^2, a case for site specific management could be made, according to the results of the sensitivity analysis.

There is evidence that the sites respond differently to weed control, with yield loss ranging from 1.7-2.5 kg/ha per ryegrass head/m^2, but the order of increasing yield response does not conform to the classification of sites as high or low yield potential. Indeed, the yield of all four sites was similar.

Users guide for site specific weed management

What is the problem?

Weeds **are not** uniformly distributed across paddocks. Despite this, most weed control tactics **are** applied uniformly across paddocks, regardless of the weed density. This results in inefficient product usage, with the possibility of over or under application of weed control inputs at many locations within a paddock.

What is the solution?

Site specific weed management (SSWM) is the targeting of weed control to where weeds are located. Targeted application of inputs should result in the most efficient use of those inputs.

What is the process for implementing site specific weed management?

There are four main steps in implementing site specific weed management. These are;

1. Identify and locate the target weed,
2. Determine the control tactic for that weed,
3. Apply the control tactic to that weed,
4. Document the application and monitor its success.

1. Identify and locate the target weed

Weed identification and mapping of location can be achieved in several ways. These include :

Ground based visual estimation can produce accurate weed maps. Methods for recording this include touch sensitive screens flagging weed presence and density with GPS location. This can be achieved while performing other paddock operations such as harvest, spraying and spreading, however if the operator is distracted by the primary job of spraying or spreading or by a phone call and forgets to flag a change in weed density then the weed map will be inaccurate. Visual ratings may also be biased by lack of training of observers, fatigue and complexity of observations. Research has shown that this can be useful for detecting higher density weed patches, but accuracy can decline when targeting lower weed density thresholds.

Remote and proximal sensor measurements of vegetation indices, most commonly the normalised difference vegetation index (NDVI), have been used to discriminate weed infestations from weed free crop based on the change in reflectance due to increased biomass associated with increased weed density. Sensing platforms can include satellite, aeroplane, UAV, and vehicle mounted sensors such as Greenseeker, N-Sensor, Crop Circle and Crop Spec.

This technique identifies the location of weed infestations but does not identify weed species. Changes in green leaf area related to changes in weed density are confounded where spatial variability exists in the background crop growth in addition to the weed density as the sensor measurement is responsive to total green leaf area, any variation in crop growth can obscure weed patches or lead to false positives. The success of this approach and the weed densities that can be detected are affected by differences in growth rates of weed and crop, time of emergence, differences in vigour and timing of flowering and maturity. This approach can also be used in the fallow period to identify weed patches. In general, this is an opportunistic approach to mapping weeds that will only be possible when the right set of crop and weed conditions present. That is, when the crop is relatively uniform and the weed patches of interest have sufficient leaf area to affect the vegetative index.

Machine vision weed sensors will be the next generation of sensors that advance the capability of site specific weed management. These sensors identify weeds within a growing crop based on shape parameters from high resolution images. Crop and weed shape features are extracted from the image and compared to a database for classification. Weed identification from shape based features are hampered by occluded or overlapping leaves, wind, variations in plant leaf size and shape as a function of growth stage, and the variable three dimensional orientation of leaves in relation to the machine vision sensor. There are a number of groups working in this space globally. A SAGIT funded project is currently investigating the capability of the H-Sensor for application in South Australian cropping systems. Developed in Germany by Agricon it is designed to identify weeds within a growing crop. It uses leaf shape and size parameters to classify different plants into different shape classifications. The sensor can directly control a sprayer or can be used to generate a map for later use.

Soil type can be used to map some weeds indirectly where weed density is related to soil type. Soil type characteristics can be mapped with sensors such as EM38, gamma radiometrics, Veris pH, Organic Carbon and EC or yield data can be used to identify different production zones that are often related to soil properties. Ground truthing is always required in these situations to ensure the soil zones properly reflect the weed patches. In addition to relationship between soil type and weeds, there can also be relationships between herbicide activity and soil type for soil applied herbicides. The activity, movement and breakdown of herbicides can be affected by pH, organic matter and soil texture and in some cases it may be prudent to vary herbicide rate according to soil type to ensure adequate weed control in each soil while also minimising potential for crop damage.

Many growers have tried "patching out" weeds, usually based on their own observation of the weed patches and the weed map they have in their mind. This can be successful, but often the experience is that they should have sprayed more or sprayed the whole paddock because they missed weeds and this was obvious later in the season when the weeds went to seed. This experience indicates that the weed map was not sufficiently accurate. Either more effort needs to be invested in developing the weed map, or a more robust and reliable method needs to be employed. However, a lack of reliable and robust mapping methods remains the biggest stumbling block to the uptake of SSWM, which current research efforts (such as machine vision sensors) are addressing.

2. Determine the weed control tactic

Available weed control tactics will depend on the weed in question and the crop scenario. A list of weed control options that can be targeted for site specific management are detailed below (table 1). This is not an exhaustive list but covers those techniques most readily available to the majority of growers.

In some instances, options for herbicide control will be limited to pre-emergent options due to herbicide resistance. For example, ryegrass control with herbicides in cereal crops in many paddocks is limited to pre-emergent herbicides, with no effective post emergent herbicides. Pre-emergent herbicides will often be applied before there is an opportunity to map weed distribution in that season, as the weeds have not yet emerged. Therefore, site specific herbicide application will require a historic weed map from a previous season. Some weed species are more suitable to this application than others. Weeds that are stable in their location from one season to the next are more suitable. For example, weeds such as ryegrass are relatively stable in their patches. This is due to its seed dispersal being limited to a few meters naturally and generally less than 20 m from harvester or other machinery movement. Other weeds can be moved further, up to 100 m from harvester and machinery movement. To account for weed seed movement a buffer can be added to the historical weed map, for example a 20 m buffer could be added to an historical ryegrass map from the previous season. This can be reduced if techniques to capture or destroy weed seeds in the harvester chaff is implemented. These techniques include the use of chaff carts, seed destructors or narrow windrow burning. Weeds that may be less suitable for patch management from historical maps include species that use wind dispersal to spread their seed longer distances and in unpredictable directions, such as flea bane.

Table 1. Steps 2 & 3: What are the control strategies and how are they applied?

Site specific control	Requirements and comments
Cultural methods	
Hay cutting and baling	Hay equipment and a weed map
Stubble burning	A fire break around the weed patches
Increased crop competition through higher seed rates	A georeferenced prescription map based on weed density can be used to automatically adjust crop seed rates. This is reliant on a historical weed map. Most modern sowing equipment is now fitted with GPS ready rate controllers. Alternatively seed rates can be doubled by completing a second pass with the seeder, or adjusted by using a manually operated variable seed rate controller.
Brown manuring	High density weed patches in crop can be sprayed out non-selectively (usually with glyphosate or glyphosate mixes) before seed set but all income is foregone from those patches in that year.
In crop herbicide control	
On/off decision	A conventional boom spray and a weed map. Can be set up for automatic switching through a rate controller or switched on/off manually by the operator.
Add an extra herbicide to a base tank mix where the weed patches occur	The only way this can be achieved with a standard boom spray is by spraying the base tank mix in one application and then completing another pass over the field with the additional herbicide and only turning on the boom over the weed patches. A boom set up with direct injection and dual lines can achieve this in one pass. The base mix is mixed in the tank and sprayed through the first boom line. Additional herbicides can be injected into the second boom line, which is also primed with the base tank mix. When the additional herbicide is required the second boom line is switched on and the first boom line switched off. Note. Direct injection into a single line alone cannot be used for variable rate herbicide application due to the long lag time from the point of injection to the time it reaches the last nozzle.
Adjust the rate of a herbicide mix	Currently the only way rates can effectively be adjusted in real time is by adjusting the spray carrier volume as this can be changed instantly and equally across the boom. Limitations to this process include the relationship between nozzle flow rate and droplet size distribution, and all herbicides in the mix are altered by the same percentage. With conventional booms and nozzles the limitation of the nozzle flow rate restricts the amount the carrier volume can be varied, however this can be partially compensated by adjusting ground speed. Dual line systems, Variable orifice nozzles (VariTarget), nozzle banks (Arag Seletron and Hypro Duo React), and pulse width modulation (Aim Command Case IH, Pinpoint Capstan, Hawkeye Raven and Dynajet Flex 7120 TeeJet) and nozzle banks provide greater flexibility in flow rate and so carrier volume can be varied more widely without sacrificing ground speed. Flow rates from 1X up to 8X can be achieved at the same ground speed. The latter two options allow independent rate control of the individual nozzle, increasing application resolution compared with most other options that operate at the resolution of the boom section or whole boom.

Apply a different herbicide mix to different weed zones.	Multi tank boom sprays are designed as two or more sprayers on the same chassis. The unit consists of two or more tanks and each has a separate pump, lines and nozzles that can be controlled independently. Different herbicides or herbicide mixes can be added to each tank and they can be turned on or off based on separate prescription maps. The rates of each tank mix can be varied as for a normal boom. There are examples of growers plumbing a second (smaller) tank into the second boom line allowing two different tank mixes to be applied independently.

Strategies for variable rate herbicide application



Direct injection
Arag Seletron


Multi tank boom

4. Documentation

Documentation is important for compliance, quality assurance and for future reference. Knowledge of herbicide use and other weed control tactics is important for understanding herbicide resistance issues and potential plant back issues in cropping rotations. Therefore it is important to have an accurate record of where treatments have been applied. Applications of herbicide and seed controlled by a GPS connected rate controller should record as applied rates. This data can be downloaded to mapping software for safe storage and reference. Other treatments targeted without the use of GPS recording should at least be documented through your normal record keeping process.

When does SSWM pay?

In terms of herbicide use, the most common benefit cited for SSWM is the herbicide savings calculated as the amount of herbicide used to spray the weed patches compared with what would have been required to treat the whole paddock uniformly with a full rate. It should be noted that the economic benefit of SSWM cannot exceed the cost of the control strategy used, unless the control strategy has a negative impact on the crop that affects yield. For this reason the payback from SSWM is greatest with high cost weed control options.

The economic benefit associated with SSWM is also related to the proportion of the field that is weed infested, the number of weed patches and the spatial resolution of mapping and spraying. The greatest savings are achieved when only the weed plants are targeted (Table 2). For example, if individual weeds are targeted with a full width boom or boom section there is much more wastage and much smaller savings than if a single nozzle is switched on to control the individual weed. Further reductions in herbicide use can be achieved if only the leaves of weeds are targeted so that none is wasted on the soil surface or crop plants, however increasing resolution of mapping and application also incurs higher costs.

Table 2: herbicide saving ($/ha) averaged across whole paddock when only patches are treated.

Normal herbicide cost ($/ha)	Treated area (% of total paddock)			
	100%	75%	50%	25%
10	0	2.5	5.0	7.5
20	0	5	10	15
30	0	7.5	15.0	22.5
40	0	10	20	30
50	0	12.5	25.0	37.5
60	0	15	30	45
70	0	17.5	35.0	52.5

Economics of weed control are sensitive to treatment cost, efficacy, grain price, weed density and crop yield loss associated with the weed in question. Trials were conducted in this project focusing on brome grass and ryegrass. Trials in two paddocks found grain yield loss in response to weed head density varied between 2.4-8.2 kg/ha per brome grass head/m^2 and 1.7-2.5 kg/ha per ryegrass head/m^2. Partial budget sensitivity shows how the threshold weed density at which a positive return on weed control investment is made is sensitive to treatment cost, efficacy and grain yield loss (Table 3 and Table 4). It also shows that in paddocks with high variability in weed density the return on weed control investment is equally variable and investing more on improved weed control in high density patches can be justified. This sensitivity analysis is based on only one year's response to weed control. It is known that weed control in one year will reduce weed burden in subsequent years through reduction in weed seed production, improving the return on investment in weed control. When longer time periods are considered the threshold density for weed control are much lower.

Table 3: Partial budget sensitivity ($/ha) in a wheat crop in response to herbicide price, herbicide efficacy and brome grass head density, where wheat yield (y, t/ha) in response to brome head density (x) is, y = -0.0069x. Grey shading highlights positive partial budget. Grain price = $270/t.

Brome head density	Efficacy = 70%					Efficacy = 90%					Efficacy = 100%				
(heads/m^2)	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha
1	-19	-34	-49	-64	-79	-18	-33	-48	-63	-78	-18	-33	-48	-63	-78
10	-7	-22	-37	-52	-67	-3	-18	-33	-48	-63	-1	-16	-31	-46	-61
30	19	4	-11	-26	-41	30	15	0	-15	-30	36	21	6	-9	-24
50	45	30	15	0	-15	64	49	34	19	4	73	58	43	28	13
100	110	95	80	65	50	148	133	118	103	88	166	151	136	121	106
300	371	356	341	326	311	483	468	453	438	423	539	524	509	494	479

Table 4: Partial budget sensitivity ($/ha) in a wheat crop in response to herbicide price, herbicide efficacy and ryegrass head density, where wheat yield (y, t/ha) in response to ryegrass head density (x) is, y = -0.0021x. Grey shading highlights positive partial budget. Grain price = $270/t.

Ryegrass head density	Efficacy = 50%					Efficacy = 70%					Efficacy = 90%				
(heads/m^2)	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha	$20/ha	$35/ha	$50/ha	$65/ha	$80/ha
1	-20	-35	-50	-65	-80	-20	-35	-50	-65	-80	-19	-34	-49	-64	-79
10	-17	-32	-47	-62	-77	-16	-31	-46	-61	-76	-15	-30	-45	-60	-75
30	-11	-26	-41	-56	-71	-8	-23	-38	-53	-68	-5	-20	-35	-50	-65
50	-6	-21	-36	-51	-66	0	-15	-30	-45	-60	6	-9	-24	-39	-54
100	8	-7	-22	-37	-52	20	5	-10	-25	-40	31	16	1	-14	-29
300	65	50	35	20	5	99	84	69	54	39	133	118	103	88	73

Other benefits of SSWM include reduced overall herbicide use, with potential environmental and social benefits. Increasing regulation and restrictions on herbicide use is a threat to business operation. Targeting herbicides only to where they are required will allow equivalent weed control but with much less herbicide use.

Case studies

Richard Rackham
Location: Red Hill, South Australia
Rainfall: 405mm, GSR: 295mm
Soil Types: Clay loam

Target weed: ryegrass

Richard targets ryegrass in a range of ways to stay on top of the ryegrass seed bank, including both herbicide and cultural controls. Ryegrass patches are logged on Richard's sprayer console by visually identifying the patch and 'flagging' the perimeter. A flag is dropped as the sprayer enters and then exits the patch on each swath. This can be performed while completing any other spray applications in that paddock. Richard started doing this on a KEE Lynx in 2002, followed by an X15, and has continued the process on a Trimble FMX screen he purchased in 2013.

These maps are then recalled for a variety of purposes. These include

- Desiccation. Before the ryegrass has set any viable seed Richard will desiccate the weeds and crop with glyphosate to prevent any seed set. This often sacrifices the crop too, and can be considered a targeted brown manure. This is usually in field peas, but sometimes in cereals.
- Hay cut. Ryegrass patches in wheat and barley crops will be cut for hay, providing excellent control.
- Windrow burning. Where patches can be targeted in an efficient manner, for example one end of a paddock, the harvester will be setup to drop the straw and chaff in windrows for windrow burning. These are subsequently burnt to control the weed seeds.
- Stubble burning. In some instances a fire break will be ripped around the ryegrass patches so that the stubble can be burnt after harvest to help reduce weed seed numbers. In addition to destroying some weed seeds the removal of stubble increases the herbicide efficacy of some soil applied pre emergent herbicides by minimising binding of the herbicide to stubble.

These control tactics are targeted in combination with other strategies that treat the whole paddock including knockdown sprays, pre emergent herbicides, grass selective herbicides in legumes, spray topping in legumes and oaten hay crops. Using a sequence of targeted and whole of paddock treatments allows problem ryegrass areas to receive high levels of control in three consecutive seasons and drive seed banks down. The result has been to maintain ryegrass populations at low levels, where the targeted site specific treatments are targeting less than 10% of a paddock.

Leigh Bryan
Location: Swan Hill, Victoria
Rainfall: 312mm, GSR: 174mm
Soil types: variable dune/swale Mallee soils

Target weeds: brome grass, ryegrass, wild oats, wild radish and skeleton weed have all been targeted site specifically on Leigh's property at some point.

Wild radish and skeleton weed: Leigh used visual identification to target these weeds between 2007 and 2010, which he says are now largely under control. Wild radish was targeted in the lentil phase and skeleton weed in the summer fallow period.

While spraying for heliothis grubs in lentils late in the season wild radish can be clearly visible. Using Leigh's boom spray setup with direct injection and a second boom line he was able to spike the wild radish patches on-the-go with glyphosate to desiccate these patches and stop seed set, effectively brown manuring, while at the same time applying insecticide to the whole paddock. This resulted in 15% of the paddock being sprayed with glyphosate. Similarly, during his summer spray operation Leigh would apply a base application of glyphosate, triclopyr plus oil to the whole paddock, but where he identified skeleton weed he would spike the mix with 2,4-D amine at 1.2 L/ha for improved control, which proved highly effective. Again only 15% of the paddock required treatment with 2,4-D amine (Figure 1). Visual identification only allows daylight operations when the weeds can be seen. To negate this Leigh logged the application of where the 2,4-D amine was applied in the first season and this was then used for targeting skeleton weed patches in subsequent years when spraying at night.

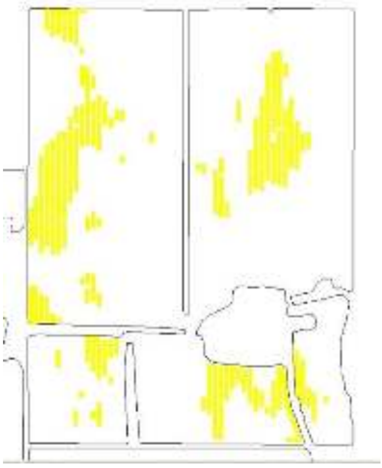

Figure 1: yellow areas show patches of skeleton weed where 2,4-D amine was spiked at 1.2 L/ha. This amounted to 46 ha out of a total of 318 (15%).

Leigh's boom is a dual boom setup, that has Dosatron direct injection systems plumbed into the second boom line that inject herbicide directly into the second line (Figure 2). A base tank mix that is applied to the whole paddock is mixed in the main tank and applied through the first boom line. Where an additional spike is required the second boom line is switched on and the first boom line is switched off. The second boom line is primed with the base tank mix and the spike chemical injected through the Dosatron. Dosatron is a water-powered proportional dosing pump. Therefore, when the second boom line is switched on and there is flow past the Dosatron it injects the spike herbicide and then when the second line is switched off and flow ceases the Dosatron stops. This setup allows for instantaneous switching between the two herbicide mixes with and without the spike and no lag.

Figure 2: Dosatron units fitted to Leigh Bryan's sprayer for dosing an additional chemical into the second boom line.

Brome grass, ryegrass and wild oats: Leigh has used NDVI images to detect grass weeds in legume crops (Figure 3). This works on the principal that the crop has relatively uniform growth and the variability detected in the NDVI is due to variability in weed density. Leigh comments that "this worked ok, but everything had to be right". Issues that reduced the reliability of detecting weeds this way occurred when there was too much variability in crop growth and in weed densities too low for NDVI to detect. When this occurs weeds growing in areas of low crop vigour can be missed due to the low NDVI signal of the crop. These maps were used to target pre emergent herbicide in the following wheat crop targeting brome grass, wild oats and ryegrass. Trifluralin and Avadex Xtra were applied to the whole paddock, with rates increased in the zones where higher weed densities were identified. These rates were varied by changing spray volume of the tank mix. The rate range was limited by the pressure range of the nozzle, droplet size and travel speed.

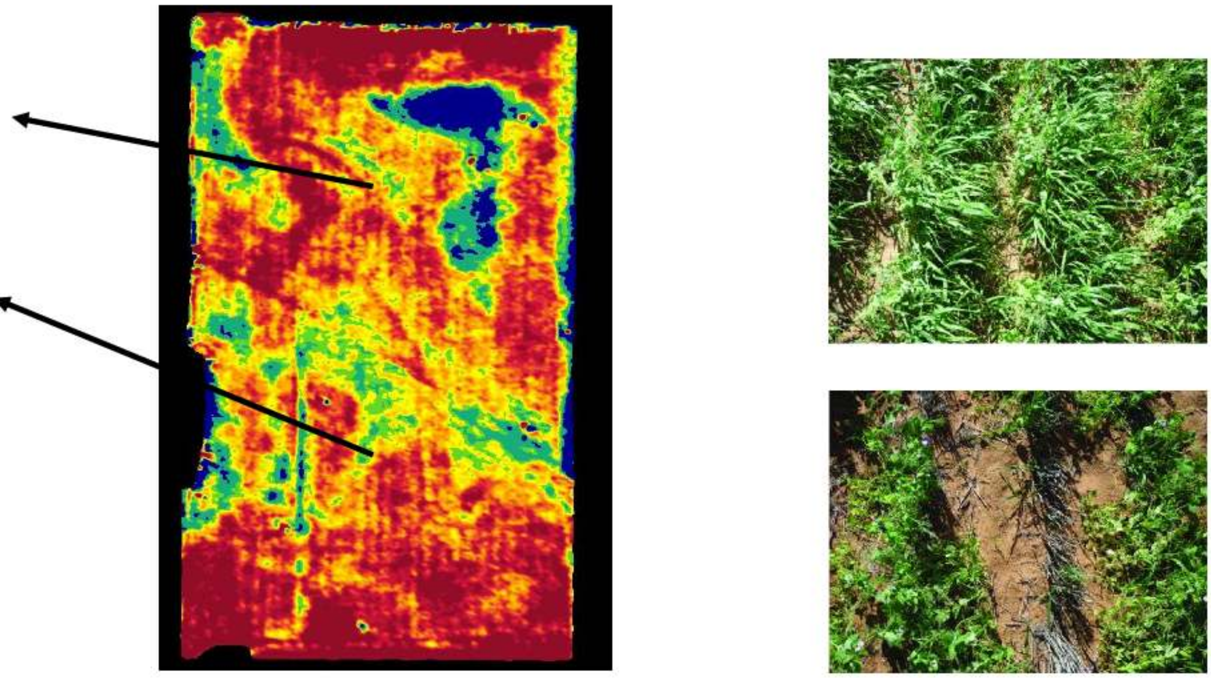

Figure 3: NDVI image of a field pea crop with patches of brome grass, wild oats and ryegrass. Grass weed patches are represented by high NDVI in blue and green.

Soil types: farming in the Victorian Mallee Leigh encounters a variety of soil types. These range from light textured sands with low organic matter to heavier clay loams with moderate organic matter. Soil applied herbicides generally have more herbicidal activity and are more mobile in the coarse textured sands where they are low in organic matter and clay content. This can increase the risk of crop damage from soil applied herbicides on these soil types. To counter this risk in chickpeas, Leigh has varied the rate of Balance herbicide according to soil type, reducing rates on the coarser textured sandy soils to reduce the risk of crop damage. This application required an extra pass of the boom spray. Balance is normally applied with the knockdown herbicide and other pre emergent herbicides that Leigh did not want to vary. Given Balance is a water dispersible granule (WDG) formulation which is not compatible with direct injection with the Dosatron without premixing. Also, as the Balance rate was varied between 50 and 100 g/ha, if applied through the Dosatron in the second line it would require the first boom line to be varied at the same time to maintain a constant rate of knockdown and pre emergent herbicides, which was not possible. Therefore, the knockdown and pre emergent herbicides were applied in one pass and Balance applied in a second pass and rate was varied by adjustment of water volume.

<u>Daniel Adams</u>
Location: Cockaleechie, South Australia
Rainfall: 410mm, GSR: 330mm
Soil types: Red brown earth, Loam over clay, Buck shot gravel, acidic grey sandy-loam

Target weed: ryegrass

Daniel Adams has been controlling ryegrass on his property using a variety of measures including herbicides, crop competition and harvest weed seed control. He has found ryegrass to be worse on certain soil types, these soils often are a combination of low pH (< 5, $CaCl_2$), coarser textured, buckshot gravel soils. These soils are often low yielding, particularly in the presence of high ryegrass populations. Using his history of yield data Dan combines yield maps from bad ryegrass years where low yield represents zones with ryegrass to produce a prescription map for targeting herbicide and seed (Figure 4). These maps are used to target pre emergent herbicides such as Sakura, Boxer Gold, Avadex Xtra and trifluralin. The maps are loaded onto his John Deere Greenstar 3 controller that controls his Hardi boom spray, where herbicide rates are varied by changing spray volume. Rates are increased by 15-25% in ryegrass zones, resulting in an average rate increase of 4-5% across the whole paddock. A 25% increase is achieved by increasing spray volume from 80 L/ha to 100 L/ha. Issues with pressure and droplet size can occur with rate changes over 15% and Dan adjusts (reduces) speed to compensate. Dan's strategy has been to use full rates as the standard treatment and then increase rates in the ryegrass areas. The pre emergent herbicides are generally in a mix with a knockdown herbicide such as paraquat and so this is also increased in the ryegrass areas. Daniel believes this is a sound strategy in targeting these problem zones, with increased paraquat rate and increased water rate improving control of ryegrass present in those zones at the time of application.

In addition to herbicides Dan will also use the same prescription map to control his seed application. In wheat Dan will target 220 plants/m^2 in the low density ryegrass zone and increase this to 250 and 280 plants/m^2 in the medium and high density ryegrass zones, respectively. By increasing seed rate the aim is to increase competition with the ryegrass and reduce its seed set.

Lime has been spread on the property to increase pH on acidic soils with applications targeted to the acidic soil types, which is often where the ryegrass is located. Increasing soil pH has improved crop growth in the acidic soils thereby increasing competition with the ryegrass and helping to outcompete it. Dan is also suspicious raising the soil pH has increased the herbicidal activity of the soil applied pre emergent herbicides on those soils also helping to combat the ryegrass.

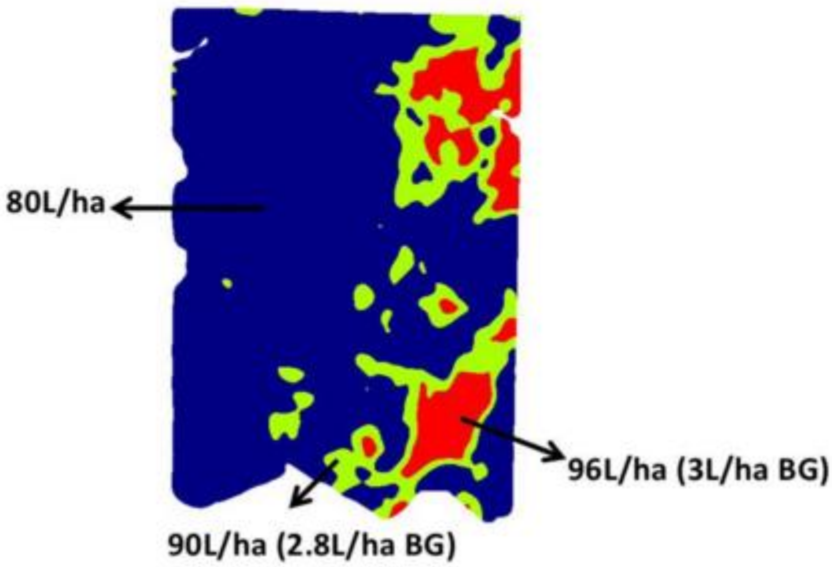

Figure 4: Pre emergent herbicide prescription map for targeting ryegrass, where the blue zone receives the base rate of 2.5 L/ha Boxer Gold (80 L/ha volume), green zone 2.8 L/ha Boxer Gold (90 L/ha volume) and red zone 3 L/ha Boxer Gold (96 L/ha volume).

Rod & Wayne Sherriff
Location: McLaren Vale, South Australia
Rainfall: 450mm, GSR: 340mm
Soil types: Loam over limestone, cracking clays and light sands

Target weed: ryegrass

Cutting and baling hay can provide excellent ryegrass control. However for many growers there is a limit to how much hay can be managed successfully due to the workload and machinery required. As a result the area dedicated to hay in a rotation is often limited. The Sherriff brothers have extended the utility of hay on their property by targeting problematic ryegrass patches in paddocks and cutting them for hay, while taking the remainder of the crop through for grain (Figure 5). By doing this they are able to maximise the agronomic weed control benefit of their hay program, while also maximising profit on the low weed zones by harvesting them for grain.

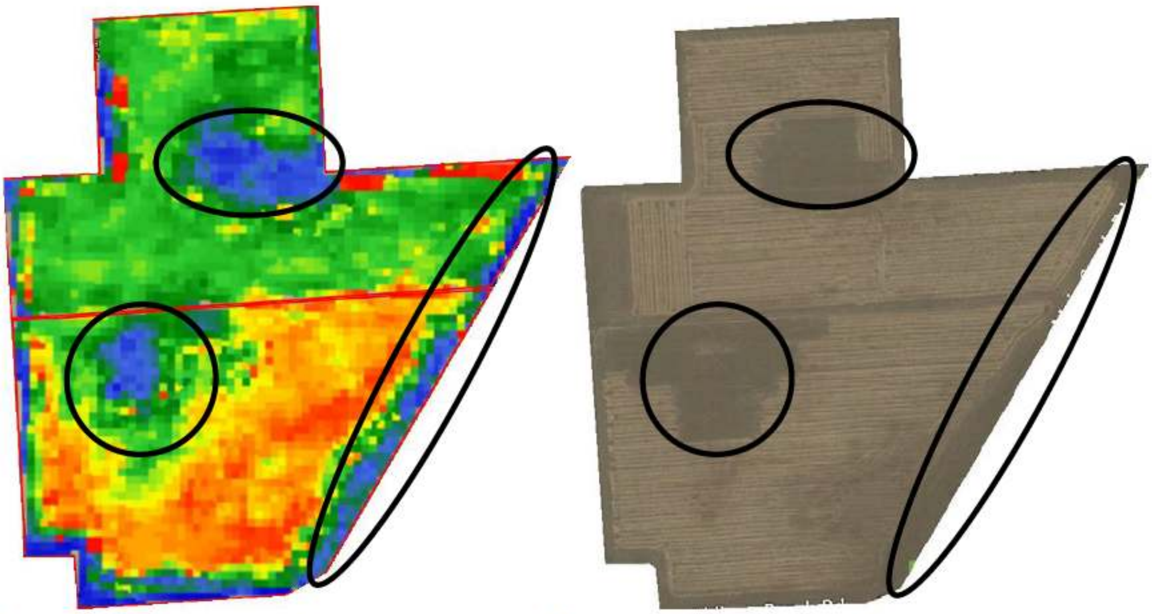

Figure 5: Left, Landsat NDVI image showing high density ryegrass patches in crop and right, post harvest Google Earth image showing regions that were subsequently cut for hay.