

Improved weed management in irrigated cotton production systems: Reducing dependence on residual pre-plant and pre-emergent herbicides.

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Introduction

The Australian cotton industry has, until recently, relied largely upon residual pre-plant and pre-emergent herbicides for weed control in irrigated production systems. These herbicides provide good protection against a broad spectrum of weeds. In some circumstances, however, residual herbicides adversely impact the growth and development of young cotton seedlings. This is particularly the case when cool wet conditions occur early in the cotton season. As well, the majority of these herbicides have a half-life of three to four months and may persist for long periods when bound to clay particles within the soil profile. Movement of these molecules bound to clay particles is common in irrigated systems. While procedures to minimise riverine contamination are in place on irrigated farming systems, herbicides are routinely detected in the river systems of the central and north-west regions (Table 1). It should be noted that of these detections atrazine and metolachlor are the only herbicides detected in significant amounts and these are used extensively in dryland sorghum.

Table 1. The number of occasions herbicides were detected in the river systems of the central and northwest regions (source M. Muschal, 2001).

Herbicide	96/97	97/98	98/99	99/00
Desethyl Atrazine	8	12	20	45
Diuron	27	56	84	87
Fluometuron	37	91	86	80
Hydroxy Atrazine	6	15	14	17
Metolachlor	24	40	65	58
Pendimethalin	2	3	1	1
Prometryn	45	61	33	37
Simazine	0	3	10	2
Trifluralin	0	1	1	0

With the introduction of cotton varieties that have the capacity to continue to grow and function normally after over-the-top applications of Roundup Ready® herbicide, the opportunity exists to reduce or eliminate inputs of residual herbicides on some fields. A study was initiated by the Australian Cotton Co-operative Research Centre to identify fields with low weed pressure in which it may be possible to eliminate the use of residual herbicides and thus reduce adverse herbicide effects on cotton seedlings and potentially reduce contamination of riverine ecosystems.

Materials and Methods

Weed surveys

In the first year of the study, weed surveys were undertaken in each of four fields on 25 irrigated cotton farms from Hillston in Southern NSW through to Biloela in Central Queensland. The abundance of each weed species per metre of row was determined along 50 metre transects for each of these fields. One hundred soil cores (20 cm deep x 10 cm diameter) were taken from each of 13 fields identified as having low weed pressure to determine whether the observed weed populations were in fact low or whether herbicide effects were masking the actual weed population (Figure 1).

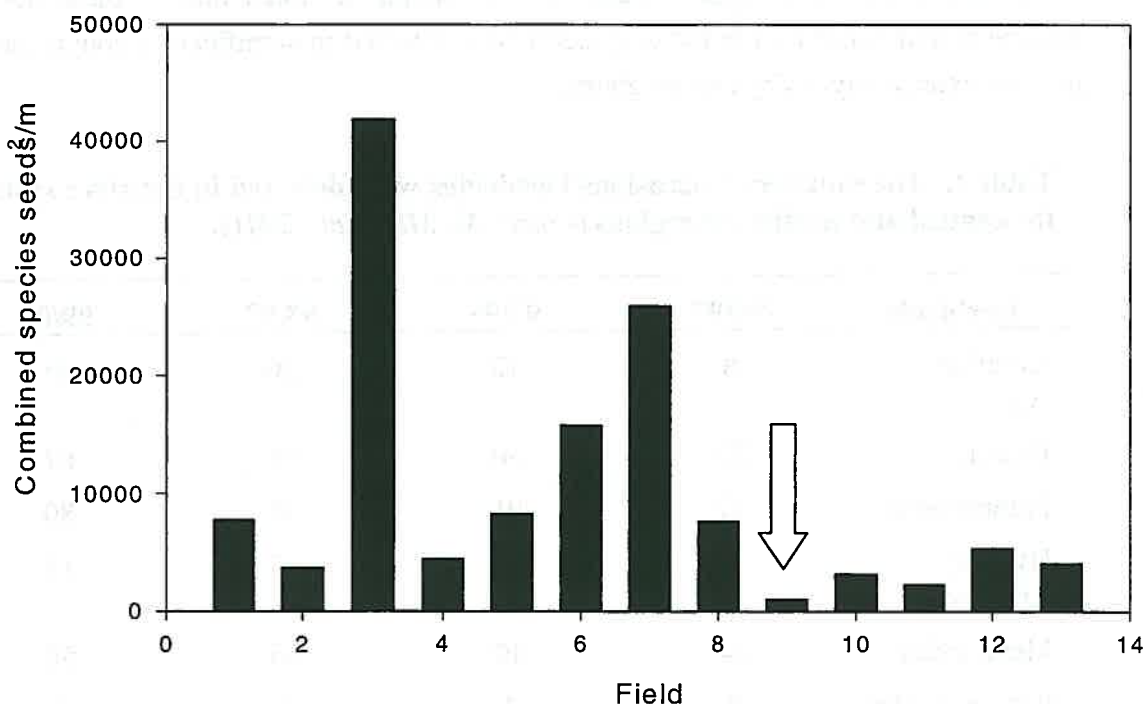


Figure 1. Mean viable weed seeds/m² taken from 13 irrigated cotton fields (n =100). The highlighted field (Biloela) was the field selected for the reduced herbicide trial.

Field trials

Duplicate field trials were established during the 2001/2002 cotton season. The first of these was located at Biloela, while the second was located at the Australian Cotton

Research Institute (ACRI) at Narrabri. The trial site at ACRI was known to have a very high weed pressure and weeds could be allowed to set seed without causing detrimental effects to a commercial field. The field at ACRI was used to determine the upper threshold limit where the use of the Roundup Ready® technology alone would be insufficient to control weed pressure.

Soil sampling

Prior to the application of the herbicides, soil cores were taken from each of the trial plots to establish the viable seed bank density in each of the plots. Ten soil cores were taken from each plot and pooled for each treatment to determine the average weed pressure across each of the treatments (Figure 2). The soil cores were washed through 0.5 mm² stainless steel mesh screens in an automated soil washer. The remaining organic fraction from each screen was then placed onto a sand/peat moss media in a glass-house to germinate. The number of weeds germinating was counted and the seedlings removed from the container.

Herbicide treatments

Biloela

Eleven herbicide treatments (Table 2) were evaluated for their ability to control weeds at each of the trial locations. The experimental design was a randomised complete block with 4 replicates of each treatment. An application of Roundup Ready® herbicide (1.5 kg/ha) was applied at planting to all of the trial plots except to the untreated control and weed free control plots. An over-the-top application was made at the four true leaf stage in November to all plots, with the exception of the untreated control and the weed free control. After the over-the-top application of Roundup Ready herbicide the weed pressure remained very low. It was decided that it would be unnecessary to apply a further two directed application of Roundup Ready herbicide. Instead those treatments relying solely on Roundup for weed control received one directed application of Roundup Ready herbicide, while those having either a Staple or Enfield treatment received these as an over-the-top application.

ACRI

Due to the greater weed pressure at the ACRI trial site, three in crop applications of Roundup Ready® herbicide as per the label instructions were made, as well as an application of either Staple® or Enfield®, as illustrated in Table 2.

Weed assessments

Counts to determine the number of weeds surviving the treatments and the number of new weeds emerging were performed in mid-December, January and February for the Biloela trial site and 10 days after treatment at the ACRI trial site. The abundance of each weed

species was recorded from two randomly positioned quadrats (1 m²) in each plot. The seed return for each of the treatments was estimated by counting the number of plants remaining in each of the plots at the end of the treatments and multiplying the number of plants by the average number of seeds produced for each weed species.

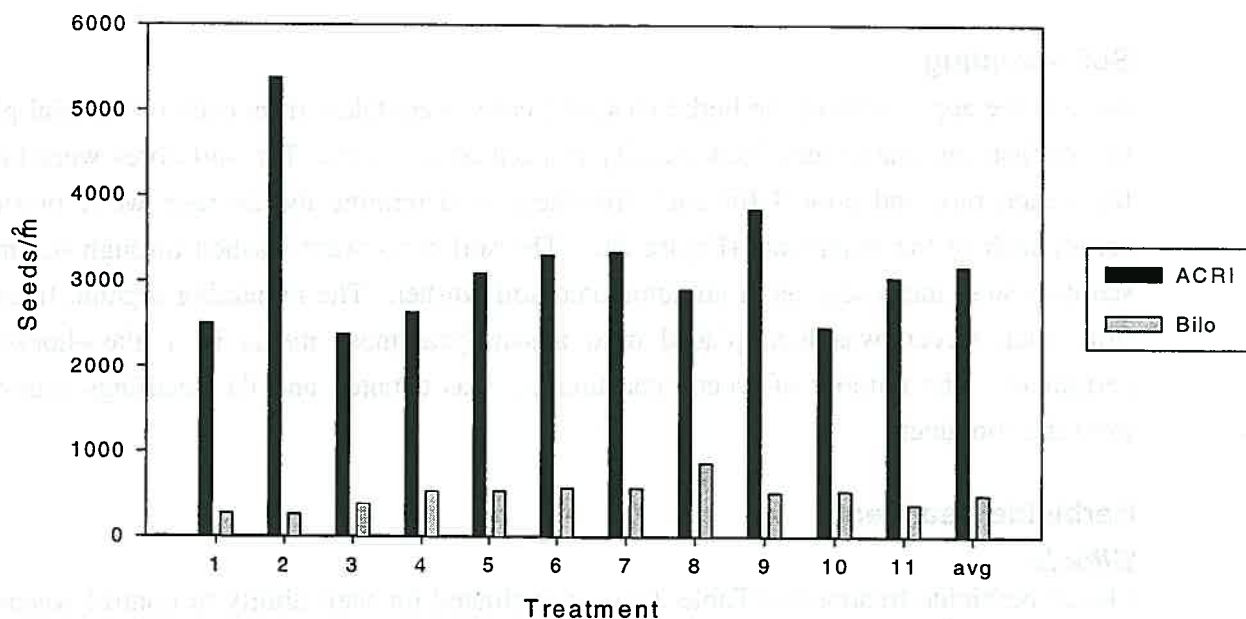


Figure 2. Mean number of viable seeds across each of the treatments for plots located at the Australian Cotton Research Institute and Biloela.

Table 2. Herbicide treatments evaluated at the ACRI and Biloela trial sites.

Treatment	Herbicide Regime
1	Prometryn + Stomp pre-plant (full rates) + Roundup Ready x 3 (1.5 kg/ha)
2	Prometryn + Stomp pre-plant (half rates) + Roundup Ready x 3 (1.5 kg/ha)
3	Roundup Ready x 3 (1.5 kg/ha)
4	Weed free Control
5	Untreated Control
6	Prometryn pre-plant (half rate) + Roundup Ready x 3 + Enfield 15 g/ha
7	Roundup Ready x 3+ Enfield 15 g/ha
8	Roundup Ready x 3 + Enfield 30 g/ha
9	Prometryn pre-plant (half rate) + Roundup Ready x 3 + Staple 60 g/ha
10	Roundup Ready x 3 + Staple 60 g/ha
11	Roundup Ready x 3 + Staple 120 g/ha

Yield assessments

Four one metre row lengths were hand harvested from each of the 44 plots at Biloela to determine the yield for each treatment. Plots were harvested at the ACRI site using a single row picker. Further soil seed bank measurements will be undertaken in each of the plots to fully determine seed recruitment or seed decline once stubble mulching and pupae busting are completed.

Results.

Weed counts at the ACRI trial site

Weed pressure at the ACRI site was very high, with greater than 250 weeds/m² being observed in the untreated control plots (Figure 3). The majority of weeds in the untreated control plots were liverseed and barnyard grass. However, in plots that received herbicide treatments, the major weed species were bladder ketmia, chinese lantern, dwarf amaranth and red pigweed. Best control in these plots during November and December was achieved using full rates of prometryn and pendimethalin, applied six weeks prior to planting, in conjunction with an over-the-top application of Roundup Ready® herbicide at planting. The level of control achieved was in fact greater than is shown on the graph. This is because the counts were undertaken 10 days after herbicide application to allow the glyphosate to have maximum effect. During this time, a number of new weeds germinated, in particular red pigweed, barnyard grass and liverseed grass, giving a higher weed count than should have been the case. The next best treatment was treatment six, the half rate of prometryn in conjunction with Roundup Ready® herbicide. While treatments two and nine also consisted of a half rate of prometryn, the number of seeds contained in the soil seed bank (Figure 2) were much greater in these two treatments. Consequently, the graph does not truly reflect the level of control achieved in these treatments. The weed counts performed in January at ACRI reflect the combined effect of the two final herbicide applications and an inter-row cultivation. The weeds remaining in the plots are those that were in the plant line and were not controlled by the directed application of Roundup Ready® herbicide. While the Staple® and Enfield® applications were applied in this field, the spectrum of weeds present during this time was not those recommended for control on the herbicide labels. Consequently, Staple® and Enfield® had little impact on the weed abundance at the ACRI site.

Weed counts at the Biloela trial site

A Roundup Ready herbicide application (1.5 kg/ha) at planting, in conjunction with an over-the-top application of Roundup Ready herbicide (1.5 kg/ha) at the four true leaf stage, provided excellent control of the majority of weeds present in the experimental plots at Biloela (Figure 4). A directed application of Roundup Ready® herbicide was applied to treatments 1, 2, and 3 on December 18. Enfield® was applied to treatments 6, 7, and 8, while treatments 9, 10, and 11 were sprayed with Staple® to control the few sesbania pea

and bellvine plants emerging at this time. Counts were performed in early-January. A light chip was conducted at the northern end of the field for Bellvine control in late December and 2 inter-row cultivations (early-December and early-January) were used to control weeds in the furrow. No further herbicide applications were required after those applied on December 18 at the Biloela trial site.

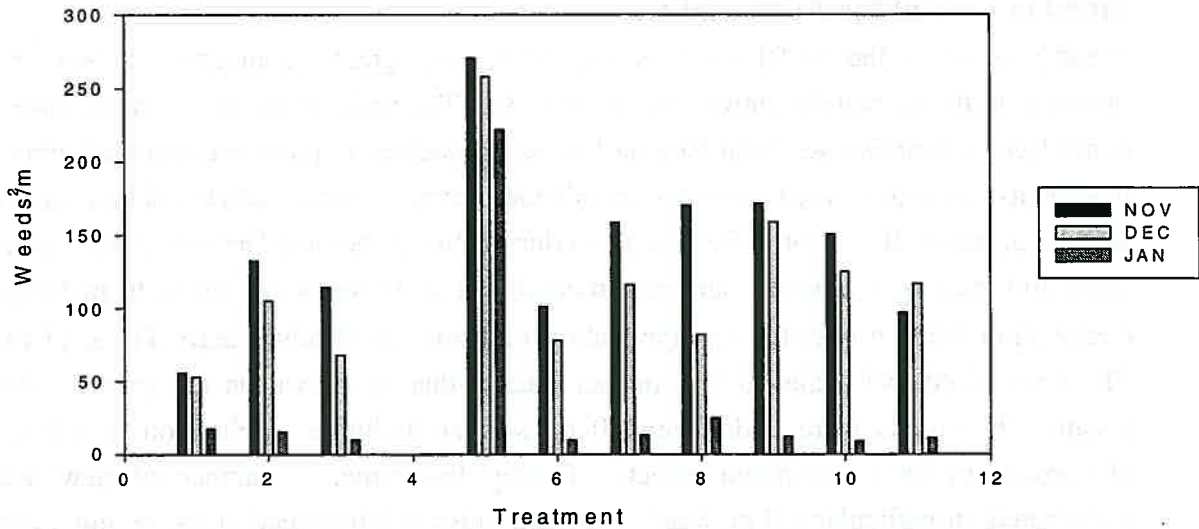


Figure 3. Mean weed counts from 1 m² quadrats for 10 herbicide treatments at the ACRI trial site

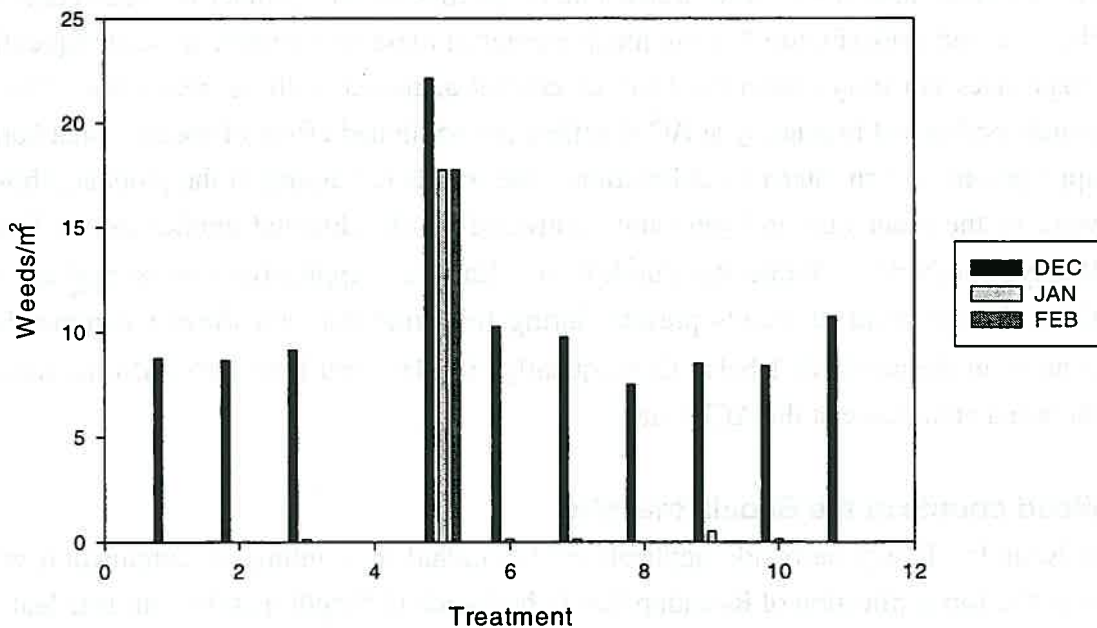


Figure 4. Mean weed counts from 1 m² quadrats for 11 herbicide treatments at the Biloela trial site.

Seed return

An estimate of the seed being added to the soil seed bank at the ACRI site was made for each plot based on the number of surviving plants remaining after treatment and the average number of seeds produced per plant for the particular species (Figure 5).

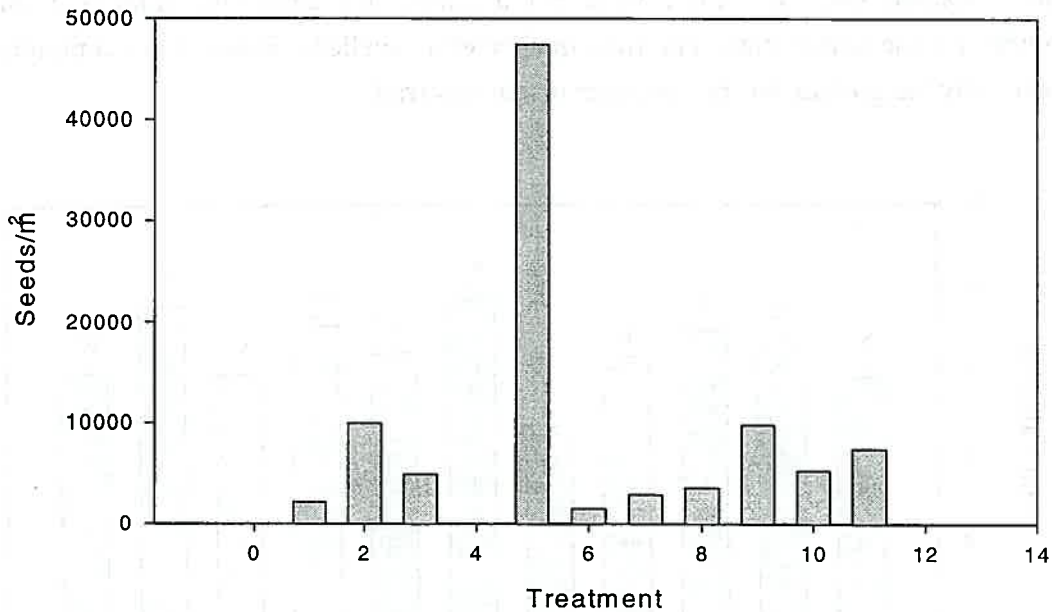


Figure 5. Seed return to the soil seed bank from each of the 11 herbicide treatments used at the ACRI field site.

Yield

Biloela

Yields from each of the treatment plots at the Biloela site varied from 7 bales/ha (untreated control) through to 10 bales/ha (treatment 6, ½ rate of prometryn plus Roundup Ready® plus Enfield) (Figure 6). Treatment 6, however, was not significantly different from treatment 2 (½ rates of residual herbicides plus Roundup Ready® herbicide), treatment 3 (Roundup Ready® only treatment), treatment 7 (Roundup Ready® plus Enfield® 15 g/ha), treatment 8 (Roundup Ready® plus Enfield® 30 g/ha) or treatment 10 (Roundup Ready® plus Staple® 60 g/ha). The untreated control, weed free control and treatments 1, 9 and 11 were significantly different from treatments 6 and 10. From the data sets it would appear that Staple® applied at 120 g/ha, or in combination with residual pre-emergent herbicides, does have some impact on yield. Further experimentation is required to ascertain whether this is true for all situations or may be due to soil type on the Biloela farm. Similarly, the yield from treatment 1, where full rates of pre-emergent residual herbicides were used, was also significantly lower than treatments 6 and 10, perhaps indicating the effect that residual herbicides may have on yield. The reason for the lower yield from the weed-free control is

not entirely clear at this point in time. However, some variation in growth was noted in the field and two of the weed free control plots were located in regions where poor growth occurred, which may have contributed to the lower yields from these plots.

Lint and fibre quality data was also recorded for the Biloela trial site to provide an indicator of overall cleanliness of the site as well as general effectiveness of using low input herbicide systems. Data were not available for each individual plot but were provided for the whole trial. The fibre quality was excellent (Table 3) and a premium was received by the grower for the cotton grown in this trial.

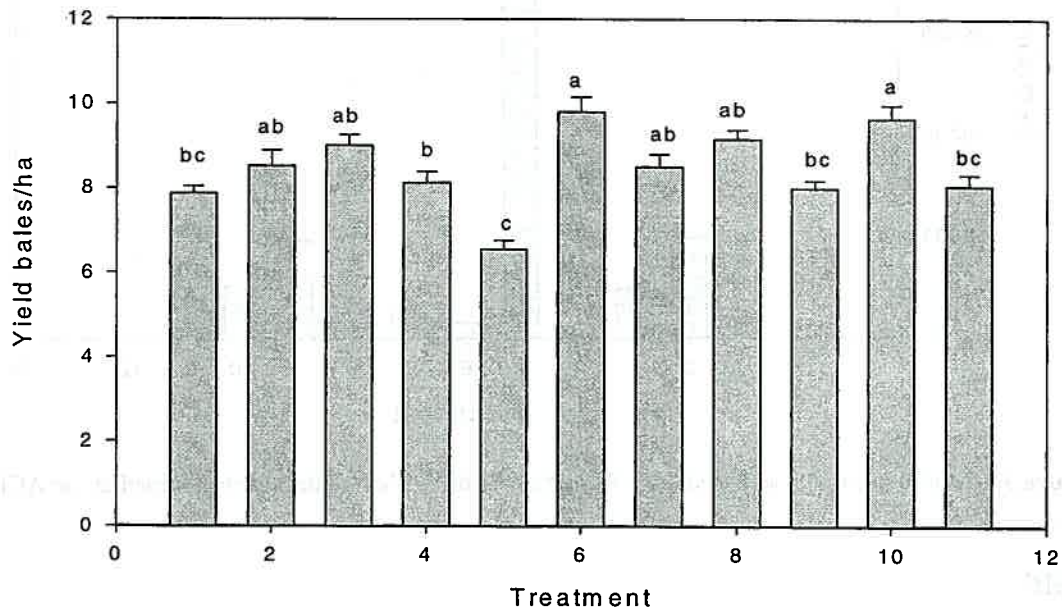


Figure 6. Yields obtained from the Biloela trial site under 11 herbicide treatments. (Treatments with the same letter are not significantly different).

Table 3. Fibre characteristics and percentage gin turnout from cotton grown at the Biloela trial site

Grade code	Colour	Leaf	Length	Mic	Strength Gms/Tex	AVG Lint Turnout
21-1	21	1	36	G5A	32+	38.17%

ACRI

Yield from the ACRI trial site was substantially lower than that of the Biloela trial site (Figure 7). While this is partially attributable to much higher weed densities at this site, other factors such as variety, environmental conditions, soil type and agronomic practices all influenced the final yield. Consequently, no comparisons can be made between the sites.

There were no significant differences in yield between the treatments at ACRI, except for yields from the untreated and the weed-free control treatments. While differences from the untreated control were to be expected, staff were unable to maintain the weed-free control plots weed free due to the very high weed pressure. Thus, by default, these plots also became untreated control treatments. As the majority of treatments relied upon Roundup Ready® herbicide and/or other post emergent contact herbicides and did not incorporate any lay-by herbicide treatments, yield by the end of the trial was severely reduced by the weed abundance. The ACRI site demonstrates how important it is to carefully select the fields where residual herbicides may be left out. In hindsight, it would have been beneficial to incorporate a treatment that also included lay-by herbicides to demonstrate the necessity of using residual herbicides for weed control on high-pressure fields.

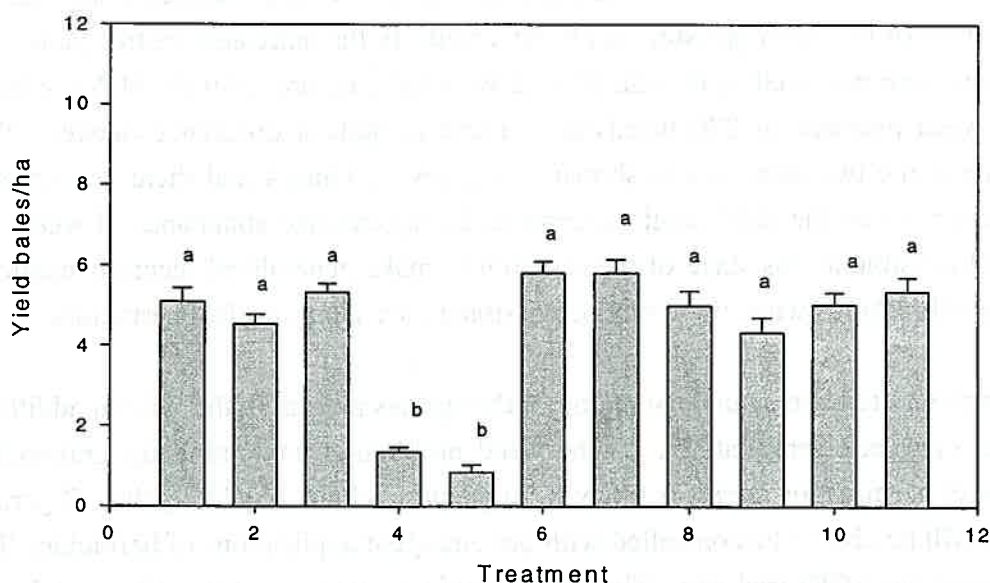


Figure 7. Yields obtained from the ACRI trial site under 11 herbicide treatments. (Treatments with the same letter are not significantly different).

Discussion

Excellent weed control was achieved at the Biloela trial site under all treatment regimes, with the exception of the untreated control. There were no differences in the level of weed control achieved, whether or not pre-plant residual herbicides were used. The results achieved from the Biloela trial site suggest that with the use of emerging technologies, good weed control can be achieved on fields with low weed pressure without the use of residual pre-emergent or pre-plant herbicides.

The most difficult assessment then is to be able to determine whether the weed pressure in a field is low enough to not use a residual herbicide program. At the ACRI and Biloela

sites two assessments were made. Firstly, weed abundance was determined along transects across the whole of the field and the number of weeds/metre of row determined. In a practical sense, this count gives an indication of the weeds escaping the herbicide treatment but does not necessarily indicate the actual weed pressure in the field. Soil cores were taken from each of the trial plots to more accurately determine the weed pressure and the number of weeds germinating counted to determine the actual weed pressure present within the field. At Biloela the highest viable seed density was approximately 900 seeds/m², whereas at ACRI the highest viable seed density was approximately 5400 seeds/m².

For a grower/agronomist, this method of assessment may be impractical, as it takes some months before all the viable weeds have germinated. A simple alternative, however, is to use a series of nil-herbicide strips (small lengths of row with no herbicides applied), so that an estimate of the weed pressure can be obtained. In the untreated control plots, the mean weed pressure observed at Biloela was 22 weeds/m², compared with ACRI, which had a mean weed pressure of 270 weeds/m². There is quite a difference between the weed pressure at the two sites as was shown in Figures 1, 3 and 4 and there was considerable variation between the fields, both in terms of the species and abundance of weeds present. It is not possible at this stage of the research to make generalized recommendations as to the weed thresholds whereby it may be possible to leave out residual herbicides.

It is important to have an understanding of the species present in the field in addition to the number of weeds germinating,. If the weed problem is predominantly grasses then the number of germination events is likely to be greater and it is less likely that all germination flushes will be able to be controlled with pre-emergent applications of herbicide. This was the case at the ACRI trial site. The major weed species present were liverseed grass and barnyard grass and these proved extremely difficult to control with Roundup Ready® applications alone, when large seed bank numbers were present. This is not to suggest that the Roundup Ready® formulation did not adequately control the grass weeds, in fact quite the opposite was true. However, with a large number of germination flushes and only three in-crop applications of Roundup Ready® herbicide permitted, it was impossible to control all the grass weeds that emerged.

The major weed species observed at Biloela were sesbania pea, black pigweed, and bellvine. While the bellvine was more difficult to control, there were only two major germination flushes of the other weeds and these were adequately controlled by the Roundup Ready® herbicide. The Staple® and Enfield® formulations also provided some control of the younger bellvine plants.

Sustainability

One of the major questions that must be raised, is how sustainable is a system that is heavily reliant on one form of weed control. In the above example at Biloela, the system is heavily reliant on Roundup Ready herbicide and it was shown that good weed control and very good yields were achieved just using the Roundup Ready® technology. We will attempt to answer the sustainability issue on three levels. These are: 1.) seed rain and the soil seed bank; 2.) species shift, and; 3.) herbicide resistance.

Seed rain and the soil seed bank

In attempting to control annual weed species, control methods are aimed at preventing the replenishment of the soil seed bank by stopping weeds from setting seed. By preventing seed set over a period of years, seed levels in the seed bank should decrease to more manageable levels, where it may be possible to not use residual herbicides within the farming system. When relying on post-emergent herbicide applications alone, it is important to monitor fields frequently to ensure that weeds are not being allowed to set seed. This is particularly important for many of the Asteraceae weeds, such as sowthistle, and the grass weeds, that are able to flower and set seed from a very early age. Any addition to the soil seed bank is a step backwards in terms of weed control. Seeds of many weed species are able to remain dormant for quite long periods of time and therefore control methods must take into account the dormancy period for the problematic weeds. The seeds of Bathurst burr, for example, may remain viable for periods up to 20 years. Control measures for a particular problem weed, such as Bathurst burr, may need to be in place for long periods.

The introduction of the Roundup Ready® technology can greatly assist in the management of the soil seed bank, by allowing more flexible weed control that prevents seed set in species that escape current weed control programs. On fields that have a high weed pressure, Roundup Ready® technology should be used in addition to current control programs, rather than in place of these programs. This will expedite the depletion of the soil seed bank, allowing growers to reduce or eliminate inputs of residual herbicides once the weed problem has been brought under control.

Species Shift

No weed management tool controls all weeds well. Some species are very susceptible to control using a given management tool, while other species are naturally tolerant. For example, inter-row-cultivation effectively controls most grass and broadleaf weeds but is less effective on the perennial weeds such as nutgrass and polymeria take-all.

The effect of using any weed management tool, or set of weed management tools is to select out the species that are most tolerant of the tools. These species will quickly spread and will dominate the weed spectrum in a field. This change is termed **species shift**. Species shift is not a new phenomena, but is constantly occurring. The weed species that are currently in cotton fields are generally not the species native to the area, but are the species that were most tolerant of the management tools used in the past.

Where Roundup is used in-crop as an additional management tool, there is likely to be little change in the weed spectrum. However, if Roundup is used to replace other management tools, such as residual herbicides, inter-row cultivation or chipping, there will be a relatively rapid change in the in-field weed spectrum towards those weeds that were previously controlled by the alternative management tools, but are relatively tolerant of Roundup. This change may become apparent within three or four seasons on Roundup Ready® cotton. A change in the weed spectrum (species shift) is inevitable where Roundup is used to replace other weed management tools. However, the change should be easily identified and easily managed. Regular field observations will identify changes in the weed spectrum. Changes in management must then be targeted to address these problems.

In the long-term, a sustainable weed management system will be one that employs a range of weed management tools in combination so that all weeds are controlled by some management tools.

Herbicide resistance

As distinct from species shift, which relates to naturally tolerant weed species, herbicide resistance is a result of the very small number of individual plants within a weed species that have natural resistance to a herbicide. These individuals may occur at very low frequency within a population where all other individuals are easily killed by the herbicide. Herbicide resistance occurs when repeated use of a herbicide selects out these individuals such that the resistant individuals spread and eventually dominate the weed population. The herbicide is no longer of any value for controlling the weed when this happens.

At present there are no known herbicide resistant weeds in the Australian cotton industry. However, herbicide resistance can occur. There are numerous examples of herbicide resistant weeds in some of the other cropping systems in Australia. The primary reason for herbicide resistance not being a problem in Australian cotton production has been the traditional philosophy of weed management and the reliance on a combination of weed management tools. Inter-row cultivation and especially hand hoeing have been the most important resistance management tools, as both these tools are relatively non-selective. Any weeds that were not controlled by herbicides, and so were potentially herbicide

resistant, were removed by the combination of cultivation and chipping. The philosophy of using these tools to remove all weed escapes from the field has prevented the emergence of herbicide resistant weeds.

The development of herbicide resistance is influenced by a number of factors including:

- the intensity of the selection pressure,
- the frequency of herbicide resistant genes within a particular species,
- the fitness of the resistant biotype, and
- and the biology of the particular weed species.

With the introduction of Roundup Ready® cotton, it is likely that one or two additional Roundup applications will be introduced to the cotton production system. This increased herbicide use will slightly increase the selection pressure for glyphosate resistant weeds. Additionally, a reduction in the use of alternative control methods will accompany the widespread introduction of Roundup Ready® cotton. This reduction will greatly increase the selection pressure on Roundup, and increase the likelihood of glyphosate resistant weeds developing (being selected out by a management system that relies too heavily on glyphosate).

The situation now exists where good weed control in some fields can be achieved with just Roundup Ready® herbicide. Consequently, the temptation exists to forgo all other weed control methods in favour of using this technology alone. From a short-term economic perspective this may make sense, and good weed control may be achieved (in the short-term). In the long-term, species shift and herbicide resistant weeds are a reality. Dealing with herbicide resistant weeds will be far more costly to the entire industry than maintaining an integrated approach to weed management.

To slow or prevent the development of herbicide resistance, it is important that growers maintain an integrated approach to their weed management. The Roundup Ready® Management Guide requires that after growers apply their final in-crop Roundup application, they:

- assess the occurrence of surviving weeds on three 100 metre lengths of row per 40 ha crop,
- take remedial action to stop seed set of these weeds, and
- report any adverse findings (potential resistance problems).

This resistance management plan appears to be very simple, but is technically sound. It is based on the principle that any weed that is not controlled by the Roundup application

(potentially resistant) is controlled by some other means before it is able to set seed. This plan will prevent the occurrence of herbicide resistance if it is properly implemented.

The resistance management plan also makes good farming sense. Weeds that are controlled before they set seed don't contribute to future weed problems, maintaining the stability of the system. Weeds that survive the Roundup application may or may not be resistant, but will contribute to a larger problem in future years of weeds that are not controlled by Roundup if they are allowed to set seed.

The introduction of new technologies offers many benefits for improved weed management. It must be remembered though, that these technologies need to be managed correctly, within their limitations, and an integrated weed management approach maintained.

References

Muschal, M. (2001) Central and north west regions water quality program. Centre for Natural Resources, NSW Department of Land and Water Conservation.

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