UNDERSTANDING THE CRITICAL PERIOD FOR WEED CONTROL

Graham Charles and Ian Taylor
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Contents

Introduction

The last few years have brought new innovations in weed management in the Australian cotton industry. These include the transgenic herbicide tolerance options of Roundup Ready®, Roundup Ready Flex® and Liberty Link® cottons, the post-emergence, over-the-top herbicides Staple® and Envoke®, and more accurate inter-row cultivation, with additional options likely over the next decade.

These new options allow growers to develop more effective and flexible weed management programs, but the old dilemmas still remain. Growers have to answer the questions; should I use multiple pre-emergent herbicide applications, with pre-planting as well as at-planting herbicides? Or maybe just one of the options, but if so, which herbicide/s and at what rates, broadcast or banded? When should I inter-row cultivate or chip, or should I just apply another herbicide? Should I use a layby?

Using more and more herbicides gives better weed control, but pre-emergence residual herbicides can contribute to establishment problems and additional post-emergence herbicides will not necessarily result in better yields, or improved returns. In fact, controlling weeds in a fairly clean field may just reduce profits. Conversely, inadequate weed control can be costly to remedy, and can result in lost yield and weed problems for years to come. So the question is, what herbicide/ cultivation/ chipping combinations will give optimal weed control, and maximise yields and returns?

The answers are complex and vary from field to field and season to season.

A weed control threshold

Post-emergence herbicides, such as glyphosate, bring the advantage that they are applied to a known weed population. This allows the choice of herbicide, rate and application timing to be targeted to the weed population. These herbicides can substitute for pre-emergent residual herbicides, cultivation and chipping inputs to maximise weed control and minimise costs.

However, the application timing of post-emergent herbicides remains an issue. Growers must balance spraying too often, which provides good weed control, but increases cost and selection pressure for herbicide resistance and species shift, against spraying too little. Delaying control may save costs by reducing the number of applications needed over the season, but increases the risk of weed escapes that can be costly to control, and may lead to yield losses and a build up of weeds over time.

A weed control threshold is needed to help balance the pressures of spray efficacy and cost. The threshold must take into account the characteristics of the weeds, their density and the control options available, to provide guidelines on if and when a weed population should be controlled.

Determining the economic threshold for weed control

The decision to control a weed is influenced by crop growth stage, the availability of suitable herbicides, labor and equipment, the weather, and financial aspects such as lint price, expected yield, and the cost of weed control. The actual level of the economic threshold (the critical number of weeds that triggers a grower to control a weed infestation) is a personal choice reflecting how much loss a grower is willing to tolerate before deciding to control the weed.

For example, a grower may consider using a Roundup Ready Herbicide® application costing around $23/ha, including application. The grower will probably not use the herbicide unless the weeds will cause at least a $23 per ha yield loss, with additional benefit expected in harvest efficiency, lint quality and reduced weed problems in later years. At a bale price of $380 and an expected yield of 8 bales per ha, this establishes an economic threshold for applying Roundup Ready Herbicide at around 0.8% yield loss. That is, **the economic threshold is the 0.8% level of yield loss**.

The economic threshold is easily established. The trick is in being able to quantify the yield loss caused by the weeds.

Understanding the impact of weeds

A weed control threshold must take into account the characteristics of the weeds, their density and the control options available. Competitive ability is one of the more important characteristics of a weed, but other features, such as the ability to host insect pests and diseases, seed production, and lint contamination potential are also important.

The competitive ability of a weed relates to its growth rate and architecture (height, shape, leaf size, branching characteristics, root structure, rooting depth, etc.), and varies with each weed species. Generally, smaller weeds are less competitive, and large weeds, such as noogoora burrs, are highly competitive.

The competitive impact on a crop is also affected by the time the weed emerges and the time of the weed's removal. Weeds that emerge late in the season may have little impact on the crop's yield, whereas even relatively uncompetitive weeds that emerge with the crop are likely to impact on yields if not controlled.

Determining the yield loss from weeds

The impact of weed competition on crop yield is demonstrated in Figure 1, generated from a field population of 4 thornapples per meter of cotton row.

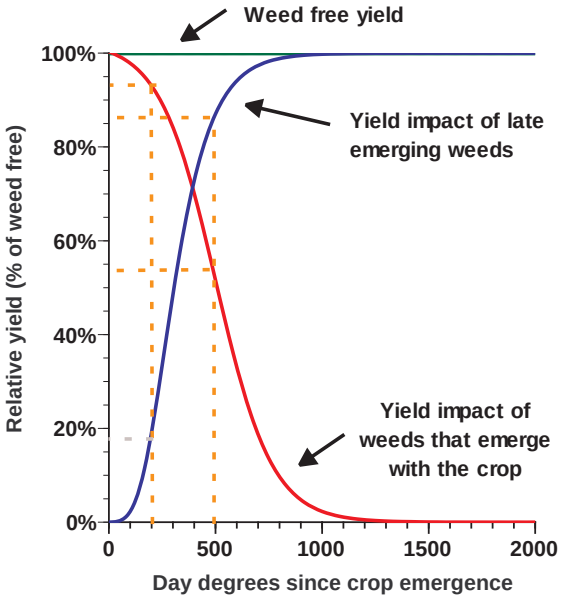

Figure 1. *The impact of 4 thornapples/m on crop yield. The orange lines demonstrate the impact of control 200 and 500 day degrees after crop emergence.*

In Figure 1, the green line across the top is the yield if there were no weeds in the field (the weed free yield).

The red line is the yield loss from a thornapple infestation where the weeds emerged with the crop and were removed some time after emergence. For example, if the thornapples were controlled at 200 day degrees, crop yield would be reduced to 93%, a 7% yield reduction (indicated by where the orange line at 200 day degrees hits the red line). If the thornapples were removed at 500 day degrees, the yield would be reduced to 54%, a 46% yield reduction (500 degrees days orange line). Yield would be reduced by 100% if the thornapples were not controlled before 1300 day degrees.

The blue line is the yield loss from a thornapple infestation where the weeds emerged after the crop and were not subsequently controlled. If, for example, thornapples emerged at 200 day degrees and were not controlled, yield would be reduced to 18%, an 82% yield reduction (where the orange line at 200 day degree hits the blue line). However, if the thornapples didn't emerge till 500 day degrees and were not controlled, the yield would only be reduced to 86%, a 14% yield loss.

Although a single red line is shown for simplicity in Figure 1, there would actually be a family of red lines, representing thornapples that emerged after each weed control input (inter-row cultivation, herbicide etc.), as shown in Figure 2.

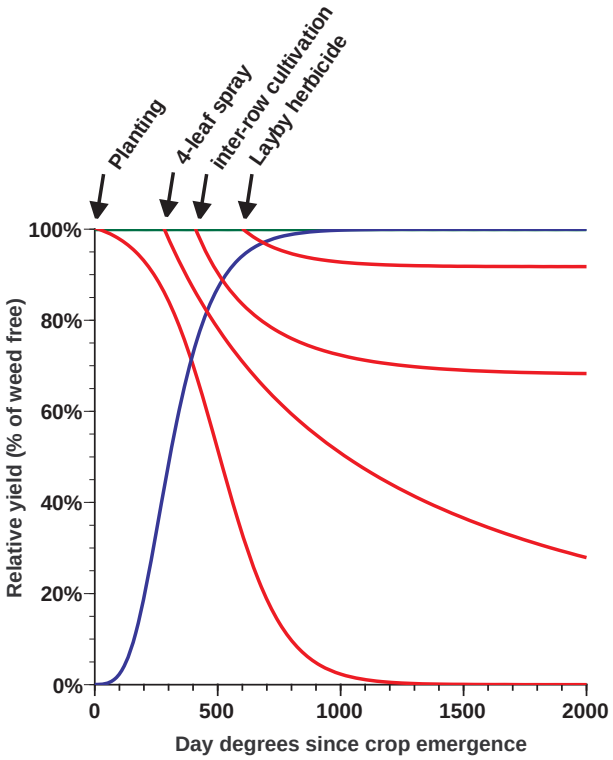

Figure 2. *The impact of weed competition on crop yield following weed control inputs.*

A further set of lines would be needed to show the impact of thornapples at another density, and still more sets of curves to show the impact of other weeds, as the curves are different for each species and density.

The critical period for weed control

A concept known as the 'critical period for weed control', can be derived from the interaction of these relationships with the economic threshold for weed control.

The critical period for weed control starts at the intersection of the first red line with the economic threshold (yellow line), and ends with the intersection of the blue line with the economic threshold, as shown in Figure 3. A new critical period for weed control is defined after each weed control input, beginning where each subsequent red line intersects with the economic threshold. The end of the critical period does not change.

The critical period for weed control is defined by the economic threshold chosen, the weed species and the weed density. In this example, the critical period for weed control for 4 thornapples/m of cotton row is 166 to 621 day degrees at a 5% economic threshold. Thornapples not controlled during this period will cause economic yield loss.

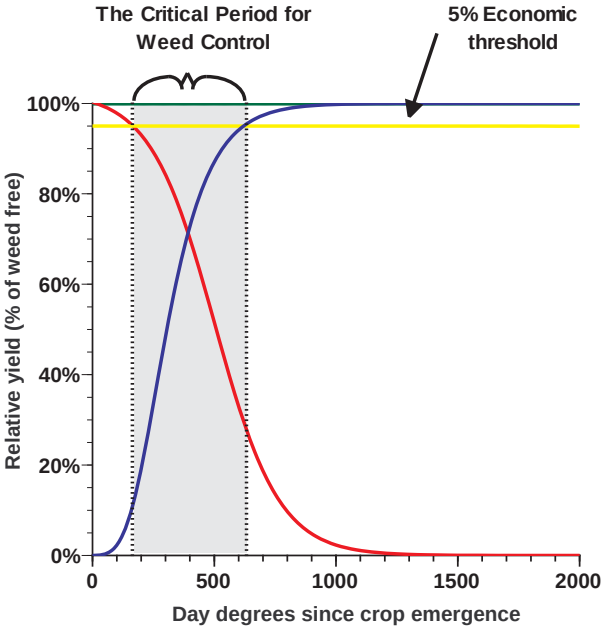

Figure 3. *Deriving the critical period for weed control (the blue shaded area).*

Beyond the critical period for weed control

A strength of the critical period for weed control concept is that it clearly defines the period during which weed control is required, and conversely, the periods during which weeds cause insufficient yield loss to justify their control. Figure 3, for example, shows that where thornapples emerged with the cotton crop at 4 plants/m, there is no justification for controlling them before 166 day degrees of crop development.

Conversely, if up to 4 thornapples/m establish after 621 day degrees, they would not cause an economic yield loss (using a 5% yield loss threshold). However, they might still need to be controlled to avoid seed production, harvesting difficulties and thornapple problems in later seasons.

This information is especially important for the management of relatively clean fields where weed control decisions can be difficult to make, as it may be unclear whether a weed density is sufficient to justify control.

However, the critical period for weed control concept has several weaknesses. It assumes that weeds are equally easily controlled at all growth stages, that the cotton grower has the capacity to control all weeds at the required time, and that the weeds have no negative impact except on crop

yield. Weed control decisions may also be justified for irrigation and harvesting efficiency, to reduce pest and disease carryover, to prevent lint contamination, and to prevent weed seed set, reducing future weed burdens.

Also, the critical period for weed control is affected by the economic threshold adopted. At a 1% yield loss (economic) threshold, compared to a 5% economic threshold, for example, the critical period in Figure 3 extends from 61 to 818 day degrees after crop emergence. At this threshold, the first-post-emergence treatment would occur while the crop was at the 1 node stage, and subsequent treatments would need to occur within a week or so of weed emergence to avoid reductions in crop yield.

Timing of herbicide applications

Application timing is critical to achieving good results with post-emergent herbicides. Herbicides should be applied when they will provide effective control and before weeds begin to reduce crop yield potential, ideally at the start of the critical period for weed control (Figure 3). Best control with herbicides is obtained when weeds are small, when there is adequate soil moisture and when temperatures are ideal.

However, the germination of weed seeds is mainly governed by temperature and soil moisture conditions, (it may also be influenced by seed dormancy). Consequently, there are normally a number of weed flushes throughout a season following rainfall and irrigation events. Cotton growers must take into account the likely number of germination events, the cost of weed control, the capacity to cover a number of fields with the application equipment available, and possible yield reductions due to weed pressure when making a weed control decision. Control of very small weeds prior to the weed removal time would be efficient in terms of herbicide, as lower rates are required to control smaller weeds, but may be very inefficient if subsequent germinations quickly replace the previous weed population, requiring repeated treatments.

Preventing weed seed set

The aim of weed management is to minimise economic loss in the current crop, but also to protect future crops by preventing weeds from setting seeds and adding to future weed problems. To achieve this, weed management strategies may need to continue beyond the critical period for weed control.

However, rather than focusing on controlling the weeds, emphasis needs to be placed on preventing those weeds from setting seed. This may be achieved using a lay-by herbicide, or with spray topping, where a sub-lethal dose of herbicides is applied to cause weeds to abort seed or to set non-viable seed. Defoliants or Roundup applied at or prior to defoliation may also help to reduce seed set. Further research is needed to confirm the value of these options.

APPLYING THE CRITICAL PERIOD FOR WEED CONTROL IN THE FIELD

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Contents

Sunflowers in cotton at the start of November mimicking an infestation of large broad-leaf weeds.

Introduction

The critical period for weed control is a concept that relates the yield reduction caused by weed competition to an economic threshold. It establishes a period at the start of the season when weeds do not need to be controlled as they cause no economic loss, and a period at the end of the season when weeds again cause no economic loss. These periods define the middle, critical period for weed control, in which weeds must be controlled to reduce yield losses.

The relationships which define the critical period are affected by weed species, weed density and the economic threshold chosen.

The critical period for weed control

Experiments were conducted at the ACRI at Narrabri over the past 4 seasons to define the critical period for weed control for irrigated cotton in Australia. These experiments used sunflowers, mung beans and Japanese millet to mimic the competition from a large broad-leaf weed such as thornapple, a medium sized broad-leaf weed such as bladder ketmia and a grass weed such as barnyard grass.

Relationships for these weeds at two densities are shown in Figure 1. The curves show the competitive effects of weeds that emerge with the crop and are subsequently controlled (maroon line) and weeds that emerge after the crop and are not subsequently controlled (brown line).

At the densities shown, the large broad-leaf weeds had the greatest effect on the crop, suppressing yield by up to 100% when not controlled. The medium broad-leaf and grass weeds had less effect, with 79% yield reduction from season-long competition of 40 grass plants per metre of cotton row.

Japanese millet at 40/m row in cotton at the end of December mimicking a heavy infestation of a grass weed.

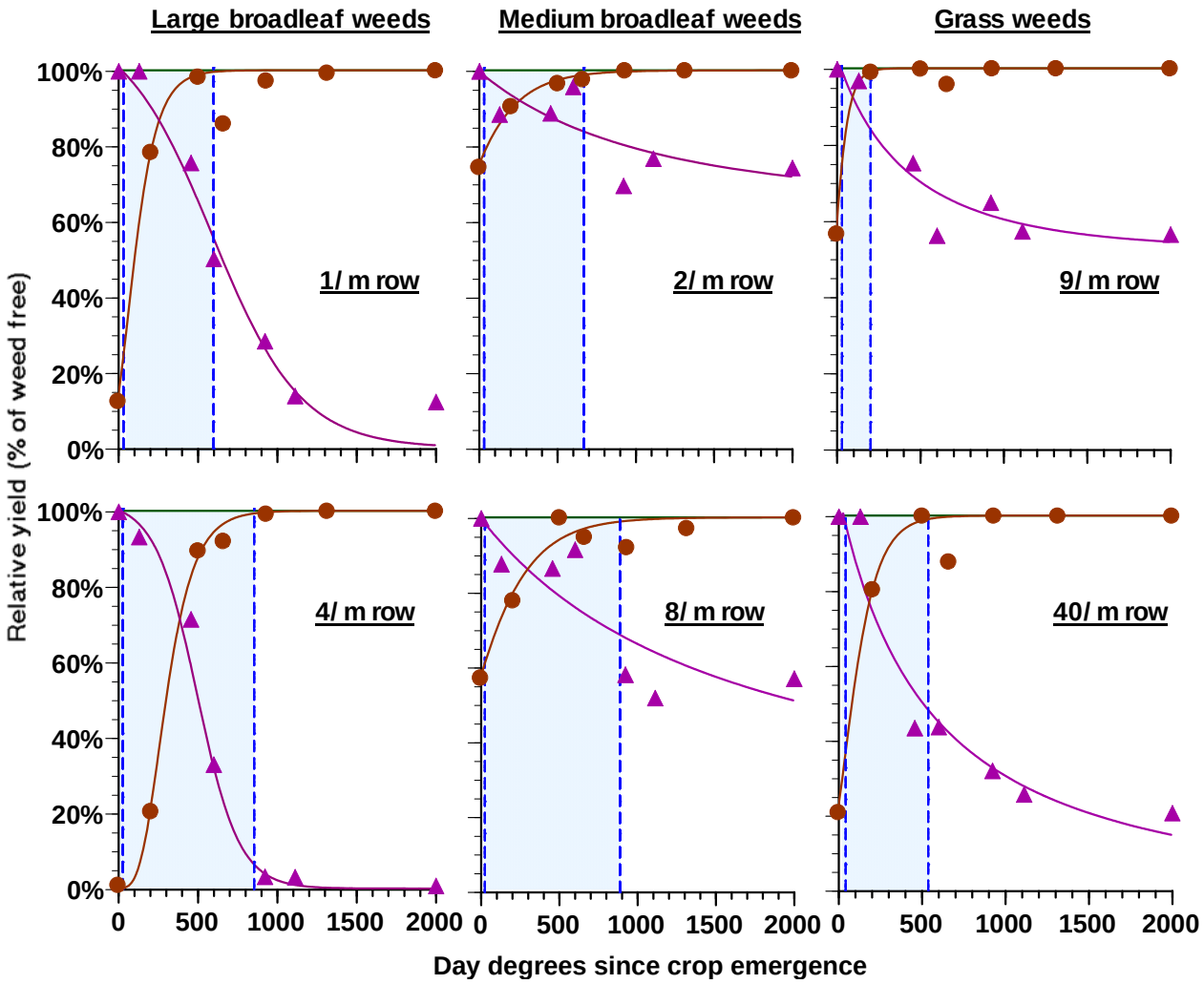

Figure 1. *Yield relationships for weeds competing in irrigated cotton. Data for large and medium broadleaf and grass weeds are shown. Weed densities are indicated on each figure. The critical period for weed control at a 1% yield threshold is the shaded blue area in each figure. This area is determined by where the curves in each figure cut the chosen economic threshold, which in this example is at 1% yield loss (99% yield).*

The critical periods for weed control defined by these weed competition relationships are dependant on the economic threshold chosen. As an example, results for a 1% yield threshold are indicated in Figure 1 by the shaded blue areas in each figure. These areas are defined by where the maroon and brown lines cut the economic threshold, and determine the start and end of the critical period in day degrees on the bottom axis.

Figure 1 shows that the critical period for weed control at a 1% economic threshold for one large broad-leaf weed/m row starts 30 day degrees after crop emergence and continues till 598 day degrees. In other words, at one large weed/m row, if weed control starts later than 30 day degrees after crop emergence, a yield loss of greater than 1% will occur. Conversely, large broadleaf weeds that emerge at up to 1/m row later than 598 day degrees after crop emergence cause less than a 1% reduction in crop yields. Consequently, controlling these weeds that emerge later than 598 day degrees after the crop can't be justified on the basis of the yield reduction they will cause. They may still need to be controlled, however, as they may interfere with harvesting and may produce a seed load that leads to increased weed problems in later seasons. A layby application of a residual herbicide may be the best option at this point in the season.

The length of the critical period for weed control increases with increasing weed density, climbing from 598 day degrees after crop emergence for 1 large broad-leaf weed/m row to 854 day degrees for 4 weeds/m. The start of the critical period declines slowly as weed density increases, decreasing from 30 day degrees at 1 large broad-leaf weed/m to 26 day degrees for 4/m.

Predicting the critical period for weed control

These data were put together to produce relationships to predict the start and end of the critical period of weed control for any density of these weeds. The relationships predict that for any density of weeds, the maximum critical period is 996 day degrees post crop emergence (Table 1). Weeds that emerged later than 996 day degrees after crop emergence didn't cause more than 1% yield loss, regardless of their type or density.

The start of the critical period for weed control was fairly insensitive to weed density, declining from 43 day degrees at the lightest density of grass weeds.

The length of the critical period was much shorter for the grasses compared to the broad-leaf weeds at the same densities. Season long competition from fewer than 3 grass weeds/m causing less than 1% yield loss. Consequently, control of fewer than 3 grass weeds/m row can't be justified on the basis of yield loss alone. However, failure to control grasses at this density early in the season will lead to problems later in the season with harvesting difficulties and lint contamination. Not controlling grass weeds will result in seeds being added to the seed bank. This seed may germinate following the next rainfall or irrigation event, resulting in greatly increased weed problems later in the season or in subsequent seasons.

Table 1. *The predicted start and the end of the critical period for weed control for a range of weed species and densities.*

Weed density (weeds/m row)	Critical period (day degrees)	
	Start	End
Large broad-leaf weeds		
0.1	31	130
0.2	31	230
0.5	30	427
1	30	598
2	29	747
4	26	854
Medium broad-leaf weeds		
0.1	31	92
0.2	31	169
0.5	30	336
1	30	503
2	29	668
4	26	800
Grass weeds		
2	-	-
3	42	61
4	42	80
8	42	148
16	40	258
32	37	410

Other weeds, such as the vines, may have little impact on yield at low densities but can cause major difficulties for harvesting. Low densities of some weed species may also be problematic as they may harbour pests or diseases, or have the ability to rapidly spread if not controlled. Controlling a low density of small weeds may make a lot more sense than trying to control a heavy density of large weeds later in the season.

Using the 'critical period for weed control' data set

The critical period for weed control data will be a valuable tool for managing weeds in cotton into the future. However, the current data is very preliminary and should be viewed with caution. Other research has shown that the results of this type of research can be site and season specific, meaning that different results might be obtained in other seasons and in other cotton areas.

Future research in this project will cover a number of additional points, including developing data sets for mixed populations of real weeds, testing the findings in other regions and developing more robust weed competition assessment tools. Weed densities are never uniform in the real world, and staggered weed germinations can make for difficult decisions. Developing a weed management guide based on measurements such as weed and crop leaf area may give much more robust guidelines than the current findings simply based on weed density.

Nevertheless, these preliminary findings can be used to guide weed management decisions, especially in Roundup Ready Flex® and Liberty Link® cotton crops where over-the-top broad-spectrum herbicides are available. The results firstly indicate that weed control should be commencing early in the season, soon after weed emergence, when light rates of herbicide give good control on small, susceptible weeds. Weeds should not be allowed to grow unchecked in the hope of being able to control multiple weed germinations with a single, high rate herbicide application later in the season.

Secondly, the duration of the weed control period is influenced by weed species and density, but may extend until well into the season in dirtier fields. Weed control may have to be maintained until mid- to late-January, depending on the region and the season. Conversely, weed control with an over-the-top herbicide in relatively clean fields may be largely cosmetic and not justified on the grounds of competition alone. Controlling these weeds with inter-row cultivation or a lay-by herbicide later in the season would be a better option. This is especially the case in fields that are not going back to cotton.

Avoiding herbicide resistance and species shift

One of the biggest concerns with adopting a system which relies largely on a single weed control tool is the development of species shift and herbicide resistance. This is a potential issue for systems such as a Roundup Ready Flex cotton system where few other inputs might be used.

An obvious strategy might seem to be to limit the number of Roundup Ready applications, using maximum rates to control big weeds. This is not advisable for two reasons. Firstly, the critical period for weed control work shows that this strategy will lead to large yield losses. Secondly, using a lesser number of applications of a heavy herbicide rate will not necessarily reduce selection pressure compared to multiple applications of lighter rates on small weeds. The issue is not how many applications are made per season, but whether successive generations are exposed to the same selection pressure.

There are three keys to successfully adopting a low input weed control system. These are:

- Ensuring the herbicide will control all weeds at the rate used,
- Ensuring successive generations of weeds are not exposed to the same herbicide, and
- Ensuring all weed escapes are controlled using a different management tool **before they set seed**.

High yielding cotton crops can be grown for many years into the future if these strategies are adopted.

USING THE CRITICAL PERIOD FOR WEED CONTROL IN ROUNDUP READY FLEX® COTTON

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Contents

A cotton crop with a heavy infestation of grass weeds in the plant line. This was part of the experiments used to establish the CPWC in cotton.

Introduction

The Critical Period for Weed Control (CPWC) is a concept that relates the yield reduction caused by weed competition to an economic threshold. It establishes a period at the start of the season when weeds do not need to be controlled as they cause no economic loss, and a period towards the end of the season when weeds again cause no economic loss. These periods define the middle, CPWC, in which weeds must be controlled to reduce yield losses.

Work by NSW DPI staff at the Australian Cotton Research Institute (ACRI) at Narrabri has for the first time defined the CPWC in irrigated Australian cotton. Articles describing the work were published in the August-September 2007 edition of the Australian CottonGrower.

Still, the question remains, how can a cotton grower best use this information in a cotton crop?

The main aim of this article is to explore how applying the critical period concept might have worked out in grower's fields over the last three seasons.

The critical period for weed control

In practice, the critical period is defined by the type of weed present, the density of weeds, the potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses.

The CPWC is defined in Table 1 using 1% and 3% weed control thresholds for fully irrigated cotton (1% threshold) and lower yielding or rain-fed crops (3% threshold). These control thresholds were determined from the point where the yield loss caused by the weeds exceeds the cost of control with Roundup Ready Herbicide. As well as reducing lint yield, uncontrolled weeds set seed

leading to increasing weed problems over time, impede water flow and pesticide penetration, harbor pests and diseases, and cause harvesting difficulties and lint contamination.

To show how these thresholds might be used in the field, we applied them to Narrabri data for each of the last three seasons.

The simulations and discussion focus on management of a Roundup Ready Flex cotton crop because the critical period approach is most readily adapted to this system. However, the concept can be equally applied to conventional and Liberty Link® cotton crops.

***Table 1**. The predicted start and the end of the CPWC for a range of weed species and densities using 1% and 3% thresholds. The critical period is measured in day degrees from planting.*

Weed density (weeds/m row)	Critical period			
	Start		End	
	1%	3% threshold	1%	3% threshold
Large broad-leaf weeds				
0.1	111	-	210	-
0.2	111	178	310	222
0.5	110	177	507	365
1	110	175	678	508
2	109	170	827	653
5	105	158	959	798
Medium broad-leaf weeds				
0.1	111	-	172	-
0.2	111	-	249	-
0.5	110	-	416	-
1	110	175	583	227
2	109	170	748	331
5	105	158	913	517
10	101	142	987	661
Grass weeds				
2	-	-	-	-
3	123	-	141	-
5	122	137	178	148
10	121	136	259	206
20	120	132	383	299
50	115	124	600	477

Model inputs

We tested the CPWC on a relatively dirty field with a mixed weed population of 1 large broadleaf weed/m^2 (eg. thornapple or noogoora burr), 5 medium sized broadleaf weeds/m^2 (eg. bladder ketmia) and 10 grass weeds/m^2 (eg. barnyard grass). Simulations were made for both fully irrigated and rain-fed crops in each season.

Weed germinations were related to rainfall and irrigation events. The simulations assumed most of the weeds emerged between 50 and 100 day degrees after rain (or irrigation), and all weeds were susceptible to Roundup Ready Herbicide.

The irrigated crop was pre-watered and planted on 5th Oct. each season. No residual herbicides were applied prior to or at planting. Roundup was applied before crop emergence to ensure a clean start to the season. Applying a 1% yield loss threshold, the CPWC extended from cotyledon to mid-flowering growth stages (105 to 913 day degrees) for the simulated weed population, as shown by the red lines in the figures.

The "rain-fed" simulations used similar assumptions, with no pre- or at-planting residual herbicides. Planting occurred on the first opportunity following rain after the 5th Oct., and Roundup was again applied before crop emergence to ensure a clean start to the season. Applying a 3% yield loss threshold, the CPWC extended from the 2 node stage to early squaring (136 to 517 day degrees).

A cotton crop showing the effect on crop height and biomass of a heavy weed infestation following a Roundup Ready application (foreground). Weeds have been uncontrolled since planting in the plot behind this. These plots are part of an experiment to test the CPWC in Roundup Ready Flex cotton.

The CPWC in 2004-5

Reasonable rainfall fell in the first half of the 2004-5 season at Narrabri, with a daily maximum of 138 mm recorded in Dec. Multiple weed germination events were triggered by early season rainfall and irrigation later in the season (Figure 1).

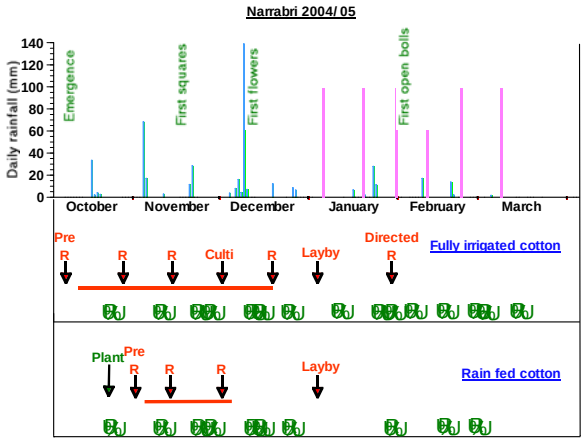

***Figure 1**. A simulation of how the CPWC might have been applied in the 2004-5 season at Narrabri (ACRI). Simulations are for both fully irrigated and rain fed crops. Symbols are: blue bars, daily rainfall (mm); pink bars, irrigations; red lines, the CPWC; red arrows, weed control inputs (R = Roundup Ready® Herbicide, Pre R = a pre-crop emergence Roundup, Culti = inter-row cultivation, Layby = a residual layby herbicide); and green arrow, planting. Periods of peak weed emergence are indicated by .*

With no pre-planting or at-planting residual herbicides used, post-emergence weed control was required following weed emergence on four occasions during the critical period, at 6 nodes, first squares, first flowers and mid-flowering (310, 511, 719 and 946 day degrees). Ideally, weeds need to be controlled within 105 day degrees of their germination, which will be only a few days after seedling emergence. Roundup Ready Herbicide could be used on three of these occasions, with inter-row cultivation and chipping used on one occasion. This combination of inputs conforms with the Roundup Ready Flex Crop Management Plan which requires that: (1) no more than three Roundup Ready Herbicide applications are made during this crop growth period; and (2) that weeds that survive a Roundup Ready Herbicide application are controlled by an alternate method before they set seed (the combination of inter-row cultivation and chipping conforms with this requirement). Only a very light chipping should have been required as few weeds would have survived two Roundup applications and a cultivation pass.

Weeds that emerged later in the season would still need to be controlled to prevent problems such as harvesting difficulties, lint contamination and the build up of the weed seedbank (leading to increasing weed problems over time). These weeds could be controlled with a lay-by application of residual herbicide before canopy closure and a directed application of Roundup Ready Herbicide during the 16 to 22 node stage if required. A pre-harvest application of Roundup Ready Herbicide could also be used to prevent late-season weeds setting seed if sufficient late-season weeds were present to justify this input.

This herbicide program would potentially have used the maximum number of early-season Roundup Ready Herbicide inputs allowed by the label, but probably not all these inputs would have been required in practice, with at least one inter-row cultivation pass replacing a Roundup application. It is also likely that lower than maximum label rates would have been used for the first two Roundup applications as these were applied to young weeds which are easily controlled with lower rates. Rates of 0.5 to 1 kg/ha would give excellent control of most susceptible weed seedlings. An early lay-by application of residual herbicide could have been applied in late-Dec. if an additional weed control input had been required during the critical period.

Rainfall in mid-Oct. allowed a rain-fed crop to be planted on 24th Oct. Post-emergence weed control was required on two occasions, at 5-6 nodes and first squares (282 and 490 day degrees). Weeds which emerged later in the season could have been controlled with a lay-by application of residual herbicide in early Jan. It is unlikely that further weed control inputs would have been required in this season.

The CPWC in 2005-6

Reasonable rainfall again fell in the 2005-6 season at Narrabri, and multiple weed germination events were triggered by rainfall and irrigation (Figure 2).

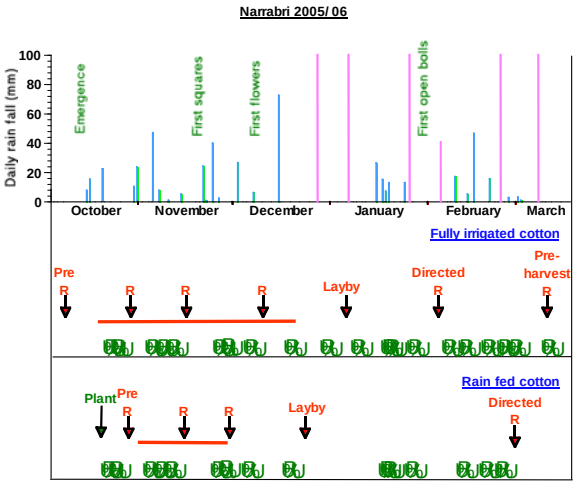

***Figure 2**. Using the CPWC in the 2005-6 season. Simulations for fully irrigated and rain-fed crops are shown. Weed control operations during the CPWC protect cotton yield. Weed control operations after the CPWC prevent weeds from adding seed to the soil seed bank, leading to problems in later seasons.*

Using a 1% yield loss threshold, post-emergence weed control was required at 5 nodes, first squares and first flowers (259, 460, and 803 day degrees). Roundup Ready Herbicide could have been used on all occasions, although an inter-row cultivation and light chipping may have been used on one occasion to remove any weeds that survived the Roundup application, as required by the Crop Management Plan. Weeds which emerged later in the season could have been controlled with a lay-by application of residual herbicide in early Jan. and a directed application of Roundup Ready Herbicide during the 16 to 22 node stage if required. A pre-harvest application of Roundup Ready Herbicide could also be used to prevent late-season weeds setting seed.

This herbicide program may have again used the maximum number of Roundup Ready Herbicide inputs allowed by the label. Lower than maximum label rates would have been required for the first two applications to young weeds, enabling the total in-crop use to remain within label requirements even if both the directed application and the pre-harvest application were required.

Rainfall in mid-Oct allowed a rain-fed crop to be planted on 20th Oct. With a 3% yield loss threshold, post-emergence weed control was required at 7-8 nodes and mid-squaring (245 and 586 day degrees). Later emerging weeds could have been controlled with a lay-by application of residual herbicide in early Jan. A pre-harvest application of Roundup Ready Herbicide may also have been required to prevent late-season weeds setting seed following good rain in Feb.

The CPWC in 2006-7

Very little rain fell in the 2006-7 season at Narrabri, with most weed germination events triggered by irrigation (Figure 3).

Using a 1% yield loss threshold, post-emergence weed control was only required at first squares (460 day degrees). Weeds which emerged later in the season could have been controlled with inter-row cultivation or a lay-by application of residual herbicide. No other weed control may have been necessary.

Rainfall in early Nov. may have allowed a rain-fed crop to be planted on 8th Nov. With a 3% yield loss threshold, no rainfall occurred during the CPWC and it is likely that few if any weeds emerged during this period. Weeds which emerged later in the season could have been controlled with a lay-by application of residual herbicide.

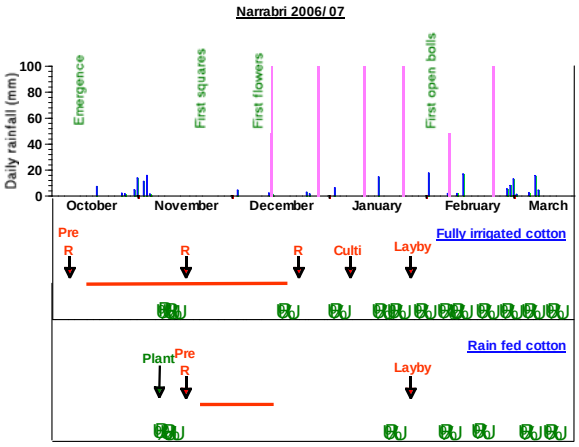

***Figure 3**. Applying the CPWC in the 2006-7 season. Simulations are for fully irrigated and rain-fed crops.*

Observations from these simulations

The CPWC approach can be successfully applied in both irrigated and rain-fed cotton. Applying Roundup Ready Herbicide inputs to small weeds soon after emergence will maximize herbicide efficacy and yields but will not necessarily result in the maximum number of applications being used too early in the season, especially where inter-row cultivation or other herbicides are used on some occasions instead of Roundup.

In seasons where the early season weed pressure is too high (requiring too many early Roundup applications), an early layby application of residual herbicide can be used to replace a Roundup application and reduce weed pressure. Prometyrn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and will control a wide range of emerged weeds provided they are applied to small weeds, as well as giving residual control, reducing weed pressure. An alternative residual, such as diuron, could then be applied later in the season as a standard layby application.

Resistance to Roundup

Some cotton growers are concerned that relying too heavily on Roundup is likely to lead to future problems with weeds that are resistant to Roundup (glyphosate). The potential for resistance is very real, as shown by the increasing resistance problems with Roundup Ready crops in the US.

However, resistance can be avoided by following two simple rules.

1. Always follow the Roundup Ready Flex Crop Management Plan. Central to this plan is the requirement that crops are checked after a Roundup application and any surviving weeds controlled using an alternative weed management tool before the weeds set seed.
2. Ensure at least one effective alternative weed management tool is used each season. An inter-row cultivation combined with a light chipping is a sound strategy for avoiding resistance. Alternatively, using a directed layby residual herbicide, incorporated with inter-row cultivation can be equally effective, although a light chipping may still be required to control larger weeds in the plant line.

Conclusions

- Using Roundup Ready Flex cotton without pre- or at-planting residual herbicides can be a sound weed management strategy in low weed pressure fields in most seasons.
- Applying the CPWC and controlling weeds within a few days of germination will minimize yield losses from weeds, while not leading to excessive herbicide use.
- Weeds that emerge after the CPWC still have to be controlled, but timing is not critical provided they are controlled before they set seed.
- Fields that have significant populations of troublesome weeds should always be treated with residual herbicides before or at planting.
- Alternative weed management tools such as inter-row cultivation and chipping can reduce the pressure on Roundup applications.
- Include a directed layby residual herbicide, incorporated with inter-row cultivation in the system.
- Consider an early layby herbicide application if seasonal conditions lead to excessive early season weed pressure.
- These strategies can be applied equally with an alternative technology, such as Liberty Link cotton, although an at-planting residual grass herbicide will be required on most fields with Liberty Link cotton.

Acknowledgements

We gratefully acknowledge the input of the “weeds team” who did the hard and often tedious field work involved in the experiments contributing to this article. This work was funded by NSW Dept Primary Industries, the Cotton Catchment Communities CRC and the Cotton R&D Corporation.

Summary

Application of the Critical Period for Weed Control (CPWC) concept was tested for irrigated and rain-fed Roundup Ready Flex® cotton crops using data from the last three seasons.

The CPWC was applied to a relatively dirty field situation, where large numbers of weeds emerged after each rainfall and irrigation event.

The CPWC required that weeds were controlled while still small, potentially using up the in-crop Roundup Ready® applications early in the season.

The seasons varied from relatively wet (first half of 2004-5) to extremely dry (2006-7).

All weed flushes were able to be controlled in each season using the CPWC approach, with an early application of a residual layby herbicide available as a backup additional weed management tool.

The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will minimise yield losses from weeds.

USING THE CRITICAL PERIOD FOR WEED CONTROL IN THE 2007/8 SEASON

Graham Charles and Ian Taylor

(NSW Dept of Primary Industries)

Roundup Ready Herbicide® was a powerful tool for controlling weeds in Roundup Ready Flex® cotton in the very wet early-season conditions experienced in the Burdekin this year. The question of the optimum time to apply herbicides still remains.

The critical period for weed control

The critical period for weed control is a concept that relates the yield reduction caused by weed competition to an economic threshold. It establishes an initial period when the weeds are small and do not need to be controlled as they cause no economic loss, and a period at the end of the season when late emerging weeds again cause no economic loss as the cotton plants are relatively large and competitive. These periods define the middle, critical period for weed control, in which weeds must be controlled while still small to avoid significant yield losses. Weeds can be tolerated in the last stage, after the critical period, as they will not reduce crop yields, but may still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. These weeds can also harbour pests and diseases.

In practice, the critical period is defined by the type of weed present, the density of weeds, the potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses.

The critical period for weed control is defined in Table 1 for large and medium sized broadleaf and grass weeds using 1% and 3% thresholds. These thresholds approximate likely control thresholds for applying glyphosate to fully irrigated cotton (1% threshold) and lower yielding or rain-fed crops (3% threshold). The thresholds approximate the point where the yield loss caused by the weeds equals the cost of control with glyphosate. The point of the threshold is determined by the cost of the control input and the value of the crop.

To show how these thresholds would be used in the field, we applied them to 3 weed densities in irrigated and dryland cotton crops, using climatic data from Narrabri for the 2007/8 season. We used dirty, average and clean fields, with mixed populations of large and medium broadleaf and grass weeds. Weed germinations were related to rainfall and irrigation events. The models assumed most weeds emerged 50 to 100 day degrees after rain (or irrigation), and all weeds were controlled with glyphosate.

It is essential that glyphosate is not the only herbicide used in fields with very heavy weed densities, or where glyphosate tolerant weeds are present. Residual herbicides, such as prometryn, fluometuron and diuron, or alternative contact herbicides, such as Staple® or Envoke®, should be used in fields were significant numbers of glyphosate tolerant weeds, such as burr medic, rhyncho and emu foot are present. The choice of herbicide(s) is determined by the weed species present.

Table 1. *The predicted start and end of the critical period for weed control for a range of weed types and densities, using 1% and 3% control thresholds. Examples of weeds in each category are: thornapples and noogoora burrs (large broad-leaf weeds); bladder ketmia and Chinese lantern (medium broad-leaf weeds); and barnyard grass (grass weed). The minimum weed densities needed to trigger the critical period are also shown.*

Weed density (no./m²)	Critical Period for Weed Control (day degrees since planting)											
	Large broad-leaf weeds				Medium broad-leaf weeds				Grass weeds			
	1% Yield loss threshold		3% Yield loss threshold		1% Yield loss threshold		3% Yield loss threshold		1% Yield loss threshold		3% Yield loss threshold	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	111	210	-	-	111	172	-	-	-	-	-	-
0.2	111	310	178	222	111	249	-	-	-	-	-	-
0.5	110	507	177	365	110	416	-	-	-	-	-	-
1	110	678	175	508	110	583	175	227	-	-	-	-
2	109	827	170	653	109	748	170	331	-	-	-	-
3	108	895	166	725	108	831	166	409	123	141	-	-
5	105	959	158	798	105	913	158	517	122	178	137	148
10	101	1014	142	864	101	987	142	661	121	259	136	206
20	94	1044	119	901	94	1029	119	774	120	383	132	299
50	84	1063	89	926	84	1057	89	866	115	600	124	477
Min.density	0.03		0.14		0.04		0.62		2.1		4.2	

Very dirty fields are normally best managed by applying residual herbicides before or at planting, reducing the pressure on glyphosate later in the season. This is generally more satisfactory than applying these herbicides later in the season after problems have already occurred, when it is difficult to achieve good incorporation of the herbicides, especially in the plant line.

The discussion in this article focuses on the management of Roundup Ready Flex cotton crops because the critical period approach is readily adapted to the Roundup system and this is currently the most common cropping option used. The concept can be equally applied to conventional and Liberty Link cotton crops, but the thresholds will need to be modified to take into account the costs of alternative inputs with these crops.

The critical period in irrigated cotton

The crops were watered-up on 8th Oct. No residual herbicides were applied before or at planting.

The start of the critical period was relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. This minimum number of weeds was very low for large broadleaf weeds, at 3/100 m row (1% threshold), but much higher for grass weeds at 2.1/m row.

Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (105 – 110 day degrees after planting), as shown in Figure 1. The end of the critical period for weed control was strongly influenced by weed type and density, rising from 583 day degrees post-planting in the clean field, to 1029 day degrees in the dirty field.

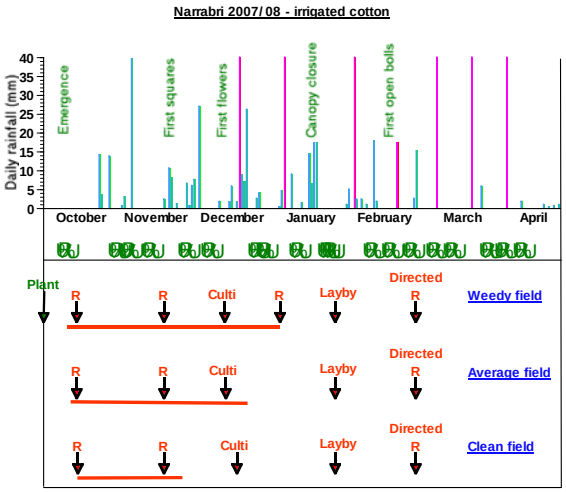

Figure 1*. How the critical period for weed control could have been used in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (top section) rainfall (**vertical blue bars**) and irrigations (**vertical pink bars**); (middle section) periods of peak weed emergence, ; and (bottom section) the critical period for weed control, **horizontal lines**; and planting and weed control inputs, **arrows**. Symbols used on arrows are: planting, **Plant**; Roundup Ready Herbicide sprays, **R**; inter-row cultivation passes, **Culti**; and application and incorporation of a residual herbicide, **Layby.***

Reasonable rain fell over late spring and summer, in a relatively long, cool season. This resulted in multiple weed germinations, with later germinations triggered by irrigations. A 2nd Roundup application was required on all fields in early-November to control a flush of weeds after rain in late-October. A fall of 40 mm on 6th November delayed this application till mid-November.

Lower than maximum label rates would have been suitable for Roundup applications to young weeds, as weeds are more easily controlled while they are small, provided they have sufficient leaf area to catch the spray. Rates of 0.8 to 1 kg/ha should be sufficient to control susceptible weed seedlings, reducing cost and maintaining late-season options (the product label precludes the use of maximum label rates for all applications if the maximum number of in-crop Roundup applications is used).

An alternative input, such as a cultivation and light chip, may have been required to remove surviving weeds after this application, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors. Controlling surviving weeds with an alternative management input is essential to avoid species shift and herbicide resistance.

No further weed control in the critical period was required on the clean field, but all fields were inter-row cultivated in early- to mid-December prior to the first irrigation. This cultivation was undertaken to facilitate water movement and would also have controlled most weeds present. A residual herbicide could have been applied and incorporated at this time if required. No further treatment was required in the critical period on the average field, but an additional Roundup was required at the start of January on the weedy field.

A large number of weeds emerged following good rain in December and January, necessitating treatment by Roundup or the use of an incorporated residual herbicide in late January. Roundup could not have been used on the weedy field as only 3 post-emergence applications are permitted up to the 16 node stage of crop growth (this is a requirement of the product label). An additional directed Roundup application could have been made in late February, and a pre-harvest application could also have been used to prevent late-season weeds setting seed if sufficient weeds were present to justify these inputs.

Applying an incorporated, residual herbicide at canopy closure is a sound strategy for most fields. A residual “layby” herbicide should control any weeds that have survived the Roundup applications (reducing the risk of glyphosate resistance developing), and reduce the risk of weeds emerging later in the season when they will be difficult and expensive to control.

The critical period in dryland cotton

The crops were planted on 28th Oct, following rain on the 25th. No residual herbicides were applied before or at planting.

The start of the critical period was again relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. This minimum number of weeds was low for large broadleaf weeds, at 1 in 10 m row (3% threshold), but much higher for grass weeds at 4.2/m row.

Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (158 – 177 day degrees after planting) (Figure 2). The end of the critical period for weed control was strongly influenced by weed type and density, rising from 365 day degrees post-planting in the clean field, to 798 day degrees in the dirty field.

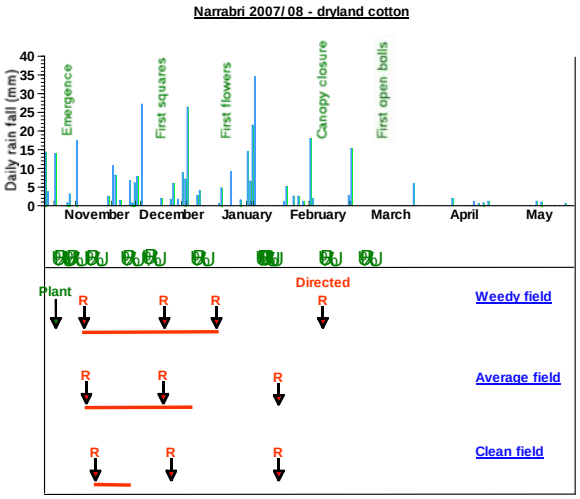

Figure 2. *Using the critical period for weed control in dryland cotton in the 2007-8 season at Narrabri for weedy, average and clean fields.*

A 2nd Roundup application was required on the average and weedy fields in early-December to control a flush of weeds after rain in late-November. An application may have also been used on the clean field to manage weeds before they set seed.

Lower than maximum label rates would have been suitable for those Roundup applications applied to young weeds, as these weeds are more easily controlled. Rates of 0.8 to 1 kg/ha would give excellent control of susceptible weed seedlings, reducing cost and maintaining late-season options.

No further weed control in the critical period was required on the clean and average fields, but a Roundup may have been used in late-January, again to control weeds before they set seed. A Roundup was required at the start of January on the weedy field.

An alternative treatment, such as a cultivation and light chipping, may have been used to remove surviving weeds after the Roundup applications in mid-December, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors.

Observations from the 2007/8 season

Using the critical period for weed control approach in this season didn't encounter any difficulties for either irrigated or dryland cotton production and would have closely mirrored the inputs made by good managers. Weeds could have been controlled using Roundup Ready Herbicide within the restrictions of the label.

The main difference for crop management with this approach is that weed control is focussed on the critical period, soon after crop emergence, with all inputs during this period occurring on very small weeds. This contrasts with a more common philosophy, that glyphosate applications to Roundup Ready Flex crops can be delayed to maximise the efficiency of each spray, minimising the number of sprays and ensuring that the maximum number of weeds are controlled with each input. Many cotton growers have concluded that since they are no longer constrained to the 4-node over-the-top glyphosate application window, glyphosate applications can be delayed to about 6 nodes, with a 2nd application at 10 to 12 nodes giving good weed control. While this approach appears to be valid, the science of the critical period has shown that the first glyphosate application may need to occur soon after crop emergence, with further applications following closely after successive weed germination events. This strategy of controlling very small weeds may require more Roundup applications, but can utilize lower herbicide rates and maintains the potential for higher crop yields.

The critical period for weed control approach was successfully applied in both irrigated and dryland cotton in the 2007/9 season. Applying Roundup Ready Herbicide to small weeds soon after emergence maximized herbicide efficacy and crop yields but didn't result in the maximum number of Roundup applications being used too early in the season.

In seasons where the early season weed pressure is excessive (possibly requiring more Roundup applications than are permitted by the product label), an alternative herbicide or early layby application of residual herbicide could be used to replace a Roundup application and reduce weed pressure. Prometyrn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and control a wide range of emerged weeds provided they are applied to small weeds, as well as giving residual control, reducing weed pressure. An alternative residual, such as diuron, could be applied later in the season as a standard layby application if necessary.

Resistance to Roundup

Some cotton growers are concerned that relying too heavily on Roundup is likely to lead to future problems with weeds that are resistant to Roundup (glyphosate). The potential for resistance is very real, as shown by the increasing resistance problems with Roundup Ready crops in the US.

However, resistance can be avoided by following two simple rules.

1. Always follow the Roundup Ready Flex Crop Management Plan. The core principle of this plan is to ensure crops are checked after a Roundup application and any surviving weeds are controlled using an alternative weed management tool before they set seed.
2. Ensure at least one effective alternative weed management tool is used each season. An inter-row cultivation combined with a light chipping is a sound strategy for avoiding resistance. Alternatively, using a directed layby residual herbicide, incorporated with inter-row cultivation can be equally effective, although a light chipping may still be required to control larger weeds in the plant line.

The Critical Period for Weed Control was tested using a range of weeds planted and removed at different stages of crop growth. The effects of weeds on crop growth, development and yield was measured.

Conclusions

- Using Roundup Ready Flex cotton without pre- or at-planting residual herbicides can be a sound weed management strategy in low weed pressure fields.
- Including alternative weed management tools in the system, such as inter-row cultivation, can reduce the pressure on Roundup applications.
- Including a directed layby residual herbicide, incorporated with inter-row cultivation, in the system can assist with the management of later emerging weeds and reduce the risk of species shift and herbicide resistance.
- If seasonal conditions lead to excessive early season weed pressure, an early layby herbicide application may be a valuable investment for reducing the pressure on glyphosate.
- Fields with significant populations of glyphosate tolerant or hard-to-control weeds should always be treated with residual herbicides before or at planting.
- These strategies can be applied equally with an alternative technology, such as Liberty Link cotton, although an at-planting residual grass herbicide will be required on most fields with Liberty Link cotton.

Summary

Data from last season was used to test the critical period for weed control approach for irrigated and dryland Roundup Ready Flex® cotton crops.

The critical period for weed control was applied to dirty, average and clean fields, where weeds emerged after each rainfall and irrigation event.

Applying the critical period approach required that the start of weed control began soon after crop emergence, while weeds were still small. A lighter herbicide rate might be appropriate for small weeds. The duration of the critical period depended on the density of weeds that emerged after the first treatment.

All weed flushes in the 2007/8 season were controlled using Roundup during the critical period, with an inter-row cultivation or an early application of a residual layby herbicide available as an additional weed management tool if required.

The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will help optimize crop yields. The approach can be equally applied to irrigated and dryland crops using Roundup Ready Flex, Liberty Link® or conventional cotton varieties.

MANAGING WEEDS USING THE CRITICAL PERIOD FOR WEED CONTROL

Graham Charles and Ian Taylor

(NSW Dept of Primary Industries)

Weeds can compete strongly with cotton, reducing yields. Weeds can also harbour pests and diseases, interfere with water flow and picking and contaminate lint. This heavy infestation of Australian bindweed is far more serious than it may appear.

The critical period for weed control

The critical period for weed control is a concept that relates the yield losses caused by weed competition to an economic threshold. It establishes an initial period when weeds are small and do not need to be controlled as they cause no economic loss, and a period later in the season when the cotton plants are relatively large and small weeds again cause no economic loss. These periods define the middle, critical period for weed control, in which weeds must be controlled while still small to avoid significant yield losses. Weeds which emerge after the critical period may still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. These weeds can also harbour pests and diseases. However, the timing of this control is flexible, provided seed set is prevented, and can be delayed to minimise the number of spray applications required over the season.

In practice, the critical period is defined by the type and density of weeds, potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses. The critical period is defined in Table 1 for large and medium sized broadleaf and grass weeds in high yielding, fully irrigated cotton, and lower yielding or rain-fed crops. Earlier articles defined a critical period based on lower thresholds. The increased thresholds reflect the jump in the glyphosate prices late last year.

To show how the critical period would have worked last season, we applied it to irrigated and dryland cotton crops, using climatic data from Narrabri. We used weedy, average and clean fields, with mixed populations of large and medium broadleaf and grass weeds.

The discussion focuses on the management of Roundup Ready Flex cotton crops because the critical period is readily adapted to the Roundup system and this is the most common cropping option used. The concept can be equally applied to conventional and Liberty Link crops.

***Table 1**. The predicted start and end of the critical period for weed control for a range of weed types and densities. Examples of weeds in each category are: thornapples and noogoora burrs (large broad-leaf weeds); bladder ketmia and Chinese lantern (medium broad-leaf weeds); and barnyard grass (grass weed). The minimum weed densities needed to trigger the critical period are also shown.*

Weed density (no./m²)	Start and end of the critical period for weed control (day degrees since planting)											
	Irrigated (high yielding) cotton						Dryland (low yielding) cotton					
	Broad-leaf weeds						Broad-leaf weeds					
	Large		Medium		Grasses		Large		Medium		Grasses	
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

The critical period in irrigated cotton

The crops were watered-up on 8th Oct. No residual herbicides were applied before or at planting.

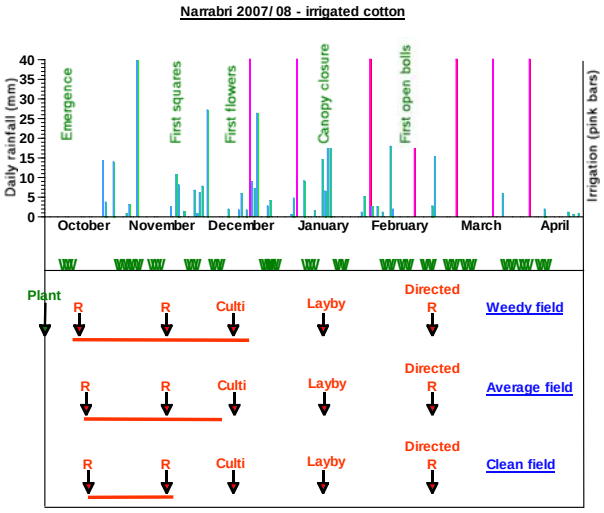

***Figure 1**. How the critical period for weed control could have been used in the 2007-8 season at Narrabri for weedy, average and clean fields. Symbols are: (top section) rainfall (**vertical blue bars**) and irrigations (**vertical pink bars**); (middle section) periods of peak weed emergence, **W**; and (bottom section) the critical period for weed control, **horizontal lines**; and planting and weed control inputs, **arrows**. Symbols used on arrows are: planting, **Plant**; Roundup Ready Herbicide sprays, **R**; inter-row cultivation passes, **Culti**; and application and incorporation of a residual herbicide, **Layby**.*

The start of the critical period was relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (106 – 141 day degrees after planting, Figure 1). The end of the critical period was strongly influenced by weed type and density, rising from 514 day degrees post-planting in the clean field, to 862 day degrees in the weedy field.

Lower than maximum label rates would have been suitable for Roundup applications to young weeds, as weeds are more easily controlled while they are small, provided they have sufficient leaf area to catch the spray. Rates of 0.8 to 1 kg/ha should be sufficient to control susceptible weed seedlings, reducing cost and maintaining late-season options (the product label precludes the use of maximum label rates for all applications if the maximum number of in-crop Roundup applications is used).

An alternative input, such as a cultivation and light chip, may have been required to remove surviving weeds after this application, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors. Controlling surviving weeds is essential to avoid species shift and herbicide resistance.

Reasonable rain fell over late spring and summer, in a relatively long, cool season. This resulted in multiple weed germinations, with later germinations triggered by irrigations. A 2nd Roundup application was required on all fields in early-November to control a flush of weeds after rain in late-October. A fall of 40 mm delayed this application till mid-November.

No further weed control in the critical period was required on the clean or average fields, but all fields were inter-row cultivated in early- to mid-December prior to the first irrigation. This cultivation was undertaken to facilitate water movement and would also have controlled most weeds present. A supplementary Roundup application and/or chipping may have been required in the weedy field.

A large number of weeds emerged following further rain in December and January, necessitating treatment by Roundup or the use of an incorporated residual herbicide in mid-January. An additional directed Roundup application could have been made in late-February, and a pre-harvest application could also have been used to prevent late-season weeds setting seed if sufficient weeds were present to justify these inputs.

The critical period in dryland cotton

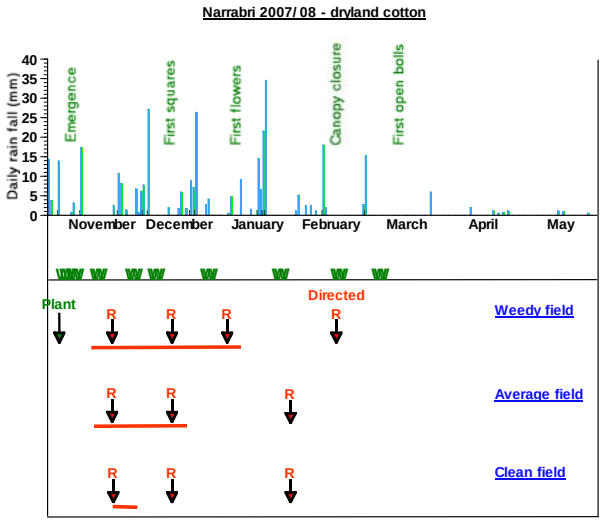

Figure 2. *Using the critical period for weed control in dryland cotton in the 2007-8 season at Narrabri. Symbols are explained in the caption to Figure 1.*

The crops were planted on 28th Oct, following rain on the 25th. No residual herbicides were applied before or at planting.

The start of the critical period was again relatively insensitive to weed density, provided there were enough weeds to trigger the critical period. Given that the threshold weed density was reached, the first Roundup application was required soon after crop emergence (241 day degrees after planting, Figure 2). The end of the critical period was strongly influenced by weed type and density, rising from 368 day degrees post-planting in the clean field, to 735 day degrees in the weedy field.

A 2nd Roundup application was required on the average and weedy fields in early-December to control a flush of weeds after rain in late-November. An application may have also been used on the clean field to control weeds before they set seed.

No further weed control in the critical period was required on the clean and average fields, but a Roundup may have been used in late-January, again to control weeds before they set seed. A Roundup was required at the start of January on the weedy field.

An alternative treatment, such as a cultivation and light chipping, may have been used to remove surviving weeds after the Roundup applications in mid-December, as required by the Roundup Ready Flex Crop Management Plan. The need for this input is determined by the in-crop survey of weed survivors.

An experiment using a naturally occurring weed population to test the application of the critical period for weed control in cotton at ACRI last season.

Observations from the 2007/8 season

Using the critical period for weed control approach in this season didn't encounter any difficulties for either irrigated or dryland cotton production.

The main difference for crop management with this approach is that weed control is focussed on the critical period, soon after crop emergence, with all inputs during this period necessarily occurring on small weeds. This contrasts with a more common philosophy, that glyphosate applications to Roundup Ready Flex crops can be delayed to maximise the efficiency of each spray, minimising the number of sprays and ensuring that the maximum number of weeds are controlled with each input. Many cotton growers have concluded that since they are no longer constrained to the 4-node over-the-top glyphosate application window, glyphosate applications can be delayed to about 6 nodes, with a 2nd application at 10 to 12 nodes giving good weed control. While this approach is valid, the science of the critical period has shown that to avoid yield losses, the first glyphosate application may need to occur soon after crop emergence, with further applications following closely after successive weed germination events. This strategy of controlling very small weeds may require more Roundup applications, but can utilize lower herbicide rates and maintains the potential for higher crop yields.

In seasons where the early season weed pressure is excessive (possibly requiring more Roundup applications than are permitted by the product label), an alternative herbicide or early layby application of residual herbicide could be used to replace a Roundup application and reduce weed pressure. Prometyrn (Gesagard) or fluometuron (Cotoran), for example, can be applied as an early layby to cotton as small as 15 cm high and control a wide range of small emerged weeds, as well as giving residual control, reducing weed pressure. An alternative residual, such as diuron, could be applied later in the season as a standard layby application if necessary.

Summary

Data from last season was used to test the practicality of applying the critical period for weed control for irrigated (higher yielding) and dryland (lower yielding) cotton crops. The critical period was applied to weedy, average and clean Roundup Ready Flex® fields.

Applying the spraying threshold required that weed control began soon after crop emergence, while weeds were still small. A lighter herbicide rate would be appropriate for these weeds. The threshold was reached later in the dryland crop. The duration of the critical period depended on the density of weeds present.

All weed flushes were controlled using Roundup during the critical period within the constraints of the Roundup Ready Herbicide label, with an inter-row cultivation or early layby available as an additional management tool.

The results show that ensuring weeds are controlled soon after emergence is a practical approach to weed control which will help maximize crop yields. The approach can be equally applied to irrigated and dryland crops using Roundup Ready Flex, Liberty Link® or conventional cotton varieties.

SAMPLING METHODS FOR THE CRITICAL PERIOD FOR WEED CONTROL

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What is the critical period for weed control

The critical period for weed control is a concept that relates the yield losses caused by weed competition to an economic threshold. It establishes an initial period when weeds are small and do not need to be controlled as they cause no economic loss, and a period later in the season when the cotton plants are relatively large and small weeds again cause no economic loss. These periods define the middle, critical period for weed control, in which weeds must be controlled while still small to avoid significant yield losses. Weeds which emerge after the critical period may still need to be controlled to avoid harvesting difficulties and lint contamination and should not be allowed to set seed, as this will lead to increased weed problems in later seasons. These weeds can also harbour pests and diseases. However, the timing of this control is flexible, provided seed set is prevented, and can be delayed to minimise the number of spray applications required over the season.

In practice, the critical period is defined by the type and density of weeds, potential crop yield, the cost of weed control and the economic threshold the cotton grower chooses. The critical period is defined in Table 1 for large and medium sized broadleaf and grass weeds in high yielding irrigated cotton, and lower yielding or rain-fed crops. Earlier articles defined a critical period based on lower thresholds. The increased thresholds reflect the jump in glyphosate prices late last year.

The discussion focuses on the management of Roundup Ready Flex cotton crops because the critical period is readily adapted to the Roundup system and this is the most common cropping option used. The concept can be equally applied to conventional and Liberty Link crops.

Applying the critical period

Determining the critical period for weed control in a field requires a knowledge of the degree days since crop planting and the type and density of weeds present in the field. Degree days are calculated from the daily maximum and minimum temperatures since planting.

The type and density of weeds is determined from an in-field assessment. This assessment may take 30 – 40 minutes for each field, but is only required in the early part of the season and only after rainfall or irrigation events trigger new flushes of weeds.

The ability to identify weeds to species level is not necessary for the weed assessment, as weeds are grouped into 3 categories. Commonly occurring weeds in each category are:

- Large broadleaf weeds:
  - the noogoora burr group (Noogoora burr, Californian burr and Italian cocklebur),
  - thornapples (fierce thornapple, downy thornapple and common thornapple),
  - sesbania and budda pea

Seedling photos of these weeds can be found in WEEDpak on the COTTONpaks cd or at http://www.cottoncrc.org.au

***Table 1**. The start and end of the critical period for weed control for a range of weed types and densities. The minimum weed densities needed to trigger the critical period are also shown.*

The Critical Period for Weed Control in cotton (day degrees since planting)												
	High yielding cotton crops						Low yielding cotton crops					
Weed density (no./m^2)	Broad-leaf weeds				Grasses		Broad-leaf weeds				Grasses	
	Large		Medium				Large		Medium			
	Start	End	Start	End	Start	End	Start	End	Start	End	Start	End
0.1	145	189	145	172	-	-	-	-	-	-	-	-
0.2	144	275	144	244	-	-	254	229	-	-	-	-
0.5	143	447	143	387	-	-	251	368	-	-	-	-
1	141	600	141	514	-	-	246	498	246	319	-	-
2	139	738	139	627	-	-	238	620	238	421	-	-
5	131	862	131	729	129	174	215	735	215	537	-	-
10	121	915	121	771	127	248	184	785	184	595	152	206
20	106	944	106	795	125	357	142	812	142	631	147	290
50	87	962	87	810	119	531	93	830	93	654	134	431
Min. density	0.06		0.07		2.5		0.24		0.59		5.4	

- Medium broadleaf weeds:

  - All other weeds can be included in this group. If in doubt, put them here.

- Grasses:

  - includes the grasses and other grass-like species, such as the nutgrasses

The field sampling technique

The sampling technique to estimate the density of each weed type is similar to the technique used in the weed survey required by the Roundup Ready and Liberty Link Crop Management Plans.

Firstly, weed patchiness is assessed by a "drive-by" survey around the perimeter of the field, noting the location of the more weedy areas in the field. The density of each weed type is then assessed in 3 to 5 different areas of the field, with more sampling required on larger fields. The location of these assessments is determined from the drive-by survey, ensuring that the more weedy areas of the field are included in the assessments. Ensure that both head ditch and tail ditch ends of the field are checked, and that the observations are not concentrated on the edge of the field. On deep fields with runs of 1000 m or more, it may be necessary to go further into the field than the 250 m suggested below.

Once the areas for assessment are located, the assessment is undertaken by walking approximately 250 m into the field in each area and estimating weed density and type. The 500m walk (250 m each way) is broken into 50m strips, moving across 10 rows after each 50 m strip and estimating the density of each weed type in each 50 m strip (each strip is 1 m wide, from cotton row to cotton row). Ensure that the survey covers both beds and furrows in 2 m beds or other configurations).

The weed assessment method is simple. In each strip, the density of large and medium broadleaf weeds and grasses is assessed. This is done by estimating the density of each weed type as <5/50 m row, 5-50/50 m row, 50-500/50 m, or > 500/50 m. At first it may be necessary to count a few weeds to get an idea of what these densities look like, but the densities can be easily estimated by eye with experience. Density can be easily calculated in cotton on a 1 m planting configuration by visualizing a 1 m square area and counting the number of weeds in this area. One weed per square m equates to 50 weeds per 50 m^2. The exact length of each transect (50 m) is not critical, but is a guide to the amount of area which should be covered. It is essential that the survey goes towards the middle of the field, as the edge area may not be representative of the whole field.

A table for the weed assessments is given at the end of this document. To use this table:

1. For each 50 m strip, write a score of 1, 2, 3 or 4 corresponding to the estimated density of each weed type.
2. Add the scores in each column and add the columns to give a total for the assessment, as in the example below.

Large broadleaf **Number per 50 m of row**

weeds	**<5**	**5 - 50**	**50 - 500**	**>500**	
	1	**2**	**3**	**4**	
0-50 m		2			
50-100 m		2			
100-150 m		2			
150-200 m	1				
200-250 m		2			
250-200 m	1				
200-150 m	1				
150-100 m	1				
100-50 m	1				
50 - 0 m			3		**Total**
Sum	**_5_**	**_8_**	**_3_**		**16**

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3. The scores from this assessment, along with the scores from the other assessments done in the paddock are transferred to the Score Summary, as in the example below.

Score Summary	**1**	**2**	**3**	**4**	**5**
Large broadleaf	16	12	23	19	30
Medium broadleaf					
Grasses					

4. These numbers are converted to weed density using the table of Scores and Weed densities on the right hand side of the page, recorded in the Assessment Summary, and the average entered, as shown below.

Assessment summary	**1**	**2**	**3**	**4**	**5**	**Average**
Large broadleaf	0.2	0.079	1	0.4	5	_1.3_
Medium broadleaf						___
Grasses						___

5. This average is the field density of broadleaf weeds used to determine the critical period for weed control for this field. In this case, a density of 1.3 translates to a critical period from 139 to 738 day degrees duration, using the closest higher number from the Critical Period table (Table 1).

   If the density of large broadleaf weeds ($1.3/m^2$) occurred within the Critical period, then a spray should be applied as soon as practical.

   Outside the Critical Period, this weed density could be tolerated, provided the weeds are controlled before they set seed. However, if another flush of weeds emerges soon after, the field may need to be reassessed, as the increased weed density may fall within the new Critical Period that is derived by the new, larger, weed population.

Summary

- Use a drive-by survey to identify patches of heavier weeds in the field
- Assess weeds in 3 - 5 of the more weedy areas (depending on field size)
- Estimate the weed type and density on a 250 m strip into the field at each assessment point
- Use these assessments to determine the Critical Period for Weed Control for this crop.
- Organise to control weeds as soon as practical if the weed flush is within the Critical Period
- If not, monitor the weeds and control them before they set seed.

Applying the critical period requires that weed control begins soon after emergence in high yielding crops, while weeds are still small. A lighter herbicide rate would be appropriate for these weeds. The threshold will be reached later in lower yielding crops. The duration of the critical period depends on the density of weeds present.

All weed flushes can be controlled with Roundup during the critical period within the constraints of the Roundup Ready Herbicide label, with an inter-row cultivation or early layby available as an additional management tool if required.

Ensuring weeds are controlled soon after emergence is a practical approach to weed control which will help maximize crop yields. The approach can be equally applied to irrigated and dryland crops using Roundup Ready Flex, Liberty Link® or conventional cotton varieties.

The Critical Period Weed Sampling Sheet

Date: Recorder:
Property: Field: Assessment:

Large broadleaf weeds	<5 1	5 - 50 2	50 - 500 3	>500 4	
	Number per 50 m of row				
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

Large broadleaf – Noogoora burrs, thornapples, sesbania & budda pea
Medium broadleaf – all other broadleaf weeds
Grasses – grasses and all grass like weeds

Medium broadleaf weeds	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

Grasses	<5 1	5 - 50 2	50 - 500 3	>500 4	
0-50 m					
50-100 m					
100-150 m					
150-200 m					
200-250 m					
250-200 m					
200-150 m					
150-100 m					
100-50 m					
50 - 0 m					Total
Sum	___	___	___	___	

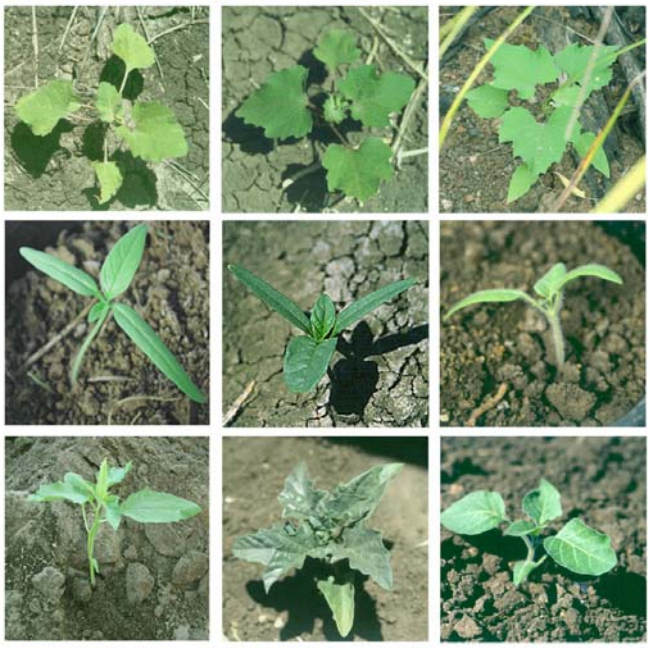
Assessment score	1	2	3	4	5
Large broadleaf					
Medium broadleaf					
Grasses					

Assessment summary	1	2	3	4	5	Average
Large broadleaf						___
Medium broadleaf						___
Grasses						___

Assessment score	Weed density
1	0.006
2	0.008
3	0.010
4	0.013
5	0.016
6	0.020
7	0.025
8	0.032
9	0.040
10	0.05
11	0.063
12	0.079
13	0.10
14	0.13
15	0.16
16	0.20
17	0.25
18	0.32
19	0.40
20	0.5
21	0.63
22	0.79
23	1.00
24	1.26
25	1.58
26	1.99
27	2.51
28	3.15
29	3.97
30	5
31	6.29
32	7.92
33	10
34	12.6
35	15.8
36	19.9
37	25.1
38	31.5
39	39.7
40	50

Examples of Large Weeds

Noogoora burr complex:
Italian cockleburr, Californian burr and Noogoora burr (L to R)



Thornapple complex:
common thornapple, fierce thornapple, and downy thornapple

Sesbania and budda pea

The Critical Period for Weed Control in cotton (day degrees since planting)												
	High yielding cotton crops						Low yielding cotton crops					
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