# Using the critical period for weed control to establish a weed threshold in irrigated cotton

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**Summary** Pest control thresholds are widely used in various disciplines and have been the aspiration of weed scientists. However, weed control thresholds have been challenging to establish as the results from competition experiments, on which thresholds are based, are almost always specific to species, site and season. This is especially true for crops where seasonal conditions, in particular rainfall, have an overwhelming influence on both weed and crop growth, such that the density of weeds required to cause economic damage to the crop can vary widely over years. This level of seasonal variation is generally not seen in fully-irrigated cotton crops in Australia, where inputs are managed to optimise cotton lint yield. Hence, quantifying a weed control threshold for these crops should be feasible.

The results from our research culminated in a dynamic, multi-species weed competition model, relating relative crop yield to weed height and biomass, together with the times of weed emergence and weed removal. Additional research has modelled the effect of successive germination and weed control events during the cropping year. These models enable cotton growers to determine the yield loss caused by a given weed population at any stage during crop growth and to estimate the cost of delaying weed control. A variable weed control threshold can be applied to the models, triggering control decisions according to crop value and the cost of control.

**Keywords** mimic weeds, weed succession, yield-loss threshold.

## INTRODUCTION

The modern Australian cotton industry began in 1961, with 120 ha of cotton planted near Wee Waa, NSW. Competition from weeds and flooding were major issues for this crop and only 26 ha was harvested. Two years later, the first large-scale planting occurred, with 1700 ha of cotton planted, but only 400 ha harvested, with the remainder lost to unmanageable competition from weeds (Jones and Shaw 2014, Marshall 2015).

Over the next four decades, cotton growers developed an integrated approach to weed management, combining residual and over-the-top herbicides, cultivation, hand-hoeing, crop rotations and fallow weed control to develop a robust weed management system. This approach gave acceptable levels of management for most weeds and the weed seedbank declined over time, but the system was expensive and not infrequently resulted in crop damage, often from residual herbicides (Taylor *et al.* 2003). The weed management system was also largely prescriptive, with heavy reliance on residual herbicides applied prior to crop planting in anticipation of weed issues, and the use of in-crop tools was largely limited to the first half of the crop season due to crop size and the need to avoid trafficking wet soils.

The introduction in the 2001/2 season of cotton varieties including the Roundup Ready® trait, which confers tolerance to glyphosate, and the later introduction of the Roundup Ready® Flex trait in 2007/8, radically changed in-crop weed management for most Australian cotton crops, with glyphosate use replacing most or all other herbicides and many in-crop cultivation passes (Werth *et al.* 2013).

The use of glyphosate-tolerant varieties simplified in-crop weed management for cotton and contributed to the increase in yields seen in Australian crops. However, the ideal timing of in-crop glyphosate applications with Roundup Ready Flex cotton was unclear. Glyphosate is a broad-spectrum herbicide that can control nearly all in-crop weeds and can be applied at up to 1 kg ai. $ha^{-1}$ at any stage of crop growth, with up to four in-crop applications allowed per season. Most weeds can be controlled with this robust rate of glyphosate at any growth stage, provided the weeds are actively growing, which is the normal situation in irrigated cotton. Hence, weed management with glyphosate in cotton is not limited by the typical window constraining herbicide applications to small, actively growing weeds, and the ideal timing for glyphosate applications in irrigated cotton is not well defined.

The need to optimise the timing of in-crop glyphosate applications is important to minimize crop yield losses due to weed competition, thus optimising the level of weed control achieved from a maximum of four spray applications, but also to ensure herbicide is not applied unnecessarily, increasing production costs and the environmental footprint of cotton production.

**Defining a weed control threshold** A series of competition experiments was conducted in cotton crops between 2003 and 2015 at the Australian Cotton Research Institute, Narrabri NSW, using three mimic weeds: Japanese millet (*Echinochloa esculenta*), a 'grass weed'; mungbean (*Vigna radiata*), a medium-sized 'broadleaf weed'; and sunflower (*Helianthus annuus*), a large 'broadleaf weed'. The mimic weeds were planted to achieve densities of 1 to 200 plants m$^{-2}$, planted with the cotton or at predetermined times following crop emergence and removed later in the season. Charles and Taylor (2007a) explored the potential of a series of published competition models to define a weed control threshold for irrigated cotton in Australia using this data. They found that although existing models could be used to define a threshold, the outputs from the models were invariably season and weed species specific, needing to be redefined for each weed species and season. More sophisticated crop growth models are also available and could be used to develop a weed control threshold, but Dean et al. (2003) found that the greatly increased complexity of these models did not improve the accuracy of the model's outputs.

Charles and Taylor (2007a) subsequently develop a multi-species statistical model that related crop yield loss ($Y$) as a function of crop growing degree days ($T$), weed height ($H$), weed leaf area ($A$), and crop height (C), where:

$$Y = 0.0297 + 0.000282T + 0.00199H + 0.00161A^{0.5} + 0.00234C$$

While this statistical model was a valuable step towards developing a weed threshold model for cotton, the inclusion of weed leaf area in the model makes the model difficult for cotton growers to use.

Charles and Taylor (2007b, 2007c) later released a weed control threshold to the Australian cotton industry for the 2007/8 season using the critical period for weed control (CPWC), based on weed density and weed type (large broadleaf weeds, medium broadleaf weeds and grass weeds). These threshold models represented a further big step in developing a weed control threshold for cotton, but were species (weed type) specific and required cotton growers to estimate the average density of a dominant weed type in a paddock. Also, they were not predictive, in that they did not predict when an under-threshold weed population would reach threshold, and they assumed all weeds emerged at the same time, not allowing for differing weed size from successive germination events.

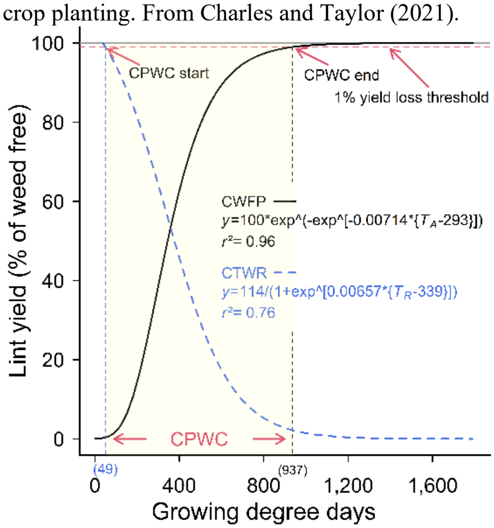
The thresholds were based on a set yield-loss of 1% of crop yield (Charles and Taylor 2007c). The yield-loss threshold (YLT) was determined by a combination of the predicted bale value and cotton yield, together with the applied cost of weed control, and will vary, responding to changes in the value of the crop and the cost of the control tool under consideration. The models of Charles and Taylor (2007c) used a 1% YLT based on 2007 values and did not allow the YLT to be varied.

**The critical period for weed control (CPWC)** The concept of the CPWC was first developed by Nieto et al. (1968) and has since been applied to a wide range of weeds in a range of crops.

The CPWC is developed from crop yield loss data obtained by: (1) allowing weeds to emerge with the crop and then removing these weeds at intervals during crop growth, and; (2) allowing weeds to emerge at intervals during crop growth and compete till harvest, when the subsequent crop yield is recorded. Analysis of this data enables the period of the season during which the crop is most sensitive to weed competition to be described, relating the yield losses from weed competition to a YLT.

The CPWC is delimited by the critical time of weed removal (CTWR) and the critical weed free period (CWFP). The CTWR defines the period during which the crop can tolerate early-season competition before unacceptable crop losses occur, and the CWFP defines the period during which the crop needs to be kept weed free to avoid unacceptable

**Figure 1.** The CPWC for 50 large weed (sunflower) plants per m$^2$ in cotton. The CPWC (shaded area) extended from 49 to 937 growing degree days after crop planting. From Charles and Taylor (2021).



losses (Charles and Taylor 2021). The CPWC is delimited by the intersections of the CTWR and CWFP lines with the YLT. An example CPWC relationship taken from Charles and Taylor (2021) is shown in Figure 1.

The value of the CPWC approach was further enhanced by Charles *et al.* (2021) who developed a multispecies threshold model by including weed height and weed biomass in extended logistic and Gompertz equations. Their relationships allow a cotton grower to determine the CPWC for any species or mix of species of weeds of size from 1 to 200 cm tall, weighing 10 to 2000 g $m^{-2}$, although the models were only tested on three mimic weeds. The value of these relationships could be further enhanced if growth curves were developed for the major weeds of cotton. Including growth curves would allow the relationships to be used predictively, identifying when in the future a weed population which is under the YLT would grow to exceed the YLT.

These models (Charles *et al.* 2021) go a long way to achieving the aim of delivering a weed control threshold to Australian cotton growers that can be applied in the field, although they require the input of data on weed height and weed biomass for each field. However, the relationships do not allow for successive germination or weed control events during the cropping season.

**Successive weed germination and understanding the CPWC relationships** The CPWC concept is based around the competitive effect of weeds that emerge in a single cohort with the crop and are removed at some time post-emergence, or weeds that emerge in a single cohort post-crop emergence and continue to grow throughout the season. However, in a cotton field, in the absence of heavy rates of residual herbicides, there is normally an initial emergence of weeds with the crop, followed by additional weed emergence throughout the cropping season, with emergence flushes triggered by rainfall and irrigation events.

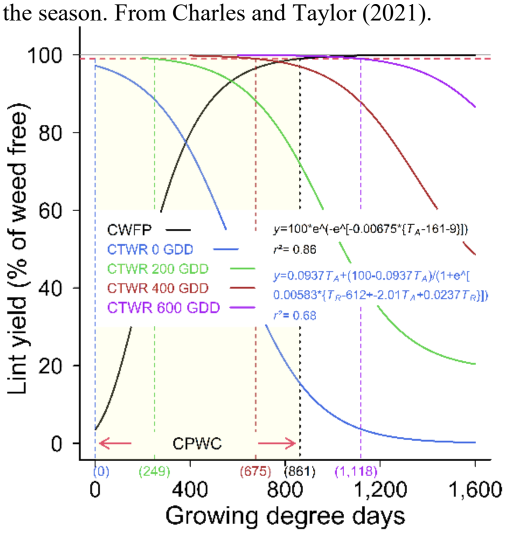
By definition, weeds present during the CPWC must be controlled to prevent yield losses exceeding the YLT. In the example of Figure 1, this means weeds that emerge with the crop have to be controlled by 49 GDD and weeds that emerge after 937 GDD will not need to be controlled to prevent yield loss greater than the YLT. These late emerging weeds may still need to be controlled before harvest as they can host pests and diseases, contaminate lint, and cause difficulties at harvest. In addition, all weeds should be controlled before they can set seed to drive down the seedbank over time and reduce the risk of herbicide resistance developing.

Thus, the in-field understanding of the CPWC has been that in-crop weed management needs to commence by the start of the CPWC and should be maintained until the end of the CPWC, as weeds present during the CPWC cause economic damage exceeding the YLT.

This understanding, however, does not take into account the impact of multiple weed emergence and weed removal events. Taking the relationships of Figure 1 as an example, weeds that emerge at 936 GDD are emerging within the CPWC, and so will need to be controlled to prevent a yield loss that exceeds the YLT. However, these weeds will not compete sufficiently with the crop that they need to be controlled by 937 GDD (the end of the CPWC), as the weeds will still be at cotyledon stage at this time. By definition, the competitive effect of these weeds will not be sufficient to require their control until just before harvest, as conversely, weeds that emerge at 938 GDD don't compete sufficiently to require removal during crop life.

Charles and Taylor (2021) explored the relationship between successive weed germination events and the CPWC using the mimic weed, sunflower, in irrigated cotton. They were able to describe weed succession in their CPWC models by including additional terms in the CTWR equations. These new equations were able to define the CPWC for weeds emerging or being controlled at any time during crop life. An example CPWC relationship

**Figure 2.** The CPWC for 2 large weed plants (sunflower) per $m^2$ in cotton. Example CTWR curves are shown for weeds emerging 0, 200, 400 and 600 GDD after crop planting. The relationship can generate curves for weeds emerging at any time in the season. From Charles and Taylor (2021).



with later weed emergence events taken from Charles and Taylor (2021) is shown in Figure 2.

In this example (Figure 2), the CTWR curve for weeds that emerge at 200 GDD exceeds the YLT at 249 GDD, that is, these weeds do not need to be controlled until 249 GDD, even though the CPWC is 0 – 861 GDD. Weeds that emerge at 600 GDD, do not compete sufficiently to cause yield loss exceeding the YLT until 1118 GDD, some 257 GDD after the end of the CPWC. Hence, these curves for later emerging weeds are not defining the CPWC, they are defining the critical time of weed control.

**Delivering a CPWC relationship for cotton growers** Our aim is to deliver to Australian cotton growers a CPWC relationship that includes models allowing for multiple weed emergence and in-season control events (Charles and Taylor 2021), into a multispecies threshold model (Charles *et al.* 2021), with the addition of growth models for the major weeds found in cotton production. Incorporating these approaches will deliver a weed threshold model that is multispecies, allows for successive weed emergence and control events, and is predictive. A combined model will be of immense value to cotton growers in allowing them to optimise their weed control inputs.

We propose that such a model could be delivered to cotton growers using a spread-sheet interface that would allow them to determine their YLT according to their expected crop yield and value, and the cost of their anticipated weed control input. The model would be limited by the number of weed growth models available but could provide valuable guidance around weed thresholds delivered to the paddock. Differences in the growth rate of crops and weeds over the now geographically widely spread cotton industry in Australia are allowed for in the models by the use of growing degree days as the measure of time, making these models equally valuable throughout the industry.

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REFERENCES

Charles, G. and Taylor, I. (2007b). Understanding the "critical period for weed control" concept. *The Australian Cottongrower* 28, 48-50.

Charles, G. and Taylor, I. (2007c). Applying the "critical period for weed control" in the field. *The Australian Cottongrower* 28, 51-53.

Charles, G.W. and Taylor, I.N. (2007a). Developing a threshold model for controlling weeds in glyphosate resistant cotton. Proceedings of the 4th World Cotton Research Conference, ed M. Stephens, pp 22. (International Cotton Advisory Committee, Lubbock, Texas, USA).

Charles, G.W. and Taylor, I.N. (2021). Extending the critical period for weed control model to better include weed succession using common sunflower as a mimic weed in high-yielding cotton. *Weed Technology*, 35, 1029-1037.

Charles, G.W., Sindel, B.M., Cowie, A.L. and Knox, O.G.G. (2021). Developing a multispecies weed competition model for high-yielding cotton. *Weed Technology* 35, 202-698.

Deen, W., Cousens, R., Warringa, J., Bastiaans, L., Carberry, P., Rebel, K., Riha, S., Murphy, C., Benjamin, L.R., Cloughley, C., Cussans, J., Forcella, F., Hunt, T., Jamieson, P., Lindquist, J. and Wang, E. (2003). An evaluation of four crop : weed competition models using a common data set. *Weed Research* 43, 116-129.

Jones, P. and Shaw, W.S. (ed) (2014). A life in cotton: the birth of the modern cotton industry. A documentary. Paper Moose Film. https://vimeo.com/102796184. Accessed: May 27, 2020.

Knezevic, S.Z., Evans, S.P., Blankenship, E.E., Van Acker, R.C. and Lindquist, J.L. (2002). Critical period for weed control: the concept and data analysis. *Weed Science* 50, 773-786.

Marshall, A. (2015). Cotton's man of fibre dead at 96. Farmonline National. https://www.farmonline.com.au/story/3380377/cottons-man-of-fibre-dead-at-96/. Accessed: May 27, 2020.

Nieto, J.H., Brondo, M.A. and Gonzales, J.T. (1968). Critical periods of the crop growth cycle for competition from weeds. *Pest Articles and News Summaries* (C) 14, 159-166.

Taylor, I., Charles, G. and Inchbold. B. (2003). Reducing residual pre-emergent or pre-plant herbicide use in cotton through the development of weed thresholds. Proceedings of the 3rd World Cotton Research Conference, ed A. Swanepoel, p. 835-845. (Agricultural Research Council – Institute for Industrial Crops, Pretoria, Cape Town, South Africa).

Werth, J., Boucher, L., Thornby, D., Walker, S. and Charles. G. (2013). Changes in weed species since the introduction of glyphosate-resistant cotton. *Crop and Pasture Science* 64:791-798.