Bed preparation techniques and herbicide tolerance technology for tropical dry season cotton production

Article in Tropical Agriculture · July 2005

Note

Bed preparation techniques and herbicide tolerance technology for tropical dry season cotton production

Brian L. Duggan[1], Stephen J. Yeates and Greg A. Constable

CSIRO Plant Industry, Australian Cotton CRC, Locked Bag 59, Narrabri, NSW 2390, Australia

Timely sowing and effective weed control are essential for dry season cotton production in tropical Australia. This study was conducted during the 2003 dry season to assess whether a weed and bed management system can be developed which would allow sowing to occur as soon as fields were trafficable after the wet season. The use of Roundup Ready® technology was also assessed as a potential management system for weeds after the crop has emerged. Minimum tillage cotton sown into a wet season cover crop and into a retained dry season sorghum stubble, were compared with conventionally cultivated cotton sown into tilled fallow in the Ord River Irrigation Area (ORIA) in northern Western Australia. Treatments included with and without the residual pre-emergent herbicide pendimethalin and glyphosate application was split across all treatments. Weed and cotton biomass were compared and lint yield and quality determined at the end of the season. Both pendimethalin and glyphosate effectively controlled those weeds present in the year this study was conducted, and the combination of both herbicides was not required. Cotton seedlings in the minimum tillage treatments tended to be more vigourous than those from the conventionally tilled treatments 32 days after sowing (DAS). The weeds in the fallow treatment suppressed the growth of the cotton seedlings compared to the fallow + pendimethalin treatment when glyphosate was not applied. However, 61 DAS, the effect was more obvious and the biomass of cotton was almost double that of weeds. Application of glyphosate increased lint yield through better weed control (1864 *c.f.* 1728 kg ha^{-1}, $P = 0.020$), although interaction with various treatments was highly significant ($P = 0.008$). Only the fallow treatment demonstrated a significant weed control and yield increase from the application of glyphosate. The application of glyphosate also increased fibre length, although this appears to be related to a reduction in weed competition rather than an intrinsic association. This experiment indicates that a minimal tillage system utilizing Roundup Ready® technology as part of a dry season cotton production system in the tropics shows potential, as effective weed control could be achieved without the use of residual pre-emergent herbicides.

Keywords: Cotton; Glyphosate; Roundup Ready; Weed competition; Lint yield; Lint quality; Dry season; Minimum tillage

Dry season cotton is currently being grown as an experimental crop in the Ord River Irrigation Area (ORIA) as it is a candidate crop for the proposed Ord Stage II area (Yeates, 2001). Roundup Ready® technology in cotton may be useful as a post-emergent (i.e., up to the 4th leaf stage) herbicide (Anon., 2001) and it is believed that it will augment the existing weed management strategies currently utilized in Australian cotton farming system (Roberts, 1998). If the technology achieves effective weed control post sowing, then it may allow growers in northern Australia to sow a dry season (April–November) crop earlier, resulting in earlier harvest and reduce the risk of the lint quality being affected by early wet season rains (S. Yeates, unpubl. data).

The optimal tillage system has not been determined for dry season cotton in the ORIA. A preferred system would involve the use of a wet season cover crop or retaining previous dry season

[1]Corresponding address: Central Oregon Agricultural Research Center, Oregon State University, Oregon 97741, U.S.A.

0041-3216/2005/030233-08

stubble combined with a minimum tillage system which allows fertilizer to be applied and cotton to be sown as soon as the field is trafficable. A cover crop would protect beds and maintain their shape by preventing bare soil being exposed to intense rainstorms during the wet season. The use of transgenic cultivars resistant to glyphosate (Roundup Ready®) may assist weed management in this system as it could allow weed control to be undertaken after the crop has emerged, reducing the need for some pre-emergent herbicides. Such a method may also reduce erosion of soil and leaching of nutrients during the wet season. An alternative system, based on the system used in the production of vegetables and melons in the ORIA, involves chemically fallowing beds over the wet season, cultivating and re-shaping beds at the beginning of the dry season, banding fertilizer prior to sowing, applying a pre-emergent residual herbicide such as pendimethalin, then irrigating the field. This entire process exposes beds for long periods, can be time consuming, and at a larger scale, can delay sowing by several weeks. Hand hoeing and (or) inter-row cultivation are also usually required to remove pendimethalin tolerant and later emerging weeds.

When assessing weed control options, the ability of the crop species to compete with weeds requires thorough investigation. While the interaction between the cotton crop and weed growth has been summarized (Askew and Wilcut, 2002), most focussed only on the loss of lint yield without mentioning the effect on cotton biomass. Castner *et al.* (1989) described the height effects of competition between cotton and hogpotato (*Hoffmanseggia glauca*) as well as the effect on lint yield. Hogpotato is a semi-prostrate weed and there was no effect of the weed on lint yield if it germinated seven weeks after the cotton provided plots were kept weed-free. The cotton crop was then able to out-compete any later germinating weeds. Singh *et al.* (2003) discussed the competitive ability of cotton with two of the weeds encountered in this experiment (i.e., *Trianthema portulacastrum* and *Echinochloa crus-galli*), although their experiment focussed on root competition and soil moisture use. Nalayini *et al.* (2002) also studied the effect of competition between *T. portulacastrum* and an interspecific cotton hybrid grown in the tropics during the dry season, but again focussed only on lint yield loss relative to a weed-free control.

The objectives of the experiment are to compare the effectiveness of several cultivation and weed management options and the resulting effects on yield for dry season cotton in the ORIA. The competition between weeds and cotton were compared at three times throughout the season. Several systems were tested, varying in how the plots were managed over the wet season, how beds were prepared, and weed control strategies early in the season, as options for dry season cotton production in the ORIA.

Materials and Methods

The experiment was conducted at the Frank Wise Institute of Tropical Agriculture, Kununurra, WA, Australia (15°39′ S, 128°43′ E) in the 2003 dry (winter) season. The soil is predominantly a uniform dark brown medium to heavy clay with swelling and shrinking characteristics (Gunn, 1969), known locally as a Cununurra clay (Ug 5.34; Northcote, 1979). There were three replicates with five bed management treatments:

1. retained sorghum stubble + pendimethalin post sowing, pre-emergent (PSPE),
2. dwarf pearl millet (DPM) cover crop + pendimethalin PSPE,
3. fallow + pendimethalin PSPE,
4. fallow, and
5. bare—where beds were cultivated and fertilized but cotton not sown.

Each plot was then split by the application of post-emergent glyphosate [550 g active ingredient (ai) ha^{-1} in 100 L water ha^{-1}]. Plots measured 50 m long by three beds wide. Each bed was 1.0 m wide with 0.8-m furrows and there were two rows of cotton per bed spaced 0.85 m apart.

During the previous dry season, a hybrid sorghum seed crop was grown which was harvested and the stubble cut for hay approximately 3 cm above the ground. Prior to the onset of the wet season in December, all beds except those where the sorghum stubble was retained, were cultivated and reshaped. Into selected beds DPM (*Pennisetum glaucum* cv. NPM-3) was sown at 15 kg ha^{-1} on 19 November 2002 in four rows spaced 35–18–35 cm apart. Due to insufficient rain these plots were irrigated on 27 November. The crop was then killed with glyphosate (900 g ai ha^{-1} in 40 L of water ha^{-1} — aerial application) on 3 January 2003. Residue from this crop was laid flat either by storms or subsequent mechanical operations. In mid-March, furrows of all plots were re-made with soil placed back on top of the beds. Plots other than those where the sorghum stubble was retained and the DPM cover crop was grown were cultivated and the tops of the beds of all plots were levelled. Fertilizer (200 kg ha^{-1} of

N and 50 kg ha^{-1} of P as DAP and urea) was then banded in two rows 15 cm deep and 0.9 m apart. The plots containing the fallow and bare treatments were then cultivated to a depth of 5 cm.

The transgenic cotton cultivar Sicot 289BR, which contains Bt genes *cry1A(c)*, *cry2A(b)* (Wilson *et al.*, 1992) and the glyphosate resistance gene *CP4-EPSPS* (Nida *et al.*, 1996), was sown on 22 March 2003. Pendimethalin (1.5 kg ai ha^{-1}) was applied in 200 L water ha^{-1} immediately post-sowing to treatments 1, 2, and 3. Plots were then furrow-irrigated so that soil surrounding the planting furrow was saturated. Seedling counts taken 7 days after sowing (DAS) determined that an average of 10 plants m^{-2} had established in all plots. Weed counts were taken from inside quadats (0.9 m^2) placed across the beds 13 DAS, followed by the application of glyphosate which was applied as part of the treatment onto plots requiring it. Quadrat cuts (0.9 m^2) were taken 32 and 61 DAS from all plots and partitioned into weed and cotton biomass. Due to the dramatic effect of the herbicides on reducing weed biomass development, the data for both harvests were transformed. Immediately following the first biomass harvest, an inter-row cultivation was undertaken on plots that had not had glyphosate applied. At maturity, a 15-m row was picked using a single row picker and turnout determined using a 10 saw gin. Fibre length, strength, and micronaire were determined using a high volume instrument (HVI).

All data were analyzed for a split-plot design with GENSTAT (Payne, 1996).

Results

Giant pigweed/horse purslane (*T. portulacastrum* L.), a common weed throughout the ORIA, made up 90% of the weed biomass at both sampling dates. It has a semi-prostrate growth habit and has the ability to smother crops during early growth. Wild gooseberry/pygmy groundcherry (*Physalis minima* L.) and barnyard grass [*E. crus-galli* (L.) Beauv.], the other two species present, made up less than 9 and 1% of the weed biomass, respectively, at both sampling dates. The application of pendimethalin successfully controlled all these weeds early in the season (Table 1) with no difference between treatments where it was applied. However, large numbers of weeds did emerge in the treatments where pendimethalin was not applied. Soil disturbance from the 'sowing action' in the fallow treatment also tended to encourage germination of weeds compared to the bare area.

Measurements taken 32 DAS indicate that for the fallow and fallow + pendimethalin treatments where no glyphosate was applied, there was a small difference in cotton biomass despite there being considerably more weed biomass in the fallow treatment (Table 2). There was weed suppression associated with cotton, as there was less weed biomass present in the fallow compared to the bare treatment. However, both treatments had considerably more weed biomass than the other three treatments where glyphosate was not applied as well as all those where it was. Treatments where cotton was sown under minimum tillage conditions (i.e., DPM cover crop + pendimethalin and sorghum stubble + pendimethalin, both with and without glyphosate), tended to produce more cotton biomass compared to the conventionally tilled (i.e., fallow) treatments.

The effect of weed competition on cotton growth was more evident 61 DAS. Treatments where glyphosate had not been applied had cotton biomass for the fallow treatment almost half that

Table 1 Weed density 13 days after sowing and prior to the application of glyphosate

Treatment	Weeds m^{-2}
Sorghum stubble + pendimethalin	3.7
DPM cover crop + pendimethalin	11.9
Fallow + pendimethalin	4.6
Fallow	68.1
Bare	46.7
$LSD_{0.05}$	34.7

DPM, Dwarf pearl millet
LSD, Least Significant Difference

of the fallow + pendimethalin treatment (Table 3). However, where glyphosate had been applied, there was no difference between these treatments for cotton biomass. Early in the season, where weeds had been suppressed in the fallow treatments, there was no difference in cotton biomass compared with the minimum tillage treatments.

Lint yield differed significantly between treatments (P = 0.017) (Table 4). The application of glyphosate increased lint yield (P = 0.020), although the interaction between treatment and application of glyphosate was highly significant (P = 0.008). The fallow treatment was the only one that produced a yield gain in response to glypho-

Table 2 Biomass of cotton, weeds, and transformed weed biomass, for treatments with and without glyphosate applied, 32 days after sowing and 19 days after glyphosate was applied

	Cotton (t ha^{-1})		Weeds (t ha^{-1}) (t ha^{-1}+1)^{½}			
Treatment	Glyphosate	No glyphosate	Glyphosate		No glyphosate	
Sorghum stubble + pendimethalin	0.89	0.79	0.00	1.00	0.00	1.00
DPM cover crop + pendimethalin	0.89	0.92	0.00	1.00	0.03	1.01
Fallow + pendimethalin	0.70	0.81	0.00	1.00	0.08	1.04
Fallow	0.62	0.57	0.00	1.00	1.10	1.45
Bare	—	—	0.00	1.00	1.50	1.58
$LSD_{0.05}$ Treatment effect	0.23		0.06			
$LSD_{0.05}$ Glyphosate effect	0.13		0.04			
$LSD_{0.05}$ Interaction	0.26		0.08			

DPM, Dwarf pearl millet
LSD, Least Significant Difference

Table 3 Biomass of cotton, weeds, and transformed weed biomass, for treatments with and without glyphosate applied, 61 days after sowing and 48 days after glyphosate was applied

	Cotton (t ha^{-1})		Weeds (t ha^{-1}) (t ha^{-1}+1)^{½}			
Treatment	Glyphosate	No glyphosate	Glyphosate		No glyphosate	
Sorghum stubble + pendimethalin	2.43	2.26	0.01	1.01	0.02	1.01
DPM cover crop + pendimethalin	2.59	2.42	0.00	1.00	0.13	1.06
Fallow + pendimethalin	2.68	2.36	0.00	1.00	0.02	1.01
Fallow	2.43	1.27	0.02	1.01	1.52	1.59
Bare	—	—	0.22	1.10	1.99	1.72
$LSD_{0.05}$ Treatment effect	0.20		0.06			
$LSD_{0.05}$ Glyphosate effect	0.09		0.09			
$LSD_{0.05}$ Interaction	0.23		0.14			

DPM, Dwarf pearl millet
LSD, Least Significant Difference

Table 4 Lint yield (kg ha^{-1}) for the four treatments in combination with and without glyphosate

	Lint yield (kg ha^{-1})		
Treatment	Glyphosate applied	Glyphosate not applied	Average
Sorghum stubble + pendimethalin	2064	1972	2018
DPM cover crop + pendimethalin	1891	1972	1931
Fallow + pendimethalin	1744	1738	1741
Fallow	1760	1230	1495
Average	1864	1728	
$LSD_{0.05}$ Stubble retention	287		
$LSD_{0.05}$ Glyphosate	109		
$LSD_{0.05}$ Interaction	301		

DPM, Dwarf pearl millet
LSD, Least Significant Difference

sate application and this was due to the absence of weed competition.

Fibre length was affected by the application of glyphosate and their interaction (Table 5), with the lint from the fallow treatment where no glysphosate was applied was significantly shorter than all other treatments. Fibre strength and micronaire were unaffected by either treatment or the application of glyphosate, although the micronaire value for the fallow treatment where no glyphosate was applied tended to be greater than all other combinations.

Discussion

With the exception of the fallow treatment where the absence of weed control resulted in a reduction in lint yield, there was no difference between treatments. Similar results have been found by authors working in temperate cotton growing areas (McGriff and Hudgins, 2000; McCloskey and Moser, 2002). Higher temperatures experienced soon after sowing result in a narrower application window for glyphosate than what might be expected in temperate cotton growing regions (i.e., 14 days at 37–23°C compared to 23 days at 27–17°C). This is one possible drawback to this system as the application of glyphosate after the four-leaf stage has been shown to reduce pollen viability (Pline *et al.*, 2003) and yield. Future developments of Roundup Ready® technology will allow the application of glyphosate later in the crop's development without the risk of crop damage (May *et al.*, 2004).

The application of glyphosate was highly effective in controlling all weeds that emerged in this trial. Yields from treatments where it was applied were comparable to those where it was not, but weed control was still considered good. Despite a short application window, Roundup Ready® was still an effective weed management strategy for the weed spectrum encountered in this trial. A system where Roundup Ready® technology is used in tropical, dry season cotton production may be particularly beneficial where sowing the crop as soon as possible after the wet season is desirable. Weed control can be carried out at a later date and the use of residual herbicides can be avoided.

Pendimethalin has long been known to be effective in controlling early season weeds in cotton (Wilcut *et al.*, 1988) and it was also effective in controlling the weeds that were encountered in this trial. When using this herbicide, weed control was best when the field was fallowed over the wet season or when sorghum stubble was retained. The tendency for a greater number of weeds present in the DPM cover crop treatment may have been due to higher levels of surface residue preventing complete soil coverage by the herbicide. Regardless, the herbicide resulted in fewer early season weeds emerging compared with untreated plots.

Cotton growth early in the season tended to be greater for the minimum tillage treatments. Blaise and Ravindran (2003) found an increase in early vigour for minimum tillage cotton in two out of five years but the authors did not suggest a reason.

Table 5 Fibre quality traits for the four treatments in combination with and without glyphosate

	Fibre quality traits					
	Length (inches)		Strength (g tex $^{-1}$)		Micronaire	
Treatment	Glyphosate applied	Glyphosate not applied	Glyphosate applied	Glyphosate not applied	Glyphosate applied	Glyphosate not applied
Sorghum stubble + pendimethalin	1.13	1.14	30.30	30.2	3.70	3.57
DPM cover crop + pendimethalin	1.15	1.14	29.73	29.8	3.93	3.63
Fallow + pendimethalin	1.14	1.13	30.47	30.1	3.50	3.80
Fallow	1.15	1.11	29.67	30.2	3.53	4.10
$LSD_{(0.05)}$ Treatment	ns		ns		ns	
$LSD_{(0.05)}$ Glyphosate	0.01		ns		ns	
$LSD_{(0.05)}$ Interaction	0.01		ns		ns	

DPM, Dwarf pearl millet
LSD, Least Significant Difference
ns, Not Significant

In this experiment, the effect could partly be attributed to weed competition as the effect was more evident when weeds were not controlled by pendimethalin. There may also have been better contact between the soil and the seeds during imbibing which may have lead to a more even and rapid germination in the minimum tillage treatments. Further research in this area is required.

Inter-species competition did slightly affect cotton growth 32 DAS when weed control was not undertaken. The situation is more apparent with some weeds in temperate cotton growing areas (Flint *et al.*, 1983) and it may be that the temperatures during this period (average max.–min. 37–23°C) were closer to optimum for cotton growth (Bradow, 1991) and this allowed the crop to compete more effectively with weeds. There was also a small difference in weed biomass between the fallow and bare treatments where glyphosate was not applied, indicating that the cotton was affecting the growth of the weeds. As the season progressed, the cotton biomass of the fallow treatment continued to fall further behind that of the fallow + pendimethalin treatment in those plots where glyphosate was not applied. In the fallow and fallow + pendimethalin treatments where glyphosate was applied, cotton biomass was comparable throughout the season.

The effect of competition from non-cotton crops on weed growth has been studied previously using plots where the crop was not grown. Wilson *et al.* (1995) demonstrated a reduction in the biomass of two weed species when wheat was sown and how weed biomass fell even further as the crop density increased. It was demonstrated that weed biomass was not only consistently greater in the absence of the crop that was grown, but that as the competition for resources increased, either from a greater density of other weeds or from a greater crop sowing density, the weed biomass decreased (Wilson *et al.*, 2005). Hawton and Drennan (1980) demonstrated a negative, linear relationship between biomass production of a grass seed crop and a grass weed. A similar relationship exists here between cotton and the weeds (data not shown). Early in the season the slope was steep (–1.4), indicating that the weeds, in particular the *T. portulacastrum*, were vigorous and competing strongly with the cotton. However, as the season progressed, the slope approached –1 as the cotton grew above the more prostrate weeds and became more competitive. Studies in Oklahoma, U.S.A., have shown that provided the cotton crop had established in a weed-free environment the presence of later emerging prostrate weeds, such as *H. densiflora,* had no effect on lint yield (Castner *et al.*, 1989). Cussans and Wilson (1975) had previously emphasised the importance of the pattern of growth on the competitive ability of a weed on a crop when they compared the effect of common couch (*Agropyron repens*) and wild oats (*Avena fatua*) on spring barley (*Hordeum vulgare*). A similar situation appears to have occurred in this experiment with the cotton successfully competing with weeds provided that weed control early in the season was effective.

Roundup Ready® technology demonstrated its potential as a weed management option for dry season cotton production with good control of weeds without any adverse effect on lint yield. However, while the application of glyphosate was beneficial in situations where weed control was poor (i.e., fallow with no pendimethalin), there was no benefit when weed control was good, such as the other three treatments. The current use of pendimethalin to control weeds is adequate provided that tolerant weeds such as native rosella [*Abelmoschus ficulneus* (L.) Wight and Arn] and native hibiscus (*Hibiscus panduriformis* Burm. F.) are not a problem, as was the situation in this experiment. Certainly the combined use of both pendimethalin and glyphosate was not required, a result supported by Culpepper (2000). A system of minimum tillage cotton sown into wet season cover crop mulch or retained dry season stubble also appears possible. Unlike the cotton industry in temperate Australia, *Helicoverpa* pupae in the tropics do not undergo diapause and therefore cultivation to destroy pupating *Helicoverpa* is not a relevant resistance management strategy, thus allowing the possibility of a minimum tillage cotton production system in the tropics. A system which facilitates sowing cotton in mid to late March in the ORIA will be beneficial as it will allow harvest to occur in September and avoid early wet-season storms in October and November. Further testing of this system is required to refine the management system in situations of pendimethalin tolerant weeds, the management and choice of wet season cover crops, and the use of cotton cultivars with advanced Roundup Ready® technology.

The decrease in fibre length associated with no application of glyphosate was associated with an increase in competition with weeds. The fallow treatment where glyphosate was not applied produced the shortest fibre lengths, and as with lint yield, it was the combination that resulted in the interaction being significant. Similar results have been reported in some weed competition studies (Rushing *et al.*, 1985; Castner *et al.*, 1989).

Conclusion

A dry season cotton production system utilizing minimum tillage into a wet season cover crop or retained stubble appears viable for the ORIA in Northern Australia. The use of Roundup Ready® technology would allow early sowing of cotton with weed control undertaken after the crop has emerged. Weeds in plots not treated with herbicides did not compete successfully with the crop until beyond 32 DAS, by which time they resulted in a reduction in crop biomass and subsequently lower lint yield.

Acknowledgements

The authors wish to thank Nerylie Gaff and Tony Barone for their technical assistance in conducting this experiment and the Frank Wise Institute farm staff. This experiment was part funded by the Cotton Research and Development Corporation (Project CSP 138C).

References

Anon. (2001) *Roundup Ready® Cotton Technical Manual—Version 2*, April 2001, Monsanto Australia Limited

Askew, S.D. and Wilcut, J.W. (2002) Ladysthumb interference and seed production in cotton, *Weed Sci.* **50** 326–332

Blaise, D. and Ravindran, C.D. (2003) Influence of tillage and residue management on growth and yield of cotton grown on a vertisol over 5 years in a semi-arid region of India, *Soil Till. Res.* **70** 163–173

Bradow, J.M. (1991) Cotton cultivar response to sub-optimal postemergent temperatures, *Crop Sci.* **31** 1595–1599

Castner, E.P., Murray, D.S., Hackett, N.M., Verhalen, L.M., Weeks, D.L. and Stone, J.F. (1989) Interference of Hogpotato (*Hoffmanseggia glauca*) with cotton (*Gossypiumhirsutum*), *Weed Sci.* **37** 688–694

Culpepper, A.S. (2000) Are preemergence herbicides needed in Roundup Ready (glyphosate-tolerant) cotton, in: *Proceedings of the Beltwide Cotton Conference, 2000* (eds Dugger, P. and Richter, D.), National Cotton Council of America, Memphis, TN, U.S.A., Vol. **2**, p. 1472

Cussans, G.W. and Wilson, B.J. (1975) Some effects of crop row width and seed rate on competition between spring barley and wild oat *Avena fatua* L. or common couch *Agropyron repens* (L) Beauv., in: *Status and Control of Grassweeds in Europe, 1975*, Proceedings of the European Weed Research Society Symposium, France, pp. 75–86

Flint, E.P., Patterson, D.T. and Bejers, J.L. (1983) Interference and temperature effects on growth of cotton (*Gossypium hirsutum*), spurred Anoda (*Anoda cristata*) and velvetleaf (*Abutilon theophrasti*), *Weed Sci.* **31** 892–898

Gunn, R.H. (1969) Soils of the Kimberley Research Station, Kununurra, Western Australia, CSIRO, Australia, Division of Land Research, *Technical Memos*, No. **69**, 21 pp.

Hawton, D. and Drennan, D.S.H. (1980) Studies on competition between *Steraria anceps* and *Eleusine indica*, *Weeds Res.* **20** 211–215

May, O.L., Culpepper, A.S., Cerny, R.E., Coots, C.B., Corkern, C.B., Cothren, J.T., Croon, K.A., Ferreira, K.L., Hart, J.L., Hayes, R.M., Huber, S.A., Martens, A.B., McCloskey, W.B., Oppenhuizen, M.E., Patterson, M.G., Reynolds, D.B., Shappley, Z.W., Subramani, J., Witten, T.K., York, A.C. and Mullinix, B.G. Jr (2004) Transgenic cotton with improved resistance to glyphosate herbicide, *Crop Sci.* **44** 234–240

McCloskey, W.B. and Moser, H.S. (2002) Tolerance of Roundup Ready cotton to topical and post-directed glyphosate, in: *Proceedings of the Beltwide Cotton Conference, 2002* (eds Dugger, P. and Richter, J.E.), National Cotton Council of America, Memphis, TN, U.S.A.

McGriff, D.E. and Hudgins, J.E. (2000) Comparison of Roundup Ready (glyphosate-tolerant) varieties treated with either Roundup (glyphosate) or conventional herbicides, in: *Proceedings of the Beltwide Cotton Conference, 2000* (eds Dugger, P. and Richter, D.), National Cotton Council of America, Memphis, TN, U.S.A., Vol. **2**, pp. 1477–1478

Nalayini, P., Kandasamy, O.S. and Kailasam, C. (2002) Watkinson's weed model for the weeds grown under interspecific cotton hybrid 'TCHB-213', *Res. Crops* **3** 335–337

Nida, D.L., Kolacz, K.H., Buehler, R.E., Deaton, W.R., Schueler, W.R., Armstrong, T.A., Ebert, C.C., Rogan, G.J. and Padgette, S.R. (1996) Glyphosate-tolerant cotton: genetic characterization and protein expression, *J. Agric. Food Chem.* **44** 1960–1966

Northcote, K.H. (1979) *A Factual Key for the Recognition of Australian Soils,* 4th edn, Glenside, South Australia, Rellim, 124 pp.

Payne, R.W. (1996) *Genstat for Windows Reference Manual*, 2nd edn, The Numerical Algorithms Group Limited, Oxford, U.K., 337 pp.

Pline, W.A., Wells, R., Little, G., Edmisten, K.L. and Wilcut, J.W. (2003) Glyphosate and water-stress effects on fruiting and carbohydrates in glyphosate resistant cotton, *Crop Sci.* **43** 879–885

Roberts, G. (1998) Management of weeds in a cotton system, in: *Proceedings of the 9th Australian Cotton Conference*, 12–14 Aug., Broadbeach, Queensland, Australia, pp. 145–152

Rushing, D.W., Murray, D.S. and Verhalen, L.M. (1985) Weed interference with cotton (*Gossypium hirsutum*). I. Buffalobur (*Solanum rostratum*), *Weed Sci.* **33** 810–814

Singh. S., Yadav A., Malik, R.K. and Singh, M. (2003) Rhizotron study on soil moisture and plant population effect on root competition of cotton and mungbean with *Trianthema portulacastrum* and *Echinochloa crus-galli*, in: *The BCPC International Congress: Crop Science and Technology, Vols 1 and 2*, Proceedings of an International Congress held at the SECC, Glasgow, Scotland, U.K., 10–12 Nov. 2003, pp. 1059–1064

Wilcut, J.W., Patterson, M.G., Wehtje, G.R. and Whitwell, T. (1988) Efficacy and economics of pendimethalin herbicide combinations for weed control in cotton (*Gossypium hirsutum* L.), *Appl. Agric. Res.* 3 203–208

Wilson, B.J., Wright, K.J., Brain, P., Clements, M. and Stephens, E. (1995) Predicting the competitive effects of weed and crop density on weed biomass, weed seed production and crop yield in wheat, *Weed Res.* 35 265–278

Wilson, F.D., Flint, H.M., Deaton, W.R., Fischoff, D.A., Perlak, F.J., Armstrong, T.A., Fuchs, R.L., Berberich, S.A., Parks, N.J. and Stapp, B.R. (1992) Resistance of cotton lines containing a *Bacillus thuringiensis* toxin to pink bollworm (Lepidoptera: Gelechiidae) and other insects, *J. Econ. Entomol.* **85** 1516–1521

Yeates, S.J. (2001) *Cotton Research and Development Issues in Northern Australia: a Review and Scoping Study*, Australian Cotton Cooperative Research Centre, Australia, 68 pp.