Capturing opportunities and overcoming obstacles for Australian agronomy related to weed management

Steven Walker

Queensland Alliance for Agriculture and Food Innovation, University of Queensland,
PO Box 2282, Toowoomba Qld 4350 www.qaafi.uq.edu.au/ Email s.walker11@uq.edu.au

Abstract

Weeds remain a major constraint to productivity of Australian agriculture, particularly with the increasing number of herbicide-resistant species and populations. Currently, 39 weed species are resistant to many of the key herbicides used in cropping, including five species resistant to glyphosate. This paper summarises the current weed situation in Australian grain production, with the emphasis on the sub-tropical region. Then, new chemical and non-chemical tactics as well as the weed management approach with the emphasis on the weed seed-bank are identified and evaluated, to address the current and future weed issues. Finally, a brief case study on the management of the problem weed, flaxleaf fleabane, is presented to highlight how a range of tactics focussing on the different parts of the weed's life cycle is required for successful management.

Key Words

Integrated weed management, herbicide resistance, glyphosate resistance, weed seed-bank

Introduction

Weeds have been estimated to cost Australian farmers around $1.5 billion a year in weed control activities and a further $2.5 billion a year in lost agricultural production (Australian Government 2012). If weeds are costing Australian agriculture more than $4 billion annually, then we need to ask the question whether our farming systems are in control of weeds, or are our weeds determining how we farm and cropping viability? What are our options to improve this situation?

Successful weed management relies initially on the implementation of the best available agronomic practices to optimise crop production (McGillion and Storrie 2006). This involves selection of crop and rotation, and then maximising crop competition. These best farming practices need to be overlaid with best weed management practices, known as integrated weed management (IWM), which is a planned strategy consisting of a variety of chemical and non-chemical tactics that has the objectives of both reducing weed numbers and the size of weed seed-bank in the soil.

IWM addresses the life cycles of the key problem weeds, and thus needs to implement effective tactics for each component of weed life cycle within different components of crop rotation (McGillion and Storrie 2006). Best weed management practices, not only focus on controlling emerged seedlings, but take into account the seeds in the seed-bank, replenishment of the seed-bank and new incursions. A major weakness of current weed management is not taking into account depleting and minimising replenishment of the weed seed-bank in the soil. Emerged weeds are just the symptoms of the underlying cause, which is viable weed seeds within the surface soil and are the primary source of next flushes.

This review briefly describes the current situation with weeds in Australian grain and cotton cropping systems with an emphasis on the sub-tropical region, and outlines the benefits and limitations of potential new management options. One of the current most difficult-to-control weeds flaxleaf fleabane (*Conyza bonariensis*) is used as a case study.

Current situation of weeds in Australian agriculture

Weed surveys

Surveys have traditionally recorded the weed flora in the different cropping regions (Jones et al 2005; Osten et al 2007; Owen et al 2009; Rew et al 2005; Walker et al 2005; Werth et al 2010), and have highlighted the rich diversity of the weed flora. As examples, Rew et al (2005) recorded 111 species in 46 paddocks in 18 grain and cotton farms in the sub-tropical cropping region, and Walker et al (2005) recorded 54 genera in 32 paddocks in cotton farms in the same region. These data indicate there is a very large ‘pool’ of different weeds that potentially could become major weed problems in different farming systems and environments following changes in cropping systems and agronomic practices.

Herbicide resistance status

As of September 2011, 16 grass and 22 broadleaf weed species were confirmed as resistant to selective and non-selective herbicides in 11 of the 19 herbicide mode-of-action (MOA) groups

(Table 1). Whilst this register may not cover the true extent of resistant populations, the most extensive infestations are annual ryegrass (*Lolium rigidum*), wild oat (*Avena* spp.), common sowthistle (*Sonchus oleraceus*), prickly lettuce (*Lactuca serriola*) and wild radish (*Raphanus raphanistrum*).

Table 1. Herbicide resistant weeds in Australia (2011).
Source: www.croplifeaustralia.org.au

Weed	Scientific name	MOA groups
Grass weeds		
Annual ryegrass #	*Lolium rigidum*	A, B, C, D, Q, M, L
Awnless barnyard grass	*Echinochloa colona*	M
Barnyard grass	*Echinochloa crus-galli*	C
Barley grass	*Hordeum leporinum*	A, L
Brome grass	*Bromus spp.*	A, B
Giant Parameter grass	*Sporoblous fertilis*	J
Crowsfoot grass	*Eleusine indica*	A
Crabgrass	*Digitaria sanguinalis*	A, B
Liverseed grass	*Urochloa panicoides*	C, M
Northern barley grass	*Hordeum glaucum*	A, B, L
Paradoxa grass	*Phalaris paradoxa*	A
Serrated tussock	*Nassella trichotoma*	J
Silver grass	*Vulpia trichotoma*	C, L
Wild oat #	*Avena spp.*	A, B, Z
Windmill grass	*Chloris truncata*	M

Winter grass	*Poa annua*	Z
Broadleaf weeds		
African turnip weed	*Sisymbrium thellungii*	B
Arrowhead	*Sagittaria montevidensis*	B
Bedstraw	*Galium aparine*	B
Black bindweed	*Fallopia convolvulus*	B
Calomba daisy	*Pentzia suffruticosa*	B
Capeweed	*Arctotheca calendula*	L
Charlock	*Sinapis arvensis*	B
Common sowthistle #	*Sonchus oleraceus*	B
Dense-flowered fumitory	*Fumaria densiflora*	D
Dirty dora	*Cyperus difformis*	B
Flaxleaf fleabane	*Conyza bonariensis*	M
Iceplant	*Mesembryanthemum crystallinum*	B
Indian hedge mustard #	*Sisymbrium orientale*	B, I
Lincoln weed	*Diplotaxis tenuifolia*	B
Paterson's curse	*Echium plantagineum*	B
Prickly lettuce #	*Lactuca serriola*	B
Square weed	*Mitracarpus*	L
Starfruit	*Damasonium minus*	B
Stinging nettle	*Urica urens*	C

Turnip weed	*Rapistrum rugosum*	B
Wild radish #	*Raphanus raphanistrum*	B, C, F, I
Wild turnip	*Brassica tournefortii*	B

recorded in >100 sites

As well, annual ryegrass populations are resistant to seven herbicide MOA groups, wild radish populations are resistant to four herbicide MOA groups, and wild oat populations are resistant to three MOA groups. These major weeds are resistant to some of the most important selective herbicides, making them a challenge to control in our farming systems.

A major concern as well is the number of species and extent of glyphosate resistance (Group M). Five species, annual ryegrass, awnless barnyard grass (*Echinochloa colona*), liverseed grass (*Urochloa panicoides*), windmill grass (*Chloris truncata*) and flaxleaf fleabane, have been confirmed resistant to glyphosate (Table 1) plus very recently great brome grass (*Bromus diandris*) (Preston 2012). Annual ryegrass, awnless barnyard grass, and flaxleaf fleabane are major weed problems in fallows in the sub-tropical region, whereas annual ryegrass is a major weed across the temperate cropping regions. In 2012 a survey of 39 fallow paddocks in northern New South Wales and southern Queensland recorded that 51% had glyphosate-resistant barnyard grass plants, indicating that this problem weed has become extensive in recent years.

The glyphosate-resistant populations were recorded not only in cropping situations but in a wide variety of other agricultural and non-agricultural situations where glyphosate is used frequently and extensively. For glyphosate-resistant annual ryegrass, 38% of the confirmed populations were found in cropping, 8% in horticultural situations and the remaining in non-agricultural situations such as fence lines, irrigation channels and roadsides (Preston 2012). Similarly, the majority of glyphosate-resistant flaxleaf fleabane populations have been found along roadsides. In contrast, 95% of the glyphosate-resistant awnless barnyard grass populations were found in fallows of the sub-tropical region. These differences are likely to reflect, not only differences in weed distribution, but also differences in the gene movement. Annual ryegrass is an out-crossing species and flaxleaf fleabane seeds are wind-blown, whereas seed of awnless barnyard grass, which is primarily a selfing species, will be moved mostly by floods and machinery. Thus, the rate and direction of spread of the glyphosate-resistant gene will differ between the species, and it is important to take into account when devising strategies to prevent spread and new incursions.

Difficult-to-control weeds

As well as herbicide-resistant weeds, a number of current and new weeds are not being controlled well with current practices.

An example is feathertop Rhodes grass (*Chloris virgata*), which has infested large cropping areas in central Queensland in recent years, and is currently invading and becoming a major problem in southern Queensland and northern New South Wales (Widderick 2010). This weed is highly adapted to zero-tilled farming systems, is prolific seed producer, and is not susceptible to glyphosate.

A recent survey, involving the author, recorded 49 weed species present and seeding in mature wheat, chickpea and sorghum crops and late in summer fallows across the sub-tropical grain region. The most common weeds found in the winter crops were common sowthistle, flaxleaf fleabane, wild oat, African turnip weed (*Sisymbrium thellungii*) and turnip weed (*Rapistrum rugosum*), whereas the most common in summer situations were common sowthistle, flaxleaf fleabane, barnyard grass, feathertop Rhodes grass and bladder ketmia (*Hibiscus trionum*). Many of these weeds were producing large amounts of seed, and thus replenishing substantial numbers in the soil seed-bank. For example, each surviving sowthistle plant had produced 920 – 13260 seeds in wheat, 2660 – 12435 seeds in sorghum, and 15235 – 24910 seeds in chickpea.

Reasons for these weed problems

Whilst there are more than a hundred herbicides registered for use in Australian cropping systems, a limited number of highly effective post-emergent herbicides are used extensively, particularly several Group A herbicides for selective grass control, several Group B and Group I herbicides for selective broadleaf control, and glyphosate (Group M) for non-selective control. In addition, many growers have moved to less diversified farming systems, use zero or minimum-tilled practices, and grow crops in wider rows, resulting in reduced crop competition. Consequently, weed control has relied basically on the frequent and exclusive use of a few herbicides, resulting in the evolution of many weed populations resistant to these herbicides (Table 1). In addition, the zero-tilled cropping systems have created an environment that favours weed species that germinate on or near the soil surface, such as common sowthistle, flaxleaf fleabane and feathertop Rhodes grass. These weeds also have multiple flushes, are prolific seed producers and have natural tolerance to some of the commonly used herbicides, resulting in them becoming widespread problem weeds.

Latest developments in weed management in Australia

New herbicides

In recent years, only a limited number of new chemistries appropriate for Australian cropping systems have become available to provide alternate control options for problem weeds. Unfortunately, it unlikely that there will be a new ‘glyphosate’ in the immediate future that could provide robust and broad spectrum control of broadleaf and grass weeds in fallow or pre-sowing.

The new chemistries have tended to be more use-specific. For example, two new chemistries for residual control of winter grasses in wheat have become available recently; prosulfocarb a mixture of Group J and Group K herbicides, and pyroxasulfurone a new Group K herbicide (Syngenta 2012; Bayer Cropscience 2012). Similarly, a new non-selective post-emergent herbicide that will be available in the new future is saflufenacil a new Group G herbicide, which provides control of small rosettes of sowthistle and flaxleaf fleabane (Nufarm 2012a).

However, it more likely that advances in chemical control of problem weeds are from finding new uses for herbicides already registered in Australia for other uses. This involves defining effective rates for nominated weed growth stages, identifying mixes and/or sequential treatments, and determining optimal environmental conditions for application. An example is the recent registration of Group A herbicides for grass control in fallows, such as glyphosate-resistant barnyard grass and the glyphosate-tolerant feathertop Rhodes grass.

Another option is improvements in herbicide formulations, which can increase reliability of weed control, although this will not delay evolution of resistant populations or control weeds already resistant to the herbicide. A recent advancement in formulation of glyphosate is ‘Roundup Attack’, which reportedly will deliver faster brownout, more robust and better weed control (Nufarm 2012b).

In recent years, a number of herbicide-tolerant crops have been bred, either by transgenic or traditional plant breeding, and grown in Australia (Gene Technology Task Force 2002). Some examples are triazine-tolerant canola, imidazolinone-tolerant wheat, glyphosate-tolerant cotton and canola, and glufosinate-tolerant cotton. These herbicides can now be used selectively in the cropping phase, and thus potentially offering additional effective control options for problem weeds.

Non-chemical tactics and new application technology

Tillage and crop competition were used traditionally to assist with weed control, although adoption of zero-tillage practices and sowing of wider row crops have decreased their use and impact. However, they are potential important components of IWM.

A strategic tillage operation will bury weed seed from the soil surface to depths, from which problem weeds of zero-tilled systems are less likely to emerge (Widderick et al 2012). In a recent field experiment in southern Queensland, a single operation with harrows, the least soil disturbance, reduced emergence of barnyard grass by 57%, and with an off-set disc, the maximum soil inversion, by 84% for a season compared with the non-disturbed zero-tilled treatment. For this to be an effective tactic, the soil would likely need to be then undisturbed for several years until the buried seeds lose viability (Walker et al 2010), and thus this tactic would a once-only and not a routine practice.

Crop competition can suppress substantially weed emergence, growth and seed production (Lemerle et al 2001). In addition to sowing crops in narrow rows and at high crop densities (Walker et al 2002, Wu et al 2010), there is also potential to breed more competitive varieties (Vandeleur and Gill 2004). In crops such as wheat, these traits relate to enhanced early crop vigour and light interception without affecting harvest index, and should be considered for incorporation into selected germplasm.

Recent advances have been made in development of commercial broad-acre sprayers fitted with weed detection technology that automatically detects and spot sprays weeds and not the weed-free soil sections of the paddock (Crop Optics Australia 2012). This technology is used to control low populations of difficult-to-control weeds and sprayed survivors in fallows and the inter-row region of crops sown in wide rows. An important advantage of weed detection technology is that herbicides can be applied more economically whilst using higher rates and/or more expensive alternate and effective herbicides. This approach has the potential to greatly diminish replenishment of the seed-bank and delay evolution of resistant populations.

A relatively new non-chemical tactic, known as harvest weed seed control, has been devised to destroy seeds retained on weed survivors at crop maturity (Walsh et al 2012). Examples, used primarily in wheat belt of Western Australia, are chaff carts, direct harvest residue baling and narrow windrow burning, as well as the newly devised Harrington Seed Destructor, in which weed seeds are captured and destroyed mechanically during the grain harvest. This approach successfully minimises replenishment of the seed-bank for those weeds, such as annual ryegrass, that retain the majority of seed at time of harvest. This tactic is less successful on those weeds that normally have dropped most of their seed by crop maturity.

New weed management approaches

In recent years, growers have started to change their approach from short-term weed control to minimise the economic impact on the current crop to more long-term weed management to minimise the weed seed-bank, that is a shift from treating the 'symptoms' to managing the 'cause'. The critical goals of IWM are to (i) minimise survival of emerged weeds, (ii) minimise production of viable seed on established weeds, and (iii) reduce over time the residual weed seed-bank in the soil (Powles and Bowman 2000).

For this new approach to be successful, it requires a diverse range of tactics to be applied to the different components of the weed's lifecycle in the different components of the crop rotation. This needs planning ahead to devise the different tactics and their timing. As well, regular monitoring of paddocks is very important to evaluate the applied tactic's success, to determine the need for follow-up actions and to identify early any new incursions of potential problem weeds or patches of herbicide-resistant weeds. Early attention to stopping seed set on sprayed survivors or new incursions is critical to IWM success.

These principles are demonstrated in the following case study of flaxleaf fleabane, which has recently changed from the most difficult-to-control weed in fallows to one that is now starting to be managed more successfully.

Case study: management of flaxleaf fleabane (*Conyza bonariensis)*

In the last decade flaxleaf fleabane had become a major weed problem throughout most of the sub-tropical grain region. The rapid increase in this weed's prevalence was associated with the adoption of conservation cropping systems, due to the seed remaining on soil surface and possibly due to greater soil moisture retention in no-tilled fields favouring increased seed germination. As well, the increase in this weed's abundance was thought to be favoured by the reduced use of selective residual herbicides. Other factors were that flaxleaf fleabane growth was favoured by poor crop competition associated with sowing crops in wider rows and lower population densities, and that weed control was not specifically targeting flaxleaf fleabane. In 2010, eight populations were confirmed glyphosate resistant (Walker et al 2010) and since then more glyphosate-resistant populations have been identified (Preston 2012).

However, a concerted effort of researchers and industry has resulted in the development and adoption of a management strategy that is minimising the adverse impacts of this difficult-to-control weed (Walker 2012). This best management guide focuses on four key components of the weed's lifecycle.

Tactics to deplete the seed-bank are the re-introduction of residual herbicides into appropriate components of the crop rotation and a strategic soil disturbance. Flaxleaf fleabane is very sensitive to a number of residual herbicides, such as Group C trazine (used prior to sorghum), Group C urea (used prior to cotton), Group B sulfonylurea (used prior to wheat), Group H isoxazole (used prior to chickpea), and picloram in Tordon 75D® (used in fallows and wheat). When these residual herbicides were applied under optimum conditions, they provided up to 100% control for up to six months. Similarly, recent research found that the non-chemical tactic of a light harrowing in spring reduced emergence over the following summer by >90% compared to the non-disturbed situation. Both of these tactics ideally are applied prior to the first major flush and would be useful particularly for paddocks known to have high seed-bank numbers of flaxleaf fleabane.

A number of herbicides and mixes are now available to provide effective control of small rosettes in fallow, such as glyphosate + Tordon 75-D® (picloram + 2, 4-D) and in wheat, such as Amicide Advance 700® (2, 4-D). These herbicides regularly gave greater than 90% control, although efficacy was reduced markedly when applied to large rosettes. The most consistently effective treatment of rosettes in fallows is the double-knock tactic (sequential application) particularly with glyphosate + Tordon 75-D®followed seven days later with a paraquat product. However, robust rates are needed and high water volumes for the paraquat products, particularly for dense weed populations. This treatment has provided reliably around 99% control of young rosettes (Walker et al 2012).

Flaxleaf fleabane is particularly sensitive to crop competition. Research showed that doubling the wheat density and sowing in 25cm rows compared to 50cm rows provided 90% reduction in seed production. The combination of an effective post-emergent herbicide applied to small rosettes in a wheat crop sown to maximise competitiveness to suppress seed production on any survivors provides excellent season-long control.

As a single mature flaxleaf fleabane plant can produce an average of 100,000 seeds, it is important to apply follow-up tactics for the survivors of the residual or post-emergent herbicides. As shown above, the double-knock tactic for fallows and crop competition are effective options to minimise replenishment of the soil seed-bank. However, timing is important as once the plant is well-established and flowering, it is very difficult to obtain good control.

Finally, as seeds of flaxleaf fleabane can travel several hundreds of metres, an essential component of the IWM plan is to control weeds in the adjacent non-cropping areas, such as fence-lines and roadsides. The tactic of a double knock mixed with a residual herbicide at a robust rate has been effective in keeping these areas clean for a season.

As the vast majority of flaxleaf fleabane seeds lose viability within two years in the seed-bank (Wu et al 2007), the implementation of a strategic IWM plan in paddocks infested with this weed has resulted in substantial reduction of this problem weed within a short period.

Conclusion

Australian growers are facing many obstacles to cropping viability and sustainability, and many consider that weed control is now one of their most difficult challenges, particularly with the increasing problem of herbicide resistance. Currently 39 species are resistant to many of the important herbicides used in cropping, including 6 species resistant to glyphosate. In addition, other problem weeds are not being adequately controlled, resulting in large numbers of weed seeds regularly being added to the soil seed-bank, and thus creating potentially more problems in the following seasons.

There is no simple solution to these problem weeds. However, a diverse range of chemical and non-chemical tactics are available, or being developed, that will contribute towards improved weed management. The secret to their success is that they need to be incorporated into a planned IWM strategy that focuses on all parts of the weeds' lifecycle, with a particular emphasis on minimising or stopping replenishment of the seed-bank.

As shown with the case study on the problem weed flaxleaf fleabane, implementation of this strategic approach can remove this major obstacle to successful cropping.

Acknowledgement

Much of this research was done by my colleagues, in particular Michael Widderick and Andrew McLean with Department of Agriculture, Forestry and Fisheries Queensland, and Tony Cook and Bill Davidson with New South Wales Department of Primary Industries. Funding was provided by the Grains Research and Development Corporation. The paper was reviewed by David Thornby, Department of Agriculture, Forestry and Fisheries Queensland.

References

Australian Government (2012) Impact of weeds. www.weeds.gov.au Accessed August 2012.

Bayer Cropscience (2012) Bayer Cropscience. www.bayercropscience.com.au Accessed August 2012.

Crop Life Australia (2011) List of herbicide resistant weeds in Australia. www.croplifeaustralia.org.au Accessed August 2012.

Crop Optics Australia (2012) Crop Optics – Australian distributor of Weedseeker and Greenseeker. www.cropoptics.com.auAccessed August 2012.

Gene Technology Task Force (2002) Agricultural Biotechnology: Herbicide Tolerant Crops in Australia. Bureau of Rural Sciences, Canberra. www.affa.gov.au/brs. Accessed August 2012.

Jones R, Alemseged Y , Medd R and Vere D (2005) The distribution, density and economic impact of weeds in Australian annual winter cropping system. CRC for Weed Management Systems Technical Series 4, Adealide, South Australia

Lemerle D, Gill GS, Murphy CE, WalkerSR, Cousens RD, Mokhtari S, Peltzer SJ, Coleman R, Luckett DJ (2001) Genetic improvement and agronomy for enhanced wheat competitiveness and weed management. Australian Journal of Agricultural Research 52, 527-548.

McGillion T and Storrie A (eds) (2006) Integrated weed management in Australian cropping systems – a training resource for farm advisors. CRC for Australian Weed Management, Adelaide, South Australia.

Nufarm (2012a) Sharpen WG herbicide – Products – Nufarm Australia. www.nufarm.com.au Accessed August 2012.

Nufarm (2012b) Roundup Attack herbicide with IQ inside – Products – Australia. www.nufarm.com.au Accessed August 2012.

Osten VA, Walker SR, Storrie A, Widderick M, Moylan P, Robinson GR and Galea K (2007) Survey of weed flora and management relative to cropping practices in the north-eastern grain region of Australia. Journal of Experimental Agriculture 47, 57-70.

Owen MJ, Owen RK and Powles S (2009) A survey in the southern grain belt of Western Australia did not find *Conyza* spp. resistant to glyphosate. Weed Technology 23, 492-424.

Powles S and Bowman D (2000) Crop weed management strategies. In Australian Weed Management Systems. Ed. B Sindel. CRC for Weed Management Systems, Adelaide, South Australia.

Preston C (2012) Australian Glyphosate Sustainability Working Group. www.glyphosateresistance.org.au Accessed July 2012.

Rew LJ, Medd RW, Van de Ven R, Gavin JJ, Robinson GR, Tuite M, Barnes J, and Walker S (2005) Weed species richness, density and relative abundance on farms in the subtropical grain region of Australia. Australian Journal of Experimental Agriculture 45, 711-723.

Syngenta (2012) Boxer Gold herbicide: ryegrass control, performance and flexibility. www.syngenta.com/country/au/en/products Accessed August 2012.

Vandeleur R and Gill G (2004) The impact of plant breeding on the grain yield and competitive ability of wheat in Australia. Australian Journal of Agricultural Research, 55, 855–861.

Walker S (2012) Flaxleaf fleabane – a weed best management guide. Available atwww.qaafi.uq.edu.au/content/Documents/weeds/IWM-Fleabane-guide.pdf Accessed August 2012.

Walker SR, Medd RW, Robinson GR and Cullis BR (2002) Improved management of *Avena ludoviciana* and *Phalaris paradoxa* with more densely sown wheat and less herbicide. Weed Research 42, 257-270.

Walker SR, Taylor IN, Milne G, Osten VA, Hoque Z, Farquharson RJ (2005) A survey of management and economic impact of weeds in dryland cotton cropping systems of sub-tropical Australia. Australian Journal of Experimental Agriculture, 45, 79-91.

Walker SR, Wu H and Bell K (2010) Emergence and seed persistence of *Echinochloa colona*, *Urochloa panicoides* and *Hibiscus trionum* in the sub-tropical environment of north-eastern Australia. Plant Protection Quarterly 25, 127-132.

Walker SR, Bell K, Robinson G and Widderick M (2011) Flaxleaf fleabane (*Conyza bonariensis*) populations have developed glyphosate resistance in north-east Australian cropping fields. *Crop Protection* 30, 311-317

Walker S, Boucher L, Cook T, Davidson B, McLean A, and Widderick M (2012) Weed age affects chemical control of Conyza bonariensis in fallows. *Crop Protection* 38, 15-20.

Walsh M, Harrington R and Powles S (2012) Harrington Seed Destructor: a new nonchemical weed control tool for global grain crops. Crop Science 52, 1343-1347.

Werth J, Thornby D, Walker S, Charles G and McDonald C (2010) Species shift and resistance: Challenges for Australian cotton systems. Proceedings 17th Australasian Weeds Conference, Christchurch NZ, pp20-23.

Widderick M, McLean Aand Walker S (2012) Non-chemical options for managing the seed bank of glyphosate-resistant weeds. Proceedings 18th Australasian Weeds Conference, Melbourne (in press).

Widderick M, Osten V and Walker S (2010) Managing difficult to control weeds in summer crops. Proceedings 1st Australian Summer Grains Conference, Gold Coast. Available at www.grdc.com.au/uploads/documents/2010ASGCEditedPapersPDF.

Wu H, Walker S, Rollin M, Yan D, Robinson G, Werth J (2007) Germination, emergence and persistence of flaxleaf fleabane (*Conyza bonariensis*). *Weed Biology and Management* 7, 192-199.

Wu H, Walker S, Osten V, and Robinson G (2010) Competition of sorghum cultivars and densities with japanese millet (*Echinochloa esculenta*). Weed Biology and Management 10, 185-193.