Integrated weed management for Australian cotton production systems

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Introduction

The majority of cotton growers in the Australian cotton industry are familiar with an integrated approach to insect pest management. Researchers and agronomists often tout integrated pest management or IPM as the most sustainable approach for managing insect pests in cotton. The development of IPM systems reflects societies' expectations that pest management systems will neither degrade the environment nor will they cause health problems. Hence, the primary focus of an IPM strategy should be to reduce the reliance on synthetic pesticides (Wilson 2000). Integrated weed management (IWM) is an extension of the principles of IPM as applied to weed management. The focus of an IWM program is the development of sustainable weed management practices that ensure good control of weed problems while minimising the threats of herbicide resistance and species shift to the Australian cotton industry.

To ensure that the Australian cotton industry is able to maintain high levels of weed control in modern production systems, it is essential that an integrated approach to weed management (IWM) be adopted and maintained. Recent advances in farming practices, such as the adoption of conservation farming techniques, along with the introduction of herbicide-tolerant transgenic cotton varieties, are likely to result in a change of the weed flora (succession) encountered in cotton fields. Increased use of specific herbicides, accompanying the introduction of these transgenic cotton varieties, will increase the selection pressure on many weed species and may lead to the development of herbicide resistance. VanGessel (2001) reported that fleabane (*Conyza canadensis*) developed resistance to glyphosate within three years of continual glyphosate use in glyphosate resistant soybeans.

The aim of this paper is to discuss integrated weed management techniques and how they can be used in Australian cotton production systems to minimize succession and the development of herbicide resistance in production systems using herbicide-tolerant cotton varieties.

Integrated weed management defined

Integrated weed management may be defined as a weed management system that combines all possible weed control methods. It does not solely rely on any single method but draws together a combination of methods (Sindel 2000). As the majority of weed species in cotton are annual species, the long-term goal of integrated weed management systems is to reduce the number of seeds contained in the soil seed bank. Powles and Bowran (2000) identify three key aims to ensure that there is a real net decline in seed bank numbers. These are:

1. To minimise the survival of weeds that emerge from the soil seed bank;
2. Minimise the production of seed from established weeds; and,
3. Reduce the residual seed bank in the soil over time, either by stimulating germination of weed seeds so that seedlings can be controlled, or by enhancing the death of residual seeds.

The management of perennial weed species is somewhat more complex in nature due to the ability of weeds to reproduce both from seed and vegetatively, but the same principles apply. The development of an integrated weed management strategy is a long-term approach. Success is dependant on maintaining and refining the strategy over time.

An integrated weed management plan not only needs to be economically viable in the long term, but must also reflect the individuality of each farm and take into account the variability encountered at the field level. The plan needs to take into account the weed species present in each field, the farming system adopted, and the social values of the individual growers. Wilson (2000) lists seven key elements of an IPM plan. These same elements are also relevant to integrated weed management and it is worthwhile restating those elements in terms of an IWM program. An IWM program should:

1. provide effective control of the weed complex,
2. reduce reliance on synthetic herbicides,
3. be economically viable,
4. be simple and flexible,
5. utilise compatible control measures,
6. be sustainable, and
7. have minimal harmful effect on the environment, the producer and the consumer.

A basic understanding of the biology and ecology of the dominant species within a field will help growers understand how long specific management strategies need to be in place to enable the control of problem weed species. For example, seeds from the grass weeds awnless barnyard grass (*Echinochloa colona*) and liverseed grass (*Urochloa panicoides*) typically encountered on Australian cotton farms, are short-lived and do not have complex dormancy systems. Management strategies specifically aimed at controlling these two species only need to be in place for three to four years before there is a 95-99% reduction in seed numbers. Noogoora burr, on the other hand, has seed that can remain viable for up to 20 years. Management strategies for this weed need to remain in place for this length of time.

Components of an integrated weed management plan

Integrated weed management relies on the effective use of a number of components, either in conjunction or separately to reduce weed pressure. The components of an integrated weed management strategy can be broadly classified under six headings: chemical; physical; cultural; biological; preventative, and record keeping. In cotton production systems, the typical components of weed management include the use of herbicides, crop rotations, field hygiene, cultivation, crop agronomy, irrigation management, scouting and record keeping.

Chemical control

Herbicides

Herbicides have formed the basis for weed management in most cropping systems since their extensive development in the late 1940's and early 1950's (Brian 1976). Herbicides such as MCPA and 2,4-D were widely adopted in the years after World War II, due to their selective nature and ability to control a wide variety of weeds successfully. A plethora of other herbicides followed the development of these herbicides, and a virtual arsenal of herbicides is now available to the farmer. Herbicides are relatively cheap, effective and available as either selective for the control of specific weeds or non-selective for control of a broad spectrum of weeds.

Herbicides act by interfering with particular metabolic and biochemical pathways in a plant. A number of different herbicides may target the same metabolic and biochemical pathway, and so can be grouped according to their mode of action (Walker 1994). In Australia, 14 herbicide groups are recognized and a letter has been assigned to differentiate each group (Table 1). All herbicide containers display the letter indicating the mode of action of the product. The repeated use of herbicides with the same mode of action increases the chances that herbicide resistance will develop. Separation of herbicides into these groups, based on their mode of action, enables growers to vary the herbicide groups used, to slow or prevent the development of herbicide resistance.

Table 1. Herbicide groups classified according to mode of herbicidal action. Examples of chemical and trade names are given for each chemical group. Most herbicides are available under a range of registered trade names.

Group	Mode of action	Chemical group	Chemical name	Trade name
A	Inhibitors of acetyl coA carboxylase	Aryloxyphenoxy-propionate (Fops) Cyclohexanedione (Dims)	Propaquizafop Sethoxydim	Correct Sertin
B	Inhibitors of acetolactate synthase	Sulfonylurea Imidazolinone Sulfonamide	Chlorsulfuron Imazypyr Flumetsulam	Glean Arsenal Broadstrike
C	Inhibitors of photosynthesis at photosystem II	Triazine Triazinone Urea Nitrile Benzothiadiazole Acetamide Pyridazinone Phenyl-pyridazine Uracil	Prometryn Hexazinone Diuron Bromoxynil Bentazone Propanil Chloridazon Pyridate Bromacil	Gesagard Velpar Diurex Buctril Basgran Ronacil Pyramin Tough Hyvar X
D	Inhibitors of tubulin formation	Dinitroaniline Benzoic acid	Pendimethalin Chlorthal	Stomp Dacthal
E	Inhibitors of mitosis	Thiocarbamate Carbamate Organophosphorus	Tri-allate Propham Bensulide	Avadex BW Clopham Exporsan
F	Inhibitors of carotenoid biosynthesis	Nicotinanilide Triazole Pyridazinone	Diflufenican Amitrole Norflurazon	Brodal Amitrolet Zoliar
G	Inhibitors of protoporphyrinogen	Diphenyl ether Oxadiazole	Oxyflurofen Oxadiazon	Goal Ronstar
H	Inhibitors of protein synthesis	Thiocarbamate	Thiobencarb	Saturn
I	Disrupters of cell growth	Phenoxy Benzoic acid Pyridine	2,4-D Dicamba Fluoxypyr	Various Banvel Starane
J	Inhibitors of fat synthesis	Alkanoic acid	Flupropanate	Frenock
K	Herbicides with diverse sites of action	Amide Organoarsenic Carbamate Amino propionate Benzofuran Pthalamate Nitrile	Metolachlor MSMA Asulam Flamprop-methyl Ethofumesate Naptalam Dichlobenil	Dual Daconate Asulox Mataven Tramat Alanap Casoron
L	Inhibitors of photosynthesis at photosystem I	Biprydil	Diquat	Reglone
M	Inhibitors of EPSP synthase	Glycine	Glyphosate	Roundup
N	Inhibitors of glutamine synthase	Glycine	Glufosinate-ammonium	Basta

Adapted from Walker and Dellow 1994.

Herbicide resistance is a major issue in a number of cropping systems in both the southern and northern farming regions of Australia (Adkins *et al.* 1997, Powles 1997). However, at this point in time, there are no known cases of herbicide resistant weeds in Australian cotton production systems. This infers a distinct production advantage to Australian cotton growers and it essential that this status be maintained. Moves toward minimum tillage systems and the reduced use of manual chipping increases the selection pressure imposed on the weed species in cotton fields. Thus, to maintain resistant free fields, it is important that an effective IWM strategy be developed and adopted.

Herbicide tolerant cotton

The introduction of Roundup Ready® cotton varieties over the last few years has provided a number of benefits for weed management. These benefits include:

- Reduced dependence on residual herbicides.
- Improved control of some of the more difficult-to-control weeds.
- Greater flexibility in weed management programs.
- Reduced chipping and cultivation expenses.
- Potential to improve establishment and vigour of young cotton seedlings by reducing the pre-emergence use of residual herbicides.

With the increasing adoption of this technology and the possibility in future years that other herbicide-tolerant varieties may be introduced, it is important that this technology form part of an integrated weed management plan. It is possible with the selection of the appropriate fields, that control of troublesome weeds may be achieved using only Roundup Ready herbicide. This possibility is further discussed in the paper "*Improved weed management in irrigated cotton production systems: Reducing dependence on residual pre-plant and pre-emergent herbicides*" found elsewhere in these proceedings. To use the technology in this fashion places intensive selection pressure on weeds present in the fields and hence leads to either the development of resistant weeds or the selection of weeds that are tolerant of glyphosate. Either of these, results in the reduced effectiveness of the technology.

Physical control

Physical weed control includes practices such as manual hand hoeing, inter-row cultivation, cultivation in fallows and burning. Cultivation and manual hand hoeing have been, and continue to be important components of the weed management system. In the last 30 years though, conservation-farming practices have been adopted on many farms, where the techniques are being used to reduce soil erosion and maintain soil structure (Felton *et al.* 1994). Conservation-farming practices rely on less aggressive tillage and have a greater dependency on herbicides. The high labour costs and often-variable results associated with manual hand hoeing is also driving growers to investigate more economical alternatives to this practice, generally by further increasing reliance on herbicides.

However, although hand hoeing and cultivation can be expensive and have some negative aspects, they are very important in minimising herbicide resistance and weed succession. Cultivation is important for two reasons. Firstly, cultivation controls the majority of weeds in a field. Secondly, cultivation stimulates the germination of weed seeds. Thus, cultivation can be used to trigger a germination flush of weeds (assuming adequate soil moisture), allowing broad-spectrum herbicides to be applied to control these weeds prior to planting. The introduction of herbicide-tolerant cotton and the use of over-the-top applications of herbicide will enable the control of a number of weed species. However, a few weeds are likely to escape the herbicides. A chipping bike can be a cheap and efficient method of weed control for these escapes. A farm worker equipped with a manual hoe can cover a lot of territory quickly on a bike, efficiently removing weeds that escaped the herbicide treatment.

Burning can be a useful technique for controlling some weeds and diseases. While not recommended every year, the judicious use of stubble burning can destroy weed seeds, as well as promote seed germination. The smoke from fires triggers the germination of a number of weed species (Adkins et al. 1999). While none of the species tested to date have been weeds of cotton it is likely that many will respond in a similar fashion.

Cultural

Cultural control methods involve manipulating crop agronomy and agronomic practices to favour crop establishment and vigour rather than providing a favourable environment for weeds. The majority of weeds occupy a niche in either space or time that allows them to exploit a competitive advantage over the crop. It is possible, in some circumstances, to manipulate the environment such that the crop has the advantage rather than the weeds. For example, increasing the crop sowing density may allow the crop to be more competitive and thus out-compete weeds that emerge in the plant line. In the case of cotton, increasing planting densities may lead to a yield decline, however, there is scope for the use of this technique in rotation crops.

Crop Rotations

Rotation crops are important in crop management from a weed and disease perspective. In the case of both weeds and diseases, the continual planting of the same crop allows the build-up of organisms that are detrimental to that crop. Weeds that are difficult to control in cotton continually add seeds to the soil seed bank, resulting in the build up of seed numbers and an increase in the number of weeds in the field. As these plants mature and set seed, they further add to the seed bank, until they become the dominant species within the field.

Seed produced by weeds often have complex dormancy mechanisms that ensure their survival for long periods of time. This means that the weeds are problematic for a number of years. One of the best ways to manage a scenario like this is to introduce rotation crops that allow for the control of the problem species. Rotation crops allow alternative management strategies to be employed that disrupt or interfere with the life cycle of the weed. For example, rotating out of cotton into sorghum will allow many of the broadleaf weed species to be effectively controlled with atrazine or herbicide combinations that include atrazine (Roberts and Gibb 1998).

Irrigation management

Irrigation is normally scheduled according to the demands of the cotton crop. Prior to irrigation occurring, it is not uncommon to cultivate (prior to canopy closure) between the rows to control any weeds that have established in the inter-row area. The germination of many weed seeds is stimulated by light, hence cultivation primes weed seeds for germination. Irrigation soon after the cultivation event provides the perfect environment for the seeds to germinate and hence it is not uncommon to see a flush of weeds after irrigation and cultivation. Awareness of this allows growers and agronomists to schedule herbicide applications (either shielded or directed) to control weeds emerging in the inter-row area. Alternatively, growers may shedule inter-row cultivation to follow irrigation, with the cultivation pass occurring as fields are drying down. Weeds that germinate following this cultivation are less likely to successfully germinate and establish in a rapidly drying soil.

Prior to planting, the crop growers need to decide whether to pre-irrigate or to "water up" after planting of the seed. Pre-irrigating the crop allows growers to control weeds using a knockdown herbicide prior to planting, but has the disadvantage of decreasing soil temperatures and possibly delaying the planting date. Watering up tends not to have the same impact on soil temperatures as it is performed at a later date when ambient temperatures are higher. However, as the crop seeds have been planted, the window for herbicide application between planting and crop emergence can be very limited. Weed seeds that germinate as the crop emerges compete directly with the young cotton seedlings for moisture and soil nutrients, and can be difficult to control.

Crop variety selection

Different cotton varieties have different vigour, particularly during early establishment. The choice of a variety that has good early season vigour and that will close over the inter-row spaces early, is the best choice in terms of weed management. Good early season

Controlling weeds in channels, roads and storages.

Weeds growing along the sides of irrigation channels are a major source of infestation and contamination for cotton fields. Many weed seeds are transported by water. Irrigation of fields via channels that have significant weed problems may result in those weeds becoming problematic in the field. Attention needs to be paid to those weeds growing along channels, roadsides, storages and waste areas to ensure that these do not contaminate fields.

Scouting and record keeping

Scouting and record keeping are an integral part of an integrated weed management plan. Records need to be kept not only for spray operations that are performed in the field, but should also be used to note the weed species that are present. Notes should be kept of the influence of agronomic practices on weeds, any changes in the weed spectrum, and any new weeds that appear in a field. This data can be obtained by regular observations on the weed spectrum and density in each field. The requirements for these observations are akin to the requirements for insect scouting and could be coupled with normal insect scouting practices. The keeping of detailed records will help identify practices that exacerbate weed problems and will identify areas where a weed management plan is failing. Early identification of a problem means that steps to rectify the problem can be put into place prior to the issue having a major impact on the farming system.

As well, keeping records of the level of weed control achieved after a spray will pinpoint application problems and identify weeds that may be becoming resistant to herbicides.

Integrating the management plan.

While the components of an integrated weed management plan are relatively straight-forward, it is the timing of operations that determines the overall effectiveness of the plan. The idea of an integrated weed management plan is to ensure that there is a real decline in the number of weed seeds in the soil seed bank. Each operation should be timed to have the maximum impact on the weeds present in the field. Spray operations need to be conducted when seedlings are small to ensure that herbicides have maximum efficacy. Cultivation should be timed to enhance weed control, either by directly controlling weeds present in the field, or by stimulating the germination and emergence of weed seedlings so that control can be achieved with knock down herbicides at a later date. Varieties with good early vigour should be chosen, as they are more competitive with weeds. Increasing the sowing rate may also result in a more competitive crop. Preventing the spread of weeds by ensuring that farm machinery is clean and adequate attention paid to waterways and waste areas will reduce the number of new weeds appearing on farms.

vigour allows the cotton plant to out compete weed seedlings, reducing their impact on yield.

Additionally, growers now have the choice of herbicide tolerant cotton varieties, which allow the use of additional tools for managing weeds. The choice of variety, however, is dictated by other factors, including disease resistance, yield and quality factors. These all need to be considered carefully prior to the final decision of which variety to plant.

Sowing date and planting density

Different weeds germinate at different times throughout the year. Temperature and rainfall or irrigation determine the exact time of germination of seed for the majority of weed species (Cousens and Mortimer 1995). Delaying the planting date, or planting the crop earlier may allow the crop to establish without having to compete with early season weeds. Liverseed grass (*Urochloa panicoides*), for example, often germinates early in the spring. Delaying planting until after the germination flush may allow better control of this troublesome grass weed and better establishment of the cotton. Increasing planting density may result in a more competitive crop and making it more difficult for weeds to establish. Additionally, increasing the planting density may decrease the time to canopy closure, preventing some weed seeds from germinating later in the season.

The ultra-narrow row planting configuration uses increased crop density to modify crop growth and development. This configuration maximises crop competition and greatly reduces the time between crop emergence and canopy closure. However, this planting configuration also reduces the options and opportunities for inter-row cultivation, directed herbicide applications and hand hoeing. Consequently, even though the crop is more competitive, weeds may be more difficult to manage in ultra-narrow row cotton.

Gappy cotton stands are very prone to weed invasion and competition and will need season-long attention. Replanting of gappy stands will assist with weed management as well as improving over-all crop productivity.

Stubble management

Planting cotton into standing wheat stubble has been promoted recently for reducing early season *Helicoverpa* pressure, improving water infiltration and improving soil conditions at planting and during seedling establishment (Waters and Kelly 2001). The presence of stubble, however, does interfere with the incorporation of the commonly used pre-emergent herbicides, such as trifluralin, making early season weed control more difficult. It is important in this system to ensure that weed control measures are modified to obtain adequate weed control with the presence of stubble. The use of Roundup Ready® cotton varieties enables over-the-top applications of Roundup Ready® herbicide for weed control.

Additionally, the planting of wheat in two rows on the shoulders of the beds, leaving the centre of the bed clear, enables the banded application of herbicides while still maintaining the benefits of stubble.

Biological control

There has been little use of biological control agents for weed management in cotton production systems in Australia. In conventional cotton systems the frequent-high use of insecticide sprays has precluded using other biological organisms for weed control. However, with the introduction of Bollgard II in the near future, the scope for the use of biological control agents for weed management has been widened. Several organisms have been used for biological control of weeds in Australia, including grazing animals, pathogenic fungi such as *Puccinia abrupta* var. *partheniicola* for control of Parthenium weed (Tomely 1997) and insects such as *Agasicles hygophila* for controlling alligator weed (Julien 1997).

While this is a new area for research, field observations in cotton have noted several insect species that may have an impact on weeds. In particular, larvae from leaf eating beetles have been observed to have a large impact on thornapples. These larvae primarily eat the leaves of thornapples and can completely defoliate the plants within a short time if left undisturbed. Defoliation has a significant impact on the reproductive capacity and competitive ability of these weeds. These methods of control may be useful in the future but need further research in their application to cotton systems.

Preventative measures

Where possible, it is important to prevent new incursions of weeds on to cotton fields or to prevent the spread of weeds that are already present. Weed seeds are easily transportable either by machinery used in fields or via water through irrigation channels. Procedures need to be put into place where possible to restrict the movement of seeds from one field to another, or from one farm on to another.

Field hygiene

Machinery and other equipment used in fields are primary transport mechanisms for weed seeds. All machinery used in fields that are known to have weed problems should be thoroughly cleaned prior to entry into other fields. Procedures should also be put into place to ensure that contract harvesting equipment is thoroughly cleaned down prior to entry on to a farm. Many farming enterprises have installed wash down facilities to assist in preventing the spread of Fusarium. These same facilities can be employed to ensure that vehicles entering on to farms are clear of weed seeds. Special attention must be given to the run-off areas from these facilities, to ensure that all weeds and disease are contained.

An integrated approach relying on a number of different control methods will over time reduce the weed problem encountered on a farm, as well as reduce the likelihood of succession or the development of herbicide resistance. The use of a detailed record keeping system assists the grower to monitor the performance of the integrated weed management plan and alerts the grower to problems that may develop. This enables the grower to rectify the problem prior to it getting out of hand.

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