TECHNICAL ASSESSMENT OF CHANGES IN WEED MANAGEMENT TECHNOLOGY IN CROPPING

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Summary This paper assesses the changes in weed management technologies for cropping that have occurred over the last twelve years. Information has been sourced from papers from the last four Australian Weeds Conference's and the First International Weed Control Congress.

Management technologies have been placed into four categories. Bio-technologies/control, cultural/mechanical management technology, computer technology modelling and synthesized herbicides and within these broad categories there are a number of sub-categories (Table 1).

BIO-TECHNOLOGIES/CONTROL

Biological control The number of papers on new or existing agents for biological control more than doubled at the 1990 conference and has remained static since then. Projects have included work on agents for *Emex* spp., crowsfoot grass (*Eleusine indica* Gaertn.), Paterson's curse (*Echium plantagineum* L.), silverleaf nightshade (*Solanum elaeagnifolium* Cav), thistles, St. John's wort (*Hypericum perforatum* L.), horehound (*Marrubium vulgare* L.), skeleton weed (*Chondrilla juncea* L.), fiddle dock (*Rumex pulcher* L.), Noogoora burr (*Xanthium occidentale* Bertol) and common heliotrope (*Heliotropium europaeum* L.).

The success of biological control agents has been discussed. Harley and Wright (1987) classified three programs out of eight to be successful and White and Donnelly (1993) classified one program out of twelve to be successful. There have been a number of papers reviewing the methods and direction of research into biological control (Delfosse 1987, Cullen and Delfosse 1990, Cullen 1992, Briese 1993) with the authors stating that more focus needs to be made on the biology and ecology of the target weed.

Bio-technology/mycoherbicides In 1987 Templeton (1987) stated that the greatest potential for weed control with mycoherbicides was in non-agricultural areas. Five years later he stated that mycoherbicides have a broader utility than originally thought, controlling weeds in annual crops, orchards, rangelands and forest (Templeton 1992). So far a number of agents have been researched, *Colletotrichum gloeosporioides* to control round leaf mallow (*Malva pusilla*) in Canada (Makowski and Mortensen 1992) and St. John's wort in Australia (Shepherd 1993), *Puccinia canaliculata* for the control of yellow nutsedge (*Cyperus esculentus*) in the United States (Phatak 1992), *Colletotrichum truncatum* to control weed hemp sesbania (*Sesbania exaltata*) in the United States (Schisler *et al.* 1992), *Alternaria zinniae* (Nehl and Brown 1992) and *Sclerotinia sclerotiorum* for the control of spear thistle (*Cirsium vulgare* Ten.) in New Zealand.

Auld (1992) stated that the greatest need for development of commercial biocontrol agents is improved formulation to overcome environmental constraints and to reduce end use concentration requirements. An example of this is the application of *Sclerotinia sclerotiorum* at up to 500 kg ha^{-1} Bourdot *et al.* 1993). However, Auld (1993) also comments that mass production of plant pathogens in developing countries using low-tech systems at a local level is a feasible alternative to high tech systems used in the industrialized world.

Grazing animals This is probably the oldest form of weed control and can be just as effective as other methods. Popay and Field (1992) give examples of the advantages of grazing animals and also state that opportunities for using them as biological control agents will increase in the future. This is due to the international movement towards sustainability, and the increasing development of herbicide resistance. McGregor *et al.* (1992) explains that goats are very effective, reliable and cheap weed control agents. They are more flexible and adaptable than sheep and cattle, and their ability to browse allows them to use a wider variety of plants. Bell and Guerrero (1992) studied sheep grazing to control weeds in seedling alfalfa.

CULTURAL/MECHANICAL MANAGEMENT

Cultural There have been a number of studies on mechanized buried seed monitoring and sampling (Jones and Medd 1984, Medd and Murison 1984, Jones *et al.* 1987, Medd 1992). Other studies have concentrated on rotations and new crops to manage weeds (Gammie 1987, Cheam *et al.* 1987, Code *et al.* 1987, Martin and Felton 1990, Purvis 1990, Cheam and Lee 1992). Rotations and changes to agronomic practices have not always reduced the weed burden. Tang (1993) reported a 15–20% increase in weed infestation in fields in Shanghai between 1981–91. This was due to reduced tillage, the

application of only two herbicides and a two crop rotation.

Work has also been carried out to investigate the competitiveness of crops (Cousens and Fletcher 1990, Cousens 1992, Lemerle and Cousens 1992, Zaicou and Gill 1992, Lemerle and Plater 1993). Thill and Mallory-Smith (1992) investigated the competition between spring barley and wild oats. They found that increasing the seeding rate decreased wild oat interference, changing the row spacing did not affect wild oat competition and that N fertilizer banded between paired rows reduced wild oat competition compared to broadcasting N fertilizer. They also found the greatest net return for 100 wild oat plants m^{-2} was half rates of herbicide and for 290 wild oat plants m^{-2} it was when half or full rates of herbicide were applied. Baylis *et al.* (1992) showed that the competitiveness of some weeds was reduced in low levels of nitrogen if soil moisture was high.

Cultivation and minimum tillage It is over a decade ago that the interest in minimum tillage was the strongest. At the Seventh Australian Weeds Conference, there was a section devoted to minimum tillage. Since then there has been only a small number of papers presented. Daniels (1987) stated that there was a slow adoption of reduced tillage due to its complexity. Felton and Wicks (1993) found that the adoption of minimum tillage was slow, with most farmers still using cultivation for weed control in fallow paddocks in northern New South Wales.

On the other hand, Dowling (1987) showed that direct drilling plus chlorsulfuron was as effective in

Table 1. The number of papers written about various technologies that manage crop weeds from the last four Australian Weeds Conferences and the First International Weeds Control Congress.

Technologies	1984	1987	1990	1992	1993	Total
Biological control	4	7	12	15	11	49
Biological control agents	3	4	11	10	9	37
Biotechnology	1	1	2	4	3	11
Biotechnology agents	0	1	2	3	2	8
Minimum tillage	5	2	1	1	3	12
Reduced or no chemical	0	1	2	12	5	20
Cultural/Mechanical control	3	2	6	11	4	25
Allelochemicals	0	1	2	5	2	10
Computers and modelling	1	4	1	10	7	23
Herbicide development	0	1	1	4	1	7
New grass herbicides	4	3	3	1	3	14
Other new herbicides	2	1	5	3	6	17
Crop tolerance	9	4	9	5	8	35
Residues	1	4	5	8	4	22
Efficacy	8	16	14	26	18	81
Rice herbicides	0	3	0	5	10	18
Cereal and winter crop herbicides	13	14	29	16	17	96
Summer crop herbicides	1	2	1	9	6	19
Horticultural herbicides	1	4	5	4	3	17
Application equipment	8	1	1	4	1	15
Adjuvants	3	4	4	7	2	20
Droplet behaviour	5	0	2	2	2	11
Safety and toxicity	1	1	0	2	1	5
Herbicide resistance	0	8	28	13	8	57
Herbicide resistance biochemistry	0	0	12	10	6	23
Examples of herbicide resistance	0	7	8	1	3	19
Managing herbicide resistance	0	1	7	6	4	18
Resistant crops	0	0	0	4	4	8

reducing grass weed competition as cultivation with triflualin. Streit (1993) highlighted the need for planning when using pre-emergent herbicides in minimum tillage.

Medd (1990) showed that the seed bank of wild oats fluctuated irrespective of soil disturbance methods (direct drill, shallow and deep tillage, and undisturbed soil). Covarelli and Tei (1992) supported this by showing that in herbicide treated plots, weed populations were not affected by different tillage methods.

Direct drill is a part of the minimum tillage technology in a large number of crops and this includes rice. Kim (1992, 1993) described the development of direct seeding rice and it's effectiveness in maintaining yield and weed control over conventional mechanical transplanting.

Many farmers have moved from conventional cultivation to minimum tillage, however there are still districts where conventional cultivation is more popular. Volatile herbicides such as trifluralin are less efficacious when incorporation is not carried out. Therefore, research needs to be carried out to find ways of using more volatile herbicides (which still can be considered to have a place in weed control due to their different mode of action) in minimum tillage.

Reduced or non-chemical technologies It is only since the First International Weed Control Congress in 1992 that a substantial number of papers have been presented about reducing the amount of chemicals used to control weeds. Prior to this only three papers had been presented. At the Ninth Conference Combellack (1990) proposed to reduce herbicide quantities per unit area treated by 15% in five years and 50% in ten years. He suggested that this target could be achieved by placing more reliance on non-chemical control methods, improving the efficacy of herbicides, applying them only to weeds where they occur and by getting users to accept lower levels of weed control. It is now 1996, six years has passed since the paper was written and herbicide quantities, if anything, have increased per unit area.

At the Eighth Conference Amor (1987) discussed clean equipment and seed, rotations, crop competition, changing the soil environment, biological control, cultivation, mowing pastures for hay, stubble burning and the use of natural herbicides as alternative management technologies to reduce herbicide usage. Since the First International Weed Control Congress the subject matter has not differed much from Amor's recommendations. Cover crops in vegetables have been trialled with success (Young and Hingston 1993). Vigorous and high yielding rice cultivars have been recommended (Ismail 1993) and rice irrigation systems have been modified to reduce the discharge of contaminated water into rivers (Hill *et al.* 1993). Physical barriers (Morgan 1992, Mohammad-Reza and Teymouri 1992) such as leguminous mulches (Akobundu 1992) can be used to suppress weeds and thermal control is used in Europe (Marshall 1993).

Much of the research into alternative forms of control has evolved around avoiding resistance to herbicides. Bentley (1990) stated that to extend the life of herbicides, alternative and complimentary control measures should be used so that herbicide resistance be prevented. Kon *et al.* (1992) advocated the use of post-emergence herbicides because they are only applied when necessary and avoid soil disturbance.

Allelopathy and allelochemicals Early references to allelochemicals were in trials conducted on the allelopathic properties of thornapple (*Datura stramonium* L.) (Lovett *et al.* 1987) and barley (*Hordeum vulgare* L.) (Liu and Lovett 1990). There has been more progress made with allelochemicals derived from silvergrass (*Vulpia* spp.) (Pratley and Ingrey 1990). Preliminary studies of the allelopathic impact of goosefoot (*Chenopodium pumilio*) on wheat and lupins (Cheam and Lee 1993), sunflower (*Helianthus annuus* L.) allelopathy (Frans and Semidey 1992), and studies of *Eupatorium odoratum* in shifting cultivation fields in tropical Asia (Nakamura and Nemoto 1993) were conducted and may lead to further research. Rizvi and Rizvi (1992) have studied the allelochemical terpenene and found it to be the most potent tested. Finally, the suppressive effects of one species on another may not be due to allelochemicals. Teasdale and Mohler (1992) concluded that the weed suppression effects of hairy vetch (*Vicia villosa* Roth) and rye (*Secale cereale* L.) cover crops were probably due to the residue biomass rather than allelopathy.

COMPUTER TECHNOLOGIES AND MODELLING

Since the 1992 International Weed Control Congress there have been a considerable number of papers on weed control using computer technology and modelling. Kropff and Moody (1992) reviewed eco-physiological simulation models and descriptive regression models and found that they had been used in only a few studies. Other research has used models to simulate the degradation of chlorsulfuron in acidic soils (Blacklow 1992), to simulate an increase in weed populations when economic thresholds are used (Gerowitt 1992), to predict atrazine persistence in soil (Reinhardt and Nel 1992) and to model early prediction of crop yield losses by weed competition (Lotz *et al.* 1992).

Bio-economic models have been used to study the management of wild oats (Pandey and Medd 1992,

Pandey *et al.* 1992, Thill and Mallory-Smith 1992) and used in expert systems to aid in rice management decisions in the United States (Smith *et al.* 1992).

SYNTHESIZED HERBICIDES

New grass herbicides There has been a regular number of papers discussing new grass herbicides at each of the conferences since 1984. Most papers have discussed fops and dims in cereals and winter crops but recent papers have discussed grass herbicides for sugar cane (Somervaille 1993) and rice (Landes *et al.* 1992, Ray *et al*. 1993, Matsumoto *et al.* 1993).

Other new herbicides There have been a number of new herbicides evaluated since the 1987 conference. Imazapyr was briefly discussed by Williamson (1987) and Lignowski *et al.* (1990). Fluometralin was discussed by Wilcox and Taylor (1992). Sulfonylureas (Arends and Pegg 1990, Umehara and Suzuki 1992, Peek and Kupatt 1992), Trifluralin Control Release (Flynn *et al.* 1990), glufosinate-ammonium (Perkins 1990) and pyridate (Seidel and Russell 1990) have been evaluated. At the last conference the sulfonamides were presented (Downard and Webb 1993, Phimister and Downard 1993, Snel *et al*. 1993), as were sulfamoylureas (Quakenbush *et al.* 1993, Murai *et al.* 1993) and pyrithiobac (Mesch and Arends 1993).

Herbicide development Most of the discussion about herbicide development was at the 1992 First International Weed Control Congress. Evans (1992) summarized the characteristics which will be required for new products: highly active or effective in cost per acre, ecologically benign, safe to users and the public, compatible in mixtures, appropriate in IPM, crop safety, and flexible and convenient to use. Beyer (1992) presented similar ideas and in addition pointed out the need for improvements in stewardship, education, training and delivery systems. Clearly some of these characteristics are being addressed in Australia, such as the introduction of mini bulk transfer systems.

Herbicide resistance The greatest interest in this topic was at the Ninth Australian Weeds Conference in Adelaide in 1990. There were 28 papers presented on herbicide resistance and they ranged from examples of resistance and the biochemistry and genetics of resistance to ways to manage herbicide resistance. Since 1990 there have been 13 papers presented at the 1992 congress then eight papers at the 1993 conference. Most of the papers about examples of herbicide resistance were at the 1987 and 1990 conferences, indicating the early period in resistance research. All of the papers about the biochemistry and genetics of resistance have come from the 1990 and 1993 conferences and the 1992 congress.

There has been a smaller number of papers on the agronomic management of resistance also from 1990, 1992 and 1993. Strategies to manage herbicide resistance involve cultural practices together with crop, pasture and herbicide rotation (avoiding cross resistance), pasture manipulation and delayed seeding. Other strategies have involved the formulation of industry groups such as Herbicide Resistance Action Committee (Jutsum and Shaner 1992) and the testing of suspected plants. The integration of pasture into continuous cropping systems to help manage resistance has been shown by simulation not to be profitable (Bathgate *et al*. 1993, Ghadim *et al.* 1993).

Herbicide resistance crops It is only since 1992 that papers about resistant crops have been discussed (Dalling 1992, Field *et al*. 1993). Crops have included potatoes (Moses *et al.* 1993), rice (*Oryza sativa* L.) (Pyon and Balke 1993), canola (*Brassica napul*) (Blackshow *et al.* 1992) and grain sorghum (*Sorghum bicolor* Moenen) (Moreland and Corbin 1992). There are many potential benefits from crop resistant herbicides. The main ones could be more effective weed control, reduced costs, reduction in herbicide usage and reduced cultivation. On the other hand, the main potential problem could lie in more weeds becoming resistant due to the increased frequency of application with a single herbicide.

Application equipment and droplet behaviour There were eight papers on application equipment in 1984. Since then there have only been seven, and four of the seven were at the 1992 congress. The reason for the lack of interest in application technology may be difficult to explain, although the lack of research input by machinery manufacturers in Australia may be a contributing factor. Early papers included work on granular application equipment (McLennan and Jacobs 1984), experimental plot sprayers (Hinkley and Kidd 1984, Schoonens 1984) and the aerial application of glyphosate (Clarke and Blowes 1984). Later work concentrated on ultra-low volume application (McWhorter and Hanks 1992), environmental problems associated with application (Gohlich 1992) and volatization of small droplets and air-assisted boom sprayers (Miller 1992).

There is a similar trend with papers on droplet behaviour with the majority of presented papers at the 1984 conference. Drift was mentioned at the 1984 conference (Gilbey 1984, Smart 1984) as was glyphosate use in low water volumes (Campbell *et al.* 1984). More recent work has been on the structure of leaf surfaces and droplet spread (Levick and Nicholls 1992, Levick *et al.* 1993) and twin fluid spray nozzles (Nicholls *et al.* 1993).

Adjuvants The most papers on adjuvants were presented at the 1992 congress when seven were presented. At the other conferences there were only 2–4 papers discussing adjuvants. Adjvants that improve glyphosate efficacy have proven to be a popular subject (Diatloff 1984, Field and Bishop 1987, Gaskin and Zabkiewicz 1987, Wells *et al.* 1990), as have organosilicone surfactants (Field and Tisdall 1990, Stevens and Zabkiewicz 1990, Vitelli 1990, Buick and Field 1992).

Herbicides in general As can be expected, there have been a large number of papers discussing the efficacy and crop tolerance of herbicides. There has been a smaller number on residues, most written since the 1987 conference. The majority of papers have been written about winter crops (cereals and grain legumes) with less than half the number concerning horticultural crop, summer crops and rice.

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