WHERE IN THE WORLD IS WEED SCIENCE GOING?

J.V. Lovett and S.E. Knights
Grains Research and Development Corporation, PO Box E6, Queen Victoria Terrace, Canberra, ACT 2600, Australia

Summary The concept of integrated weed management, as contrasted with weed control, is widely accepted in the Australia of the 1990s. Integrated weed management entails a multi-disciplinary approach and a reappraisal of practices which sustained agriculture in pre-herbicide times. Dependence on single factor approaches to weeds, such as herbicides or biological control, is being reduced and integrated weed management practices, incorporating herbicides and biological control, are becoming more common.

This paper explores contemporary Australian weed science against this background and compares regional and national practices with international mores.

INTRODUCTION

The harmful effects of weeds were known in early history, as humankind has had to combat weeds since practising settled agriculture (Figure 1). Weeds were, at first, removed by hand, then with hand implements, consisting of flint or wood that were later replaced by metal points and blades. Methods of weed management such as these extended from Egyptian cultures to Renaissance times.

The first efforts to turn away from simple hand methods and mechanise this arduous task of weed control started in seventeenth century England with a progression from hand removal to animal powered implements. Cattle drawn implements, wooden and metal ploughs were used over large areas as part of the cultivation process, the principal virtue of this process being the uprooting and consequent destruction of the currently present weeds.

In the 1800s horse drawn implements were introduced, including wheeled cultivators, mowers and disks. By the turn of the century a transition had been made from horse drawn to steam powered tractor implements. Traditionally, land was prepared for cropping by means of a mouldboard plough, which served to bury unwanted trash and promote a good tilth (Froud-Williams 1988). Tined cultivators have been widely used for mechanical weed management through much of the twentieth century. The realisation that crops were able to be produced with minimal soil disturbance, in conjunction with knockdown herbicides from the 1960s (for example, paraquat and, more recently, glyphosate) has made

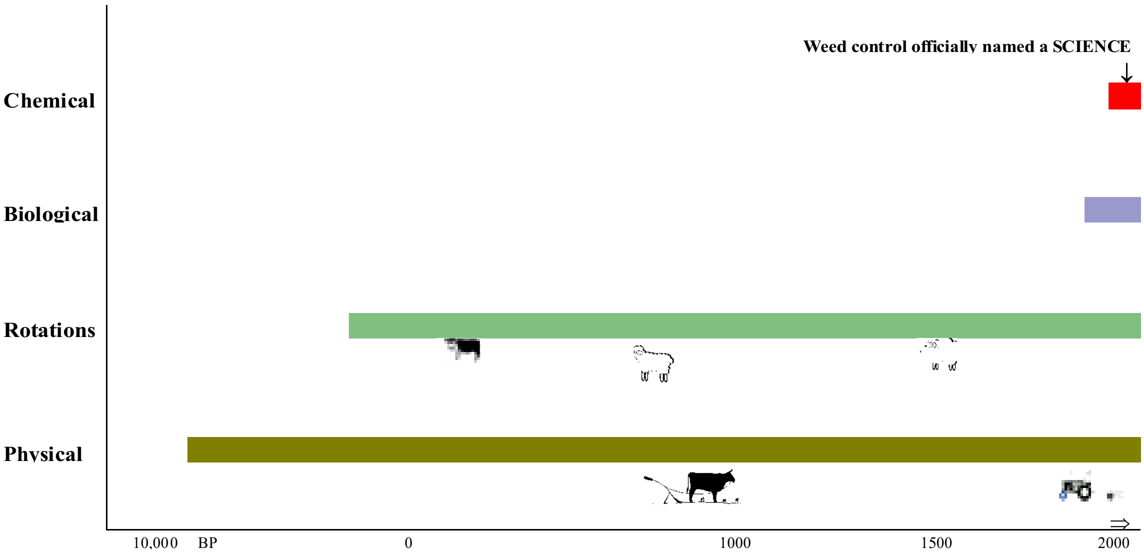

Figure 1. Weed management over the years.

reduced tillage techniques possible. The substitution of chemical for mechanical energy in this way was of profound significance for future weed management.

Together with cultivation techniques, crop rotations were adopted in Roman times as a means of promoting good husbandry. Designed to maintain soil fertility, rotations became an increasingly important foundation for efficient weed control. Rotating between crops, with different harvesting dates, also prevented any single weed or other pest species from dominating (Froud-Williams 1988).

During the period 1941–1968, 0.35% of the 7970 years since stabilized agriculture began (Ellis 1992), the greatest advances in chemical weed management were made. This was when the world went to war. A major reason for the significant growth of Australian and US agriculture was the need to compensate for the devastation of food production in areas of the world ravaged by war. The discovery of the herbicidal properties of 2,4-D (2,4-dichlorophenoxy-acetic acid) was linked with the US government's interest in developing tools for chemical warfare (Ellis 1992). Scientists researching 2,4-D and related plant growth hormone analogues were convinced that these chemicals had great potential in agriculture.

There were herbicides before 2,4-D but none were as cheap, as effective, or as selective (Zimdahl 1991). Since then, the international chemical industry has produced a range of increasingly sophisticated herbicides which have been enthusiastically adopted worldwide, especially in industrialized nations (Powles and Holtum 1994). An unfortunate consequence of the outstanding success of herbicides has meant that much research has been invested in this area with other methods of weed management often being neglected.

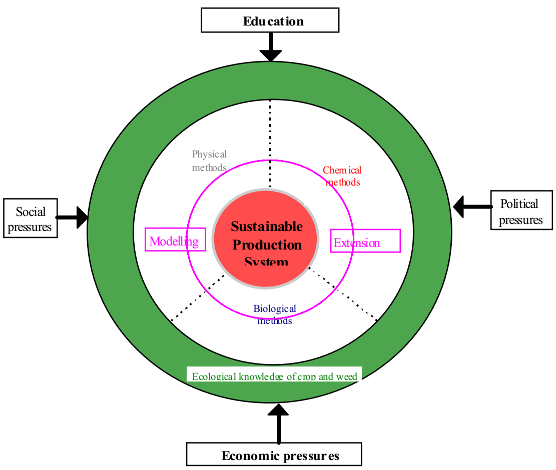

Figure 2. Integrated Weed Management System.

Over the last decade agricultural production systems have been under review. The emphasis of this process has been to change the focus of production processes away from yield maximization and closer to optimization. The challenge, now, is to produce an economically rewarding crop yield while preserving and enhancing local, regional and global environmental sustainability (Swanton and Weise 1991). This philosophical change has culminated in a concept most frequently referred to as 'Sustainable Agriculture'.

Central to this concept is the need to maintain the balance between environmental, economic, social (Kon 1993) and political concerns. Australian initiatives such as Landcare have gone a long way towards addressing some of the issues, as well as increasing public awareness of land degradation and the responsibility of the whole community to address these issues. Emphasis needs to be placed on the better use of the resource base to establish and maintain sustainable land use: cost-effective weed management plays a vital role in this process.

Weeds have always been and, so long as cultivation continues, always will be, an integral part of agricultural systems, and weed management needs to be treated as a component of such systems. Recognising this fact, weed scientists have begun to develop a unique, broad approach to systems management. Recently a reappraisal has been made of traditional methods, to enhance contemporary efforts to combat weeds. Increasing prominence is being given to a combination of methods, a concept known as Integrated Weed Management (IWM).

IWM is a multi-disciplinary approach encompassing chemical, physical, biological and ecological methods of weed management together with effective education and extension of the management components. It operates in an environment where increasingly demanding social, economic and political pressures are exerted (Figure 2).

Each method has its advantages and disadvantages and, usually, no single method is sufficient for an effective weed management program at a reasonable cost.

Historical aspects of various weed management practices and the part each may play in IWM within sustainable production systems are discussed below.

DISCUSSION

Physical management Physical weed management methods include hand weeding, hoeing, mechanical cultivation, mulching, burning, mowing, the use of electricity and solarization. Physical methods expend energy whether human, animal, fossil fuel, electrical and/or solar to disturb, uproot or destroy weeds (Watson 1992).

The most important method in this category is tillage. Throughout agricultural history tillage has been inextricably linked with weed management. In all its forms, tillage has three possible functions regarding weeds: to animate propagules, to kill emerged weeds prior to growing the crop, or to kill plants within a crop (Medd 1987).

By the end of the 1980s, the availability of selective herbicides and the development of pulse crops had allowed the development of new farming systems which approach crop and pasture management from a viewpoint of the total system and consider the benefits, or otherwise, of the system over several years rather than on the basis of a single season.

Minimum tillage, direct drilling and zero tillage are practices which fall into this category. Aimed primarily at soil conservation they also facilitate weed management. Cultivation to kill weeds in a fallow and to produce a fine seed bed is often damaging to soil structure. When the soil is dry cultivation can exacerbate susceptibility to rain and wind erosion. Implements can be altered to allow sowing into stubble and more compacted seed beds, and herbicides can largely replace cultivation for weed control. However, changes in the weed flora follow all changes in land management. Reduced tillage is likely to result in a move towards weed species which were previously managed by tillage. These may include perennial weeds and some annual grasses which were not previously regarded as weeds. Such plants will have to be managed by different chemicals aided, most likely, by periodic cultivation of the soil.

The non-selective and non-residual desiccant herbicides, paraquat and diquat, were developed in the 1950s. They were first sold as Spray Seed™ in 1972 and were the catalyst for the minimum tillage revolution. The rapid acceptance of crop establishment via minimum tillage and the dependence on knock-down herbicides was promoted by the introduction of diclofop (Hoegrass™) in 1978; the sulfonylurea herbicide, chlorosulfuron (Glean™) in 1982 for ryegrass (*Lolium rigidum* Gaud.) control, and the use of a mixture of diuron with 2-methyl-4-chlorophenoxy-acetic acid (MCPA) or 2,4-D for cheap and effective in-crop broad-leaved weed control.

Weed science has provided the vital key (adequate weed management) which has enabled these conservation tillage practices. USDA scientists have predicted that by 2010 more than 90% of the crop area in the United States will be grown with conservation tillage systems and that on more than half of the acreage some form of no-tillage farming will be practiced (Burnside 1987).

Reduced cultivation presents challenges to weed science since traditional options for managing weeds are not adaptable to conservation farming techniques. For example, there are less opportunities to stimulate weed emergence using cultivation, there is an inability to use incorporated pre-emergence herbicides in some systems, and direct drilled crops may be less competitive (Medd 1987). Containment of weed populations will be more difficult and will require greater inputs because of heavier reliance on in-crop control with conservation farming.

Ecological management Detailed reviews of ecological and biological studies and the part they play in weed management strategies have been reported at previous conferences (Briese 1993, Norris 1992). Historically, weed biology and ecology research has been directed towards understanding phenomena relevant to herbicide-based strategies. The predominance of herbicide studies in international journals, such as Weed Research, during the late 1980s resulted in a push by the European weed science community to increasingly emphasize weed biology.

In cropping, pasture and, especially, natural ecosystems the key to development of effective IWM systems lies in understanding the ecology and population dynamics of target weeds. Knowledge of reproductive, recruitment and survival mechanisms is essential to understanding the growth and life-cycle of weeds to identify the appropriate IWM system. The development of population dynamics models will be critical for successful IWM systems. This is most relevant in pasture systems, which are complex. In these situations a multi-species, systems approach should be much more effective than targeting individual weeds (Kemp 1996).

Important areas of weed ecology that need to be considered are:

Taxonomy and weed identification This is critical if the appropriate management strategy is going to be adopted. The large number of books on weed identification in all regions of the world is testimony to its importance. An example is the recently released farmer guide 'Weeds: The ute guide' (Cummins and Moerkerk 1996).

Competition and interference The different competitive abilities of crops have been inadequately studied (Medd 1987) and it is predicted that there will be much more emphasis on this in the future (Sheppard personal communication).

For example, the competitive ability of wheat (*Triticum aestivum* L.) varieties grown in Australia since early this century has gradually been eroded. This has occurred, mainly, over the last three decades and has been associated with increases in yield potential and more effective and widely used herbicides. Australia's more competitive, older, cultivars have been gradually replaced by wheats developed, initially, for high input irrigated environments where chemical weed management is practiced. The major trend in Australian varieties since Farrer has been towards cultivars that flower earlier, produce fewer tillers, are shorter, have shorter coleoptiles and emerge more slowly, and also develop leaf area more slowly. All of these characteristics result in Australian wheats being less competitive.

Recent developments in the area of crop establishment and increasing competition between crop plants and weeds include improving the early vigour of Australian wheat. Not only is a more vigorous crop better able to compete with weeds but high early vigour benefits a growing crop through improvement of its water-use efficiency and reduced reliance on herbicides (Rebetzke and Richards 1996). Research being conducted at Wagga Wagga and Roseworthy is assessing potentially more competitive wheat germplasm. Subsequent cultivars could become invaluable IWM tools.

A similar approach is also being adopted in pasture systems where more persistent cultivars, which can suppress most weeds so long as fertility and management are adequate, are being grown (Kemp 1996). The dynamics of species mixtures in pastures are only just starting to be explored (Leys 1990) and more emphasis needs to be centred on this aspect.

Allelopathy Allelopathy is interference (*sensu* Harper 1977) between plants, mediated by chemicals released from at least one of the species concerned (Norris 1992). The compounds concerned may be alkaloids, terpenes and steroids, flavanoids, toxic gases, organic acids and aldehydes, aromatic acids, simple saturated lactones, and tannins. All living plants produce secondary metabolites which may act as allelochemicals. Decomposing plant residues also provide bioactive compounds, which may be of the residues or may be produced by micro-organisms during decomposition.

While the number of workers on allelopathy in Australia has been small the range of reported examples, in native and introduced plant species, is large (Lovett 1986, 1989).

Allelopathy in crop plants can contribute to their ability to interfere with weeds. Niemeyer *et al.* (1992) have demonstrated allelopathy in wheat, stemming from hydroxamic acids, whilst in barley (*Hordeum vulgare* L.), the alkaloids gramine and hordenine confer heritable ‘self defence’ capabilities against other plants (Lovett and Hoult 1992). Subsequent work has demonstrated that these compounds have inhibitory effects on fungi, insects, mice and chickens, that is, they are biocides of broad activity.

Practically, allelopathy affords the opportunity for plant breeders to manipulate a trait which could lead to a reduced need to apply pesticides to crops; reduce the risk of development of resistance to pesticides, and contribute an extra dimension to plant interference in the context of crop rotations.

More immediately, the work of Kimber (1967) in Western Australia demonstrated the potential of crop residues to inhibit subsequent plant growth. Residues are susceptible to manipulation by farmers. Experience in Australia has shown that rapid, aerobic decomposition minimizes the risk period for succeeding crops.

Rotations The build-up of weeds in continuous cropping frequently necessitates a change in land-use, either by rotating with a break crop or by introducing a pasture phase (Medd 1987). Use of a break crop also permits a rotation of herbicides. Another option is to rotate crops having different growing seasons. Crop rotations are designed as management measures against weeds, diseases and insects and as a means of retaining and building up soil fertility and structure to produce increased yields. The use of pastures within rotations also presents an opportunity for the weeds to be grazed out of paddocks.

The development of herbicide resistance in some pasture species which also pose significant problems as crop weeds, for example, ryegrass has meant that longer term viability of chemical management, in crop, is doubtful. The use of integrated strategies will help extend the life of selective herbicides and may contribute to increased legume production. Long term studies on a range of non-chemical and chemical weed management measures in pasture/crop rotations are necessary to glean important information on weed seed bank numbers and weed dynamics. For example, the effect and timing of practices such as seed set control (spray-topping) and minimum tillage on both pastures and weeds needs to be determined. The use of crops with enhanced capacity to ‘interfere’ within rotations, also needs to be considered.

Examples of such rotational work in crops and pastures and the use of competitive wheats in wheat-pulse rotations to control brome grass (*Bromus* spp.) are underway at Agriculture WA.

Basic weed ecological data Very few weeds have been studied systematically in any crop or pasture, or on a national basis, in Australia. Cousens and Medd (1994) state that, although considerable data on weed management exists for most problematic weeds, there is little ecological information. They argue that the paucity of such basic knowledge is hampering efforts to develop ecologically sound strategies for weed management.

Additional data are required on the biochemistry, physiology and population dynamics of weeds, including:

- yield reductions caused by weeds in crops, especially crops other than wheat,
- manipulation of crop seeding rates as a management tool in a range of environments, and
- comparative studies of the growth and development of weeds and crops in a range of environments.

Better understanding of the ecology of weeds will help to identify critical phases in which they may be targeted by particular management strategies.

Biological control The concept of biological control developed from observations by early naturalists and agriculturalists (Harley and Forno 1992). In weed science it usually refers to weed management by insects or microorganisms. Biological methods include the classical (inoculative) approach, the bioherbicide (inundative) approach and herbivore management. It has limited application for weeds of cultivated crops because, typically, only one weed of a complex is addressed; it is difficult to maintain the population of an agent in a disturbed environment, and the level of control achieved may not be adequate or timely (Watson 1992). For these reasons, bioherbicides may represent the best option for biocontrol in cultivated crops.

The chances of successful establishment of released phytophages and subsequent control of invasive plants has changed little in the 197 years since the scale insect *Dactylopus ceylonicus* was used to control an alien prickly pear cactus (*Opuntia* spp.) in India (Sheppard 1992). The agent introduction rate has not increased much since the late 1960s, but the relative success rate over this period has never exceeded pre-1950s levels. Nonetheless, this non-chemical form of pest management is continuing to attract attention.

An example is the control of skeleton weed (*Chondrilla juncea* L.) by the rust *Puccinia chondrillina*. Strain IT32 of the rust was introduced and released in 1971 and was successful in controlling the narrow leaf, or form A, of the weed. However, there are three apomictic forms of the weed in Australia and the intermediate and broad leaved forms have steadily increased in distribution and economic importance. Recently, CSIRO researchers have introduced another strain of the rust from Turkey, virulent to the intermediate form of the weed, it was released in June 1996 near Swan Hill.

Current biological control research underway at CSIRO is addressing the reduction of the incidence of doublegee (*Emex australis* Steinh.) and lesser jack (*E. spinosa* L. Campd.) in southern Australia by the collection, importation, testing, quarantine and release of potential biological control agents known from lesser jack in Israel and Morocco. The aphid *Brachycaudus rumexicolens* has been identified as the main cause of 'doublegee decline'; weevils and sawflies are also being considered.

A control program for Paterson's curse (*Echium plantagineum* L.) employing the root-crown weevil (*Mogulones larvatus* Schultze) is underway at a release site near Yanco.

The use of endemic micro-organisms for bioherbicidal management of weeds is relatively new to Australia. The potential needs to be explored of using ultra-low dose rates of herbicides, to act as metabolic inhibitors of host defence, and synergistically combined with micro-organisms for weed control as part of an integrated weed management system.

Grazing animals are widely used as biological control agents, mainly in systems supporting crop/pasture and animal species in rotations (Popay and Field 1992). Weed control by animals can be further enhanced by application of sub-lethal herbicide rates which make weeds more palatable, so that they are killed by grazing rather than by the herbicide. This technique is known as 'spray-grazing'.

Chemical management Herbicide-based programs dominated weed science from the late 1940s to the 1980s (Norris 1992). Such a reliance on use of chemicals for pest management gave rise to what Zimdahl (1991) has termed the 'Pesticide Paradigm', the single minded, unquestioning devotion to pesticides as the appropriate cure for all pest problems.

The use of chemicals for weed management dates back to the last century when copper sulphate, a constituent of the Bordeaux mixture used in vineyards, was found to kill some of the weeds present between the vines (Watson and More 1956). Prior to World War II copper sulphate, kainit and, later, copper chloride, sulphuric acid and a number of other substances were used for the control of weeds in cereal crops. Sodium chlorate and arsenic compounds were used on gravel paths and patches of land where all vegetation was intended to be killed.

Herbicides are available in different physical forms and chemical composition varies widely. Herbicides may or may not be selective and their length of activity is also variable; they may be used at pre-emergence or post-emergence of weeds. The use of selective herbicides started in the middle of the 1930s when experiments were being carried out with DNC (Dinitro-ortho-cresol), but it was not until 1941 that 2,4-D was developed in America (Auld *et al*. 1987); the following year MCPA was developed in England. The former was first used in field weed control in 1944. The range of selective herbicides has increased greatly since the 1940s and is still expanding.

An increasing number of both pre-emergent and post-emergent herbicides came into the market from the early 1970s and allowed farmers to intensify cropping while reducing the hazard of erosion in cultivated soils (McLean and Evans 1996).

Herbicide use, albeit in a different context, increased rapidly in the 1980s due to the widespread adoption of conservation tillage practices in extensive cropping systems. This technology has led to shorter rotations and an increase in the amount of land sown to crops, to the point that it has been suggested that sustainable limits to cropping in Australia may have been reached or possibly exceeded (Evans personal communication). Problems of particular concern include declining soil fertility, the emergence of herbicide resistant weeds and the effects on the environment of herbicide usage. These, together with human health and trade issues, have provoked a necessary change in philosophy to the usage of herbicides.

Herbicide resistant weeds In 1956 Harper posed the question “how long before those weeds, at present susceptible to control by herbicides, become resistant?” At the time he was able to quote two examples only, both involving intra-specific resistance to 2,4-D (Froud-Williams 1988). Subsequent recognition of herbicide resistance in the northern hemisphere, where agriculture has embraced pesticides to a greater extent than has been common in Australia, was found by the identification of resistance to triazine in *Senecio vulgaris* L. by Ryan in 1970.

Within a population of weeds there may be a few individual plants that are able to resist the action of herbicides that have a certain mode of action. Those plants that survive may be insignificant in number but set seed and propagate the next year. Repeated use of the same herbicide, or other herbicides with the same mode of action, can result in the development of a resistant population of weeds and consequent herbicide failure. A dramatic example of this is the development of herbicide resistant annual ryegrass a weed widespread across areas of intensive crop production in the southern Australian cereal and pulse crop production areas. This has developed due to consistent selective herbicide application (Powles and Howat 1990). Ryegrass biotypes can be simultaneously resistant to herbicides from many, diverse chemistries (Roush and Powles in press) and, most recently, a biotype has been found with suspected resistance to glyphosate (New Scientist 1996).

The recognition of herbicide resistance has initiated both a re-classification of herbicides and, together with rising concern about the sustainability of agricultural systems, a re-assessment of how they are used.

Herbicides are now being grouped according to their mode of action. Rotating between different herbicide groups is one of the keys to preventing or delaying resistance. Plants surviving treatment from one group of herbicides will, more than likely, be killed by treatment with a herbicide from another group.

Australia has achieved a world first in this classification drive. Consultation between the industry Australian Herbicide Resistance Action Committee (AHRAC), the multinational herbicide producers and the Australian distributor networks is achieving this classification drive to provide more information to farmers. This interaction will yield a major advance for resistance management in Australia. AHRAC have been able to convince their members to support this move. The Australian government, through the National Registration Authority, has now mandated that all herbicides sold in Australia from 1 January 1996 must bear a large alphabetical symbol clearly designating the herbicide mode of action. Thus, all herbicides from Group A work in the same manner, all herbicides in Group B work in the same manner and so on.

The system is ‘user-friendly’ as the user only needs to recognise and record that an alphabetical symbol indicates a different mode of action. The introduction of this system in Australia was accompanied by a wide ranging extension program to educate growers and advisers. A numerical system has been introduced in Canada, but is not mandatory, and other countries, such as USA, are at various stages in developing systems. The agrochemical industry’s Herbicide Resistance Action Committee (HRAC) is now progressing the development of a single, uniform, accurate set of guidelines to be introduced globally, based on the Australian system.

There is also scope for reducing pesticide use in Australian agriculture through farmer education directed at improving the adoption of current best practice in herbicide application technology. This includes the selection and use of machinery, timeliness of applications and reductions in unnecessary applications (Evans 1994). Dose-response relationships have yet to be exploited, especially in pasture systems.

Adoption of Precision Farming practices may improve the efficacy of herbicide use. Australia lead the way with an early example of this in the form of the WASP (Weed Activated Spray Process), a spray system able to detect and spray weeds in fallows, developed by NSW Agriculture. Researchers at Charles Sturt University are using infra-red aerial photography to aid in identifying plants by their thermal signature. This is useful in determining nutrient status and determining herbicide resistant plants after spraying. The USA, through the adoption of Geographic Information Systems, is now at the forefront in this technology.

These techniques and their role in IWM systems, together with grazing, fertilizers and biocontrol deserve the highest priority in further development.

Environmental and health issues In the last decade there has been mounting public concern about the effect of herbicides both on the environment and on public health. These include the effects of herbicides in surface and ground water, spray drift, the long term impact of herbicide persistence in soil and effects on non-target organisms and herbicide residues in agricultural products. This has led governments in Sweden, Denmark and the Netherlands to pass legislation setting specific targets for pesticide reduction (Evans 1994). These actions are now part of a broader international movement to promote the adoption of more sustainable crop production and protection methods. Many other countries are now developing strategies to encourage the adoption of integrated pest management and other integrated crop protection techniques. For example the USA has pledged that by the year 2000, 75% of American land will be under IPM systems (see Evans 1996 these proceedings).

Trade issues The global marketplace is becoming increasingly competitive and mounting pressure is being placed on producers in the production of export goods. Concerns about food quality has led to demands for high quality food commodities with low residue status (Rowland personal communication). Freeing up of world trade has been foreshadowed by the conclusion of the Uruguay round of the General Agreement on Tariffs and Trade but the potential remains for both pesticide and herbicide residues to be used as non-tariff trade barriers.

Eco-labelling of produce including Australia's 'Clean-Green' label, is becoming increasingly common in many countries. If Australia is to maintain its edge in this market, it needs to seriously address its use of pesticides and IWM practices are critical to this.

Genetically engineered herbicide resistant crops Several crop plants show inherent tolerance to selective herbicides, thereby permitting the use of these compounds for weed management without significant effects on the crop plant itself. The molecular basis for natural herbicide selectivity can be traced, most often, to one of four possible biochemical mechanisms: herbicide detoxification, target enzyme insensitivity or lack of herbicide uptake/translocation (Kishore *et al.* 1992) or an excess capacity to maintain chemical processes that would be damaged by otherwise injurious doses of the compound. These mechanisms have enabled the genetic engineering of herbicide resistant plants which are one of the most recent refinements in the existing technology to control weeds (Radosevich *et al*. 1992).

Both the non-selective herbicides Roundup™ and Basta™ are very acceptable from an efficacy and environmental viewpoint. Their wide spectrum activity on weed species means that they could be transformed into selective herbicides if resistant genes could be expressed in crop species. Roundup Ready herbicide resistant soybeans (*Glycine max* L. Merril), cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), canola (*Brassica napus* L.) and sugarbeet (*Beta vulgaris* L.) are being grown in significant quantities in North America and Western Europe. They stand to be more widely adopted in these countries, as compared to Australia, due to the nature of the crops and rotations grown (Powles personal communication). Similarly, a range of Basta herbicide resistant crops is being developed commercially.

In Australia, Roundup Ready cotton and Basta resistant lupins are at an advanced stage. Permission has recently been given by the Genetic Manipulation Advisory Committee (GMAC) for a program of field trials throughout Australia to test a genetically modified canola which is tolerant to the herbicide glufosinate ammonium. Several other genetically engineered crops are due onto the markets in the near future (Table 1).

There has been considerable controversy surrounding the development of herbicide-resistant crops. For some crop species there is potential for the herbicide resistant gene to flow to close relatives by inter-pollination. Herbicide resistant oats (*Avena sativa* L.) will probably not be developed for this reason, and the production of herbicide resistant canola is a concern as it is an outcrossing species and potential exists for herbicide resistant genes to introgress with weedy relatives. Others have criticized this technology for encouraging the use of chemicals, however, chemicals provide the most cost-effective means of weed management and the use of such

Table 1. Release of genetically-engineered crops (adapted from Gray 1996).

Company	Product	Year of release
Ciba Geigy, AgrEvo	Herbicide resistant soybean, corn, canola	1995, 1997, 1998
Dekalb Genetics	Herbicide resistant soybean, corn	1996, 1997
Pioneer Hi-Bred International	Herbicide resistant soybean, canola	1996, 1996–97
Monsanto	Roundup-Ready soybeans, canola, cotton, corn, beets	1998–2000^{+}

plants should promote the use of high quality herbicides. It is vitally important that herbicide resistant crops are not seen as a panacea for management of herbicide-resistant weeds but, rather, as a trigger for the introduction of excellent, new mode of action herbicides. These herbicides and the transgenic herbicide resistant crops must themselves be used as part of an IWM strategy (Powles *et al.* in press)

Integrated Weed Management The development of IWM systems is a complex task and must be supported by thorough understanding of its components, which may combine several or all of the foregoing approaches. Profitability of cropping is reduced by weeds primarily as a consequence of yield losses incurred through competition (Medd 1987). This is often the sole motivating reason for expenditure on weed management. In order to decide how much to spend it is necessary to forecast the likely loss of crop yield. Economic models can assist weed scientists and farmers in decision making.

Modelling Computer models can integrate available information and predict the outcome of crop-weed relationships. Modelling of competition and population dynamics is being used to develop thresholds and is also being developed to assist in predicting the spread of weeds. These types of modelling exercises also serve a function of forcing synthesis of existing knowledge and are useful for indicating areas in which our weed knowledge is lacking (Norris 1992). The potential application of computer modelling in weed science presents a more analytical approach to weed management.

Formation of the CRC for Weed Management Systems (CWMS) The formation of the CWMS has, for the first time, provided Australia with an on-going forum for research and education into IWM methods. A concept noted by American scientists as being an excellent environment for weed science work (Worsham 1994), the Australian CWMS is the first in the world. It provides the framework to draw together weed scientists from different disciplines and enables them to work in an integrated environment.

Established in response to the growing concern about the effect weeds are having on the Australian economy, the CWMS officially began life on 1 July 1995. It was anticipated that the CWMS would develop systems that might conservatively result in a 10% reduction in weed associated losses, saving over $A300 million per year and, at the same time, protecting Australia's unique flora and fauna for future generations.

The CWMS aims to bring together expertise in weed management, incorporating research areas such as biological control and herbicide technology; it is already the major centre of herbicide resistance research, vegetation management, bioherbicides, population and economic modelling, decision support, weed ecology and population dynamics.

The three core participants in the CRC are University of Adelaide (CRC headquarters), CSIRO Division of Entomology and NSW Agriculture. The other official participating organizations are: Department of Natural Resources and Environment (Victoria): CSIRO Division of Plant Industry; Agriculture Western Australia; University of New England; Charles Sturt University; Grains Research and Development Corporation, and the National Association for Crop Protection and Animal Health, Avcare Ltd. The formation of the CWMS has provided a significant boost in funding to the tune of $A2.2 million per year for the initial seven years of its existence.

The mission of the CWMS is to:

- raise the level of awareness, knowledge and adoption of weed management systems by practitioners, land managers and the wider community; and
- increase sustainability of agriculture and protect the natural environment by developing ecologically sound, cost-effective weed management systems.

Although the CWMS's research activities will concentrate on weeds of temperate Australia, the benefits will have an effect on the entire country. It is anticipated that many other organizations and groups will become involved in the CWMS.

Three research programs in the CWMS are based around annual agro-ecosystems, perennial pasture ecosystems and natural ecosystems. Several key weed species have been targeted for study including ryegrass, wild oats, spiny emex, wild radish (*Raphanus raphanistrum* L.), vulpia (*Vulpia* spp.), Paterson's curse, Bathurst burr (*Xanthium spinosum* L.) and thistles (*Carduus* spp., *Onopordium* spp., *Carthamus* spp.) from the agricultural ecosystems, and bitou bush (*Chrysanthemoides monilifera* ssp. *rotundata* (DC.) T.Norl.), blackberry (*Rubus fruticosus* L. s.lat.), bridal creeper (*Asparagus asparagoides* L.), St. John's wort (*Hypericum perforatum* L.), horehound (*Marrubium vulgare* L.) and Scotch broom (*Cytisus scoparius* L.) from natural ecosystems.

The inception of this CRC increased communication between weed scientists across Australia, drawing them together in a way not previously achieved. In addition the CWMS has instigated specific workshops on particular issues to pinpoint research needs. Recognition of the organization and the provision of funds has enabled it to attract Honours students, PhD students and post-doctoral students. Thus far 11 Honours students have commenced studies, 13 new PhD students have started research projects in CRC laboratories across Australia and several post-doctoral positions are being filled. This ongoing education of scientists involved in weed research is essential in addressing weed problems across Australia.

Investment in weed science The Commonwealth Government has acknowledged the significant impact that weeds have on managed and natural ecosystems. Under the umbrella of nationally agreed priorities and funding arrangements the Coalition will work with the States, local Government, Landcare groups and other interested parties to finalize and implement a National Weeds Strategy. To this end the Government, pending the sale of Telstra, will provide $19 million over five years towards management of major noxious weed species identified as being of national ecological and economic importance.

Prior to the election of the present government, state departments of agriculture have been reducing their core-funded research and relying more heavily on investment by Research and Development Corporations (Cousens and Medd 1994). Evidence of this is the fact that the Grains Research and Development Corporation will invest $A3.29 million in weed management in 1996–97 compared with $A1.7 million in 1994–95.

The aim of the GRDC weed management program is to reduce the impact of weeds on farm productivity and profitability by developing sustainable management programs which optimize the integration of all cost effective measures, including chemical, physical, biological and ecological approaches.

Program objectives over the next few years include the following:

- Development, validation and demonstration of improved IWM packages for major weeds and in support of major farming systems. The work will incorporate best practice herbicide use, seeking to minimize chemical inputs where practicable in support of the 'Clean-Green' image of Australian traded grain, along with a variety of non-chemical measures, including:
  - management in rotational crops/pastures,
  - seed bank minimization by spray-topping and seed-catching, etc.,
  - crop management, including time of sowing, cultivar competitiveness, allelopathy, etc.,
  - bio-control, and
  - herbicide-resistant crops.
- Enhanced understanding of the ecology of problem weeds and development of IWM strategies to reduce 'problem' status and to manage effectively in key farming systems. This should be in association with monitoring for early signs of weed problems emerging as a result of herbicide resistance or for other reasons (especially in new crops or changing farming systems), to ensure that solutions are available ahead of the situation getting out of hand.
- Better fundamental knowledge of the biological/ecological activity, degradation and movement of residual herbicides in soil and development of acceptable use patterns that support the continued registration of important products, but minimize and eliminate, where possible, adverse non-target effects.
- A continuous improvement program of research, development and extension to ensure that herbicides are used appropriately to reduce the impact of herbicide-resistant weeds and to minimize risks in occupational exposure of users, of adverse environmental effects and of chemical residues exceeding Minimum Residue Levels (MRL) on harvested produce.

The GRDC has invested in further proposals to support sustainable weed management, in particular, economic research into the cost of long term management strategies to reduce weeds in crops/pasture rotations, and education programs for training into efficient weed control programs by agribusiness and consultants.

As the GRDC is a key partner in the CWMS this will provide a strong focus for future investment, nationally and regionally, ensuring the necessary cross-disciplinary approach to weed science which is essential to the successful development of IWM systems.

CONCLUSION

Since the late 1940s, weed control practices in crops have placed less emphasis on mechanical methods in favour of a heavier reliance on the single, cost effective and attractive option of herbicides. Systems developed became over-dependent on herbicides in the 1980s and resulted in the appearance of herbicide resistant plants. Pressure to develop more environmentally safe weed management methods, together with herbicide related concerns, has lead to a reappraisal of weed management systems, in other words, complex answers to complex problems.

If weed management strategies are to be enhanced and made more efficient, much greater emphasis needs to be placed on developing multidisciplinary approaches through IWM systems. The challenge now is to optimize combinations of physical, chemical, biological and ecological methods and to be original and imaginative in approaches to combat weed problems.

Ultimately, the future of weed science resides in the weed scientists being trained today. We need to recruit the best and the brightest and provide a good learning atmosphere, because these students are the future practitioners, researchers and teachers of our disciplines.

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Here follow 26 countries where weed is, if not legal, at least super chill and legal-ish. Recommended Video. Travel.Â You may rely on it I love Cambodia for many reasons, but among them is that you can go out to a restaurant and see a dish or menu marked â€œHappyâ€ and know that itâ€™s likely been infused with something â€¦ fun. Weed is still illegal here, but itâ€™s culturally accepted, ubiquitous, and cheap. LAOS. Should you smoke here? The most expensive weed in the world, according to the study, is in Tokyo, where a gram sells for approximately $32.66. To determine the price per gram, the study's authors conducted surveys at the local level, adjusting their findings with statistics obtained from the 2017 World Drug Report by the UNODC. These averages may be outdatedâ€"the price of weed in any given city on any given day obviously depends on the quality and whims of a dealer, among other things. For example, in BogotÃ¡, Colombia, we know from experience that you can buy a gram of weed for 2,000 Colombian pesos ($0.70 USD), Yes, weed is going to space thanks to the work of a small Lexington, Ky.-based startup called Space Tango. The company makes a â€œclean [â€¦]Â Scientists interested in cannabis as a subject for pharmaceutical studies may find an unlikely new home for their research into the plant, its byproducts and biochemistry aboard the International Space Station. Yes, weed is going to space thanks to the work of a small Lexington, Ky.-based startup called Space Tango . The company makes a â€œclean roomâ€ laboratory in a microwave-sized box. Because space is tight on the International Space Station, companies that want to conduct experiments in microgravity have to do more with less. And Space Tango gives them a small environment in which to perform