Integrated Weed Management in Australian cropping systems

A training resource for farm advisors

iWM in control

CRC Weed management

Cooperative Research Centre for Australian Weed Management

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Front cover: *Regular paddock monitoring and consultation with your agronomist are key aspects of developing and implementing an IWM plan. Peter Rogan of 'Fairview' talks to his agronomist, Derek Gunn, NSW.*
Photos: Andrew Storrie and Warwick Holding

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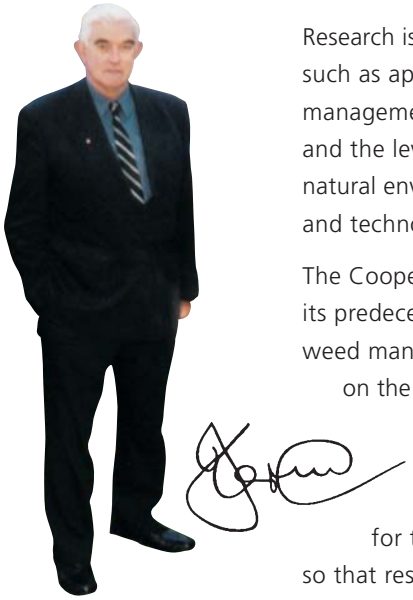
Foreword



Research is iterative, challenging, exciting and tedious, regardless of any other descriptors such as applied, basic and pure that might be used to describe it. In the case of weed management in Australia, the challenge is of a long-term nature, progress is often slow and the level of infestation in Australia is intimidating. The cost to agriculture and the natural environment is enormous and progress depends on how we build up our scientific and technological expertise and engage with land managers.

The Cooperative Research Centre for Australian Weed Management (Weeds CRC) and its predecessor CRC have now assembled some 11 years of collaborative research into weed management in our cropping industries. Of course, the research of the CRC builds on the research work and experience of generations and partner organisations at both national and state levels, which have all been part of a large network of research and extension people. The state of weed science at tertiary level and the funding of agriculture by governments meant that it was essential for there to be a cooperating and collaborating body, such as the Weeds CRC, so that research effort could be concentrated and priorities set.

This integrated weed management (IWM) manual presents the most up-to-date compilation on integrated weed management for cropping. However, much of the information will also inform other land managers about the realities of weed science and where most progress may be made in weed management and control.

At researcher, technician and communication levels, the Weeds CRC is very much aware of the commercial realities of the cropping industries, and that adoption and integration of many techniques may be difficult for individual land managers due to a raft of reasons. Scientific 'breakthroughs' or newly found approaches are not necessarily easy to develop, apply and communicate. The Board of the Weeds CRC is mindful that the presentation of the results of our research must be user-friendly and practical.

This manual traverses the economics of IWM, presenting case studies to demonstrate the gains that can be made. The perplexing issue of short-term profit versus long-term returns is discussed. A detailed section on herbicide resistance, the driving force for the widespread adoption of IWM, is succinctly presented. The reintroduction of indiscriminate cultivation to control weeds on our relatively fragile soils would result in increased land degradation; again, the manual outlines some case studies in this area of research, presenting a rationale for the use of strategic cultivation. The more pertinent aspects of agronomy are detailed and should enhance and reinforce the on-farm knowledge of farmers. The range of tactics that farmers may use to manage weed populations is presented, and not just the control of weeds for yield, followed by a section on practical implementation. Australia's 20 most important cropping weeds are profiled, with easily digested information on how to manage them. Case studies are included to show agronomists and farmers how the tactics and strategies in this manual work for farmers.

I trust that this compilation will be of widespread use and interest. The Weeds CRC will appreciate ideas and feedback on any ways in which this manual can be made more comprehensive or accurate.

The Hon John Kerin
Chair of the Board
CRC for Australian Weed Management

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Key findings

Section 1: Economic benefits of adopting IWM

The economic benefits of adopting integrated weed management

Key finding #1

Weed seed carryover in the soil seedbank has a huge impact on returns in future years.

Key finding #2

Calculating returns over the long term (eg 10 years) is the best approach for determining the value of the economic benefits of IWM.

Estimating the economic benefits and costs of IWM

Key finding #1

Herbicides are the most cost-effective weed management option, providing the most reliable weed control.

Estimating the economic benefits of IWM using simulation models

Simulation model 1: Dynamic optimisation model

Key finding #1

The dynamic optimisation model (with a limited number of IWM tactics included) suggests that including non-chemical IWM options has economic value only for the 'with resistance' case.

Simulation model 2: Combining a range of IWM tactics targeting annual ryegrass

Key finding #1

A strategy which integrated six different tactics provided the highest net present value according to the simulation model developed by Schmidt and Pannell (1996).

Key finding #2

Growers who wish to remain in a continuous cropping system must include a wide range of weed control methods as no single method provides the optimal solution.

Simulation model 3: RIM model – herbicide resistance, annual ryegrass and IWM

Key finding #1

The benefits of IWM extend beyond herbicide resistance management, also applying to the case of long-term weed population management.

Simulation model 4: Multi-species (annual ryegrass and wild radish) RIM model

Key finding #1

The most promising of the strategies examined appeared to be 3 years of pasture ('phase farming' in Western Australia) rather than the more commonly practised 1 year of pasture between crops.

Simulation model 5: Multi-species (annual ryegrass and wild radish) RIM model and GM glyphosate-resistant canola crop

Key finding #1

The value of glyphosate-resistant canola as a break crop to manage weeds is significantly higher than that of triazine-resistant canola, which currently dominates Western Australian plantings.

Key finding #2

The glyphosate-resistant canola technology package needs to be highly effective in order for its use to be justified in the management of annual ryegrass and wild radish infestations.

Simulation model 6: WeedRisk model – inclusion of variability and uncertainty

Key finding #1

Given that IWM aims to spread the risk of control failure and increase the probability of success, and because integrated weed control options are mutually supportive, ignoring risk may undervalue some control practices.

Key finding #2

IWM options that target the seedbank recruitment stage of the weed life cycle (Tactic Group 3) had the greatest impact in terms of reducing the size of seedbanks.

Key finding #3

The benefit of the IWM scenario was largely attributable to options that reduced replenishment of the seedbank (eg crop-topping, selective spray-topping) as they were able to compensate for years of failure of post-emergent herbicides due to adverse seasonal conditions.

Key finding #4

The economic returns averaged over a 20-year period for IWM are greater than for non-IWM in all cases, usually by a considerable margin, primarily due to lower seedbank numbers in IWM systems.

Key benefits and practicalities

Section 3: Agronomy to enhance the implementation and benefits of weed management tactics

Agronomy 1 Crop choice and sequence

Crop sequencing to minimise soil- and stubble-borne disease and nematodes

Key benefit

#1 Crops with dense canopies act as more effective break crops.

Key practicalities

#1 Selecting sound crop sequences and varieties to deal with the significant pathogens and nematodes of the paddock in question is good management.

#2 Weeds are alternate hosts to some pathogens. Effective integrated weed management (IWM) during the fallow and in-crop can reduce disease pressure.

#3 *Rhizoctonia* can affect seedling crop growth, leaving the crop at greater threat from weed competition.

#4 Weeds can increase moisture stress within a wheat crop, exacerbating yield loss from crown rot.

Agronomy 2 Improving crop competition

Crop type

Key benefit

#1 A competitive crop improves weed control by reducing weed biomass and seed-set.

Sowing rate

Key benefits

#1 High crop sowing rates reduce weed biomass and weed seed production.

#2 Crop yield and grain quality may improve with increased sowing rates while benefiting weed control.

Key practicality

#1 If using higher sowing rates to improve competitive ability of a crop, remember to optimise the sowing rate for grain yield and quality potential.

Row spacing

Key benefit

#1 Increasing crop density increases weed suppression. In cereals higher crop densities can achieve further suppression if narrower row spacings are used.

Key practicality

#1 It is important to match row spacing and sowing rate to obtain crop plant densities that are optimal for both yield and competition against weeds.

Sowing depth

Key benefit

#1 Sowing depth can be used to enhance crop competitive ability.

Key practicalities

#1 Use furrow sowing or moisture seeking techniques at sowing to establish the crop before the weeds.

#2 Take care to sow seed at optimum depth.

Sowing time

Key benefit

#1 Sowing at the recommended time for the crop type and variety will maximise the competitive ability of the crop, which will in turn will reduce weed biomass and seed-set.

Key practicalities

#1 When using delayed sowing to allow for control of the first germination of weeds, choose the crop type and variety most suited to later sowing to minimise yield loss.

#2 Sow problem weedy paddocks last to allow a good weed germination and subsequent kill prior to sowing.

Soil properties

Key benefit

#1 Matching the crop (and variety) to the soil type can improve crop vigour and biomass production, which in turn will optimise crop competitive ability.

Fertiliser use and placement

Key benefit

#1 Matching fertiliser inputs of both macro- and micro nutrients to crop target yield and quality will maximise the crop's competitive ability against weeds.

Key practicality

#1 Fertiliser placement can improve crop growth, yield and competitive ability.

Disease and insect management

Key benefit

#1 Preventing and/or controlling crop disease and insect damage maximises crop health and competitive ability, avoiding blow-outs in weed seed production.

Key practicalities

#1 Monitor crop health and control pests and diseases.

#2 Areas of crop death (or weakness) become a haven for weeds to proliferate.

Agronomy 3 Herbicide tolerant crops

Key benefit

#1 Herbicide tolerant crops provide additional crop choice, enabling implementation of alternative weed management tactics to target specific weeds while maintaining crop sequences.

Key practicalities

#1 Always use HT crops within an IWM framework.

#2 Ensure the user is aware of, and adheres to, stewardship agreement restrictions placed on the 'frequency of use' of herbicides within MOA groups.

#3 Always control HT crop volunteers in the following season, and minimise the risk of spread of HT crop seed.

#4 Adhere to all herbicide label directions.

#5 Good paddock management records must be kept and referred to. Mistakes are costly if a herbicide is applied to the wrong crop.

#6 Use agronomic practices to minimise out-crossing (hybridisation) from canola.

#7 Use agronomic practices to minimise out-crossing in wheat

Agronomy 4 Improving pasture competition

Key benefits

#1 Dense stands of well-adapted pasture species compete against weeds, reducing weed numbers and weed seed-set.

#2 Competitive pastures greatly improve the effectiveness of other tactics used to manage weeds in the pasture phase.

Key practicalities

#1 Select species and varieties to suit your conditions.

#2 Once a pasture gets below a threshold density for a desirable pasture species it should be manipulated to build up seed reserves, or reseeded with improved cultivars.

#3 Mixtures of pasture species will add diversity to the pasture base and improve the capacity for desirable plants to fill gaps created by disturbance (eg drought, cropping).

Agronomy 5 Fallow phase

Key benefits

#1 A fallow period on its own, or in sequence with a number of crops, can be highly effective in reducing weed seed numbers in the soil seedbank.

#2 A fallow period can incorporate a number of tactics to reduce weed seedling and seedbank numbers.

#3 With forward planning, knockdown herbicides (paraquat and glyphosate) can be rotated to reduce the risk of resistant weeds.

#4 Under carefully planned conditions, it is possible to use other herbicide MOA groups (Groups C or B).

#5 In a fallow phase it is easier to judge the efficacy of a weed control tactic as there should be no surviving weeds.

Key practicalities

#1 Control weeds of fallows when they are small.

#2 Avoid over-reliance on cultivation.

#3 Rotate herbicide MOA groups.

#4 Residual herbicides may be used for managing fallow weeds.

#5 Avoid cultivating wet soil.

Agronomy 6 Controlled traffic or tramlining for optimal herbicide application

Key benefits

#1 Accurately spaced tramlines provide guidance and a firmer pathway for more timely and accurate application of herbicide, improving weed control and reducing input costs.

#2 Precision guidance in wide-row cropping systems adds to the benefits of tramlines with new physical and chemical weed management options.

#3 Complete controlled traffic farming avoids all wheel compaction of the crop zone, resulting in a more competitive crop.

Key practicality

#1 Tramlines can be installed relatively cheaply, with benefits gained from accuracy.

Section 4: Tactics for managing weed populations

Tactic Group 1 Deplete weed seed in the target area soil seedbank

Tactic 1.1 Burning residues

Key benefits

#1 Burning can reduce viable weed seed numbers in the seedbank.

#2 Late autumn burning of crop residues can kill weed seedlings.

#3 Combining burning with other tactics (eg seed collection or narrow header trails) will increase the overall weed control impact.

#4 Burning can stimulate weed germination of some weed species for subsequent control with another tactic.

#5 Burning removes residues and thereby allows more effective incorporation of pre-emergent herbicides.

Key practicalities

#1 Best success will be achieved by a high temperature burn, accounting for seasonal risks.

#2 Prepare for the burn to ensure best placement of seeds.

#3 Time burning to suit residue conditions and legislative limitations.

#4 The impact of burning depends on residue placement and quantity.

#5 Burning is not a suitable tool for the management of all weed species.

Tactic 1.2 Encouraging insect predation of seed

Key benefit

#1 Insect predation of annual ryegrass can reduce seedbank numbers.

Key practicalities

#1 Predation levels tend to be higher in locations in close proximity to 'refuge'.

#2 Predation can be maximised by avoiding the overuse of broad spectrum insecticides.

#3 Manage stubble according to the type of seed predator present.

#4 Minimum tillage improves predation of weed seeds.

#5 Soil disturbance over summer reduces seed predation.

Tactic 1.3 Inversion ploughing

Key benefit

#1 In suitable soil types, weed seed burial is an effective method of killing weed seeds.

Key practicalities

#1 Inversion ploughing of windrows will reduce weed numbers with minimal paddock disturbance, but weed seeds will remain in the inter-windrow area.

#2 Appropriate soil type is needed for effective soil inversion.

#3 Soil inversion is most effective in reducing seedbank numbers of weeds with limited dormancy.

#4 Occasional inversion ploughing is unlikely to be deleterious to soil structure.

#5 Careful timing of inversion ploughing will reduce the risk of wind and water erosion.

Tactic 1.4 Autumn tickle

Key benefit

#1 A well timed autumn tickle will promote earlier and more uniform germination of some weed species for subsequent control.

Key practicalities

#1 Autumn tickle should be used in conjunction with another tactic.

#2 Success of autumn tickling depends on environmental conditions before and after implementation.

#3 Soil type is critical for a successful autumn tickle.

#4 Use autumn tickling in non-crop situations to stimulate germination of weeds which can then be managed with grazing or a non-selective herbicide.

#5 The efficacy of autumn tickle will vary with weed species.

Tactic 1.5 Delayed sowing

Key benefits

#1 Delayed sowing can dramatically reduce early crop competition and deplete the weed seedbank.

#2 Delayed sowing is very effective when used in conjunction with additional weed management tactics.

Key practicalities

#1 Target problem paddocks first.

#2 When planning to delay sowing in a problem paddock choose a crop or variety that is suited to later sowing to reduce the risk of yield loss.

#3 Seasonal conditions will influence delayed sowing opportunities.

Tactic Group 2 Kill weed(s) (seedlings) in the target area

Tactic 2.1 Fallow and pre-sowing cultivation

Key benefits

#1 Well-timed cultivation effectively kills weeds.

#2 In preparing a seedbed, cultivation provides a weed-free environment for the emerging crop.

#3 Cultivation can control weeds in situations where herbicides are ineffective or not an option.

#4 Pre-sowing cultivation or full disturbance cultivation at sowing reduces the reliance on knockdown herbicides and therefore the likelihood of weed populations developing herbicide resistance.

Key practicalities

#1 Strategic cultivation must take into account whole-farm practicalities.

#2 Maintain soil structure by cultivating at suitable soil moisture levels and appropriate implement ground speed.

#3 The tillage implement used will influence the level of soil disturbance and thereby the effect on the weeds present.

#4 Choice of cultivation practice can influence weed density and spectrum.

Tactic 2.2a Knockdown (non-selective) herbicides for fallow and pre-sowing control

Key benefits

#1 Knockdown herbicides are effective.

#2 Knockdown herbicides are cost-effective.

#3 Use of knockdown herbicides can improve the timeliness of sowing.

Key practicalities

#1 Consider the suitability of knockdown herbicides for fallow or pre-sowing weed control by assessing environmental conditions.

#2 Stressed weeds will not be adequately controlled by knockdown herbicides.

#3 Overuse of a knockdown herbicide will select for weed populations that are resistant to that particular herbicide.

#4 Suitable meteorological conditions for spraying can be limited, especially in summer.

Tactic 2.2b Double knockdown or 'double knock'

Key benefits

#1 Double knockdown delays or prevents the development of glyphosate resistance.

#2 Using a double knockdown or 'double knock' strategy reduces the number of glyphosate resistant weeds to be controlled in-crop.

#3 Excellent weed seedling control is obtained by using a pre-sowing double knockdown.

Key practicalities

#1 Glyphosate should be applied first, followed by paraquat or paraquat/diquat.

#2 The time between applications will vary with the main target species.

#3 Identify the weed species being targeted.

#4 Apply the first herbicide when the weeds are most likely to be killed.

#5 Double knockdown is more expensive than a single herbicide application.

#6 Seasonal conditions will influence the scale of on-farm implementation.

Tactic 2.2c Pre-emergent herbicides

Key benefit

#1 The residual activity of a pre-emergent herbicide controls the first few flushes of germinating weeds (cohorts) while the crop or pasture is too small to compete.

Key practicalities

#1 Good planning is needed to use pre-emergent herbicides as an effective tactic.

#2 Soil characteristics and environmental conditions at the time of application play an important role in the availability, activity and persistence of pre-emergent herbicides.

#3 Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase (Table T2.2c)

Tactic 2.2d Selective post-emergent herbicides

Key benefits

#1 Post-emergent herbicides give high levels of target weed control with the additional benefit of improved crop or pasture yield.

#2 Observations made just prior to application allow fine-tuning of herbicide selection to match target weeds present in the paddock.

#3 Timing of application can be flexible to suit weed size, crop growth stage and environmental conditions.

#4 Some post-emergent herbicides have pre-emergent activity on subsequent weed germinations.

Key practicalities

#1 Use careful consideration when selecting the best post-emergent herbicide to use in any one situation.

#2 Application of post-emergent herbicides to stressed crops and weeds can result in reduced levels of weed control and increased crop damage.

#3 Crop competition is important for effective weed control using selective post-emergent herbicides.

#4 The technique used for application of selective post-emergent herbicides must be suited to the situation in order to optimise control.

#5 Always use correct adjuvant to ensure effective weed control.

#6 Selective post-emergent herbicides applied early and used as a stand-alone tactic have little impact on weed seedbanks.

#7 Choose the most suitable formulation of herbicide for each particular situation.

#8 The effectiveness of selective post-emergent herbicides is influenced by a range of plant and environmental factors.

#9 Match herbicide mode of action to its use.

Tactic 2.3 Weed control in wide-row cropping

Key benefits

#1 Increasing row spacing allows improved weed control while maintaining or improving crop yield.

#2 Cropping in wide rows enables the use of shielded inter-row herbicide application, crop-row band spraying and inter-row cultivation for in-crop weed control.

Key practicalities

#1 Reduced competition from the crop can result in lower yield potential if weeds are not controlled.

#2 A change to wide rows will require modifications to sowing equipment, a complete change in equipment or use of a contractor.

#3 Precision farming technologies fit well with wide rows for weed management.

Tactic 2.3a Inter-row shielded spraying and crop-row band spraying

Key benefits

#1 Shielded spraying allows inter-row application of non-selective herbicides in-crop, which can increase crop yield.

#2 Band spraying reduces the risk of herbicide resistance development by limiting the application of higher risk selective herbicides over the crop row.

Key practicalities

#1 Herbicide MOA groups need to be rotated.

#2 Timing of shielded spraying is important.

#3 Care must be taken with the set-up and operation of shielded sprayers to minimise spray drift. All shields leak spray drift to some extent.

Tactic 2.3b Inter-row cultivation

Key benefit

#1 Inter-row cultivation gives the opportunity to control weeds without herbicides.

Key practicalities

#1 Timing of inter-row cultivation is critical to ensure maximum levels of weed control.

#2 Weed control is reduced if the soil is too wet.

#3 Heavy stubble cover may preclude the use of inter-row cultivation.

#4 Inter-row cultivation does not control weeds in the crop row, so an additional tactic must be used for the crop-row weeds.

#5 Inter-row cultivation cannot be used in conjunction with ground covering stubble mulch techniques.

#6 Inter-row cultivation can stimulate emergence of some weed species.

Tactic 2.4 Spot spraying, chipping, hand rouging and wiper technologies

Key benefit

#1 Vigilance and attention to detail can be the difference between eradication and a prolonged and costly problem.

Key practicalities

#1 Instigate accurate future monitoring by marking isolated infestations.

#2 Isolate the area of infestation to reduce the risk of further spread.

#3 Control of new weed infestations and low-density weed populations requires only simple measures.

#4 Timing of control is important to avoid seed-set.

Tactic 2.5 Biological control

Key benefits

#1 Biological control agents can be effectively used to control weeds.

#2 When classical biological control is successful it is very cost-effective.

#3 The recognised potential of bioherbicides as an effective form of weed control stimulates future investigation.

Key practicalities

#1 Weed biology factors influence biological control efficacy.

#2 Survival of the control agent relies on survival of the weed.

#3 The success of the tactic is dependent on the existence of suitable agents and their degree of host specificity.

#4 Bioherbicide technology is limited in terms of the cost of production and the need for a large-scale market to make the product viable.

TG 3 Stop weed seed-set

Tactic 3.1 In-crop weed management for seed-set control

Key benefits

#1 The use of in-crop weed seed-set control tactics can dramatically reduce future expenditure on weed management.

#2 In-crop seed-set control reduces levels of weed seed contamination in grain samples at harvest.

Key practicality

#1 Plan weed seed-set management in advance.

Tactic 3.1a Spray-topping with selective herbicides

Key benefits

#1 Correctly executed selective spray-topping will result in a 90% reduction in weed seed-set.

#2 Selective spray-topping can effectively and economically minimise seed-set where weed population is low.

#3 In high weed population situations selective spray-topping is an effective 'mop-up' tactic used to minimise seed-set of weeds that escape TG2 or earlier controls.

#4 Selective spray-topping can be used as a salvage treatment.

#5 Wild oat populations resistant to selective Group A and/or B herbicides can be managed using selective spray-topping.

Key practicalities

#1 Timing of application is the key to successful reduction in weed seed-set.

#2 Selective herbicides are best used in combination with tactics from alternative tactic groups to avoid development of resistance to the selective spray-topping herbicide.

#3 Weeds will not necessarily be killed by selective spray-topping but the growth and development of plants and subsequent seed-set will be seriously impeded.

Tactic 3.1b Crop-topping with non-selective herbicides

Key benefits

#1 Crop-topping can reduce annual ryegrass weed seed-set, reducing additions to the seedbank.

#2 Reductions in seed-set achieved by crop-topping can be increased if used in conjunction with selective herbicide treatment.

Key practicalities

#1 The ideal time for crop-topping is when the annual ryegrass is at or just past flowering and the pulse crop is as mature as possible.

#2 Crop-topping should not be performed on crops where the grain is intended for use as seed or for sprouting.

#3 Crop-topping for wild radish and other brassica weed control in current pulse varieties is not recommended because of the closely matched rate of development of weed and crop.

Tactic 3.1c Wiper technology

Key benefits

#1 Weed wiping is selective due to the application method rather than the herbicide used.

#2 Weed wiping is an effective method of reducing seed-set in weeds which have not been controlled by tactics used earlier in the growing season.

Key practicalities

#1 Care is needed to ensure that excess herbicide does not drip onto the crop and cause damage.

#2 Timing of weed wiping is the key.

#3 A special applicator is required for weed wiping.

Tactic 3.1d Crop desiccation and windrowing

Key benefits

#1 Windrowing used in conjunction with other tactics can greatly enhance weed control results.

#2 There is a 'chance' that crop desiccation or windrowing will reduce weed seed-set.

#3 Windrowing or desiccation can assist the management of late germinating weeds.

Key practicalities

#1 Timing is the key to maximum yield and quality.

#2 Weed and crop regrowth (post-windrowing) must be controlled to stop seed-set.

#3 Weeds/tillers below cutting height will not be incorporated into the windrow.

#4 Check herbicide labels.

#5 Windrowing in hot weather can increase losses due to shattering.

Tactic 3.2 Pasture spray-topping

Key benefits

#1 Strategically timed spray-topping significantly reduces weed seed-set in pastures.

#2 Both paraquat and glyphosate can be used for spray-topping.

#3 Spray-topping is a very cost-effective tactic to reduce weed seed-set, thereby reducing the weed seedbank.

Key practicalities

#1 The timing of herbicide application is critical to the success of spray-topping.

#2 Spray-topping is not an alternative to fallow spraying.

#3 Spray-topping as a lone tactic cannot control a wide range of grass species simultaneously.

#4 Grass weed levels determine the management 'fit' of spray-topping in a pasture phase.

#5 Winter cleaning or fallow spraying may be used to finalise the pasture phase before cropping commences.

#6 Spray-topping can reduce seed-set in annual pasture legumes if the stage of development of the legume pasture coincides with the development stage of the target annual grass.

Tactic 3.3 Silage and hay – crops and pastures

Key benefit

#1 Hay and silage are options that can be used in crops and pastures where excessive numbers of weeds have survived a previous tactic.

Key practicalities

#1 Carefully consider the options for marketing or using the product on-farm.

#2 Time the hay or silage tactic in accordance with the physiological development of the target weed.

#3 Understand the biological traits of the target weed to improve efficacy of the tactic.

#4 Regrowth can produce enough seed to keep the seedbank topped up.

#5 Consider the balance of using hay or silage as a weed management tactic with other farm enterprises.

Tactic 3.4 Renovation crops and pastures – green manuring, brown manuring, mulching and hay freezing

Key benefits

#1 Manuring, mulching, and/or hay freezing (all with re-growth control) reduce viable seed-set, thereby controlling high weed numbers and managing herbicide resistant weeds.

#2 Costs (income loss) from the renovation crop tactic can be offset by improved yield in subsequent cereal crops.

#3 Patches of weeds in crops can be treated prior to hectic harvest time.

Key practicalities

#1 Manuring must be carefully timed to prevent seed-set and addition to the seedbank.

#2 Choice of renovation crop species will influence the competitiveness of the renovation crop.

#3 Economics in the year of manuring can be improved by planning the use of the tactic and by understanding and valuing subsequent benefits.

#4 Ensure good coverage and penetration of herbicide, and observe withholding periods when brown manuring or hay freezing.

#5 Maximise seed kill by ensuring even and optimum head emergence of target weed.

#6 Monitor and manage regrowth.

Tactic 3.5 Grazing – actively managing weeds in pastures

Key benefits

#1 Timed grazing pressure can be used to manipulate pasture composition.

#2 Grazing can be used in conjunction with herbicides (spray-grazing) to effectively manage weeds.

#3 Grazing can be used to reduce seed-set in grass weeds.

#4 Exploiting differences in species acceptability to sheep can reduce weed numbers.

#5 Tillering of annual grasses can be decreased by timely grazing.

Key practicalities

#1 Grazing pressure needs to be high enough to prevent selective grazing.

#2 Timing of practices is critical to obtain the desired level of weed control.

#3 Manage grazing to avoid the risk of livestock importing weeds or transporting them to other paddocks.

#4 Livestock movement across paddocks can bury weed seeds.

#5 High grazing pressure can increase the proportion of broadleaf weeds such as capeweed and erodium.

TG 4 Prevent viable weed seeds within the target area being added to the soil seedbank

Tactic 4.1 Weed seed collection at harvest

Key benefit

#1 Residue and weed seed collection at harvest can prevent a large proportion of viable weed seed from entering the seedbank.

Key practicalities

#1 The weed species has a major influence on the proportion of weed seed removed from the paddock when collected at harvest.

#2 Timing of harvest will affect the amount of seed removed from the paddock when residue is collected.

#3 Seed collection should be used in combination with tactics from other tactic groups to avoid selecting for weed types which avoid collection at harvest.

#4 A strategy to dispose of chaff dumps or large quantities of baled straw must be implemented.

#5 Seed collection can reduce the speed of harvest.

#6 The initial economic outlay for machinery additions and modifications can be significant.

Tactic 4.1a Narrow header trail

Key benefits

#1 Weed seed numbers can be reduced by using the narrow header trail tactic and burning the trails.

#2 Windrowing improves the benefit of using narrow header trails.

Key practicality

#1 Grazing stock tend to spread and bury seed, which will reduce the efficacy of burning the weed seeds in windrows.

Tactic 4.1b Chaff cart

Key benefits

#1 Collecting crop residue with a chaff cart can significantly reduce the numbers of weed seeds returning to the seedbank.

#2 Windrowing improves the benefit of using a chaff cart.

#3 Reduces crop volunteers in the following season.

Key practicality

#1 A crop must be harvested as soon as it is ripe to collect the greatest number of weed seeds.

#2 Burning of chaff dumps is time consuming.

#3 Dumps may smoulder, for up to 5 days, reducing air quality in the vicinity.

Tactic 4.2 Grazing crop residues

Key benefits

#1 Grazing reduces the number of weed seeds added to the soil seedbank.

#2 Grazing can be used to dispose of, and gain value from, weed seed contaminated fodder.

Key practicalities

#1 Grazing livestock can distribute weed seeds across a paddock.

#2 The impact of grazing on weed numbers in the seedbank is dependent on the biological features of the weed.

#3 Livestock trampling tends to bury weed seed, which can decrease the efficiency of burning as a means of killing seeds. Depending on the weed species, burial may also increase germination rates.

TG 5 Prevent introduction of viable weed seed from external sources

Tactic 5.1 On-farm hygiene

Key benefit

#1 Planning and enforcing a farm hygiene strategy minimises the risk of adding weeds to the seedbank from external sources.

Tactic 5.1a Sow weed-free seed

Key benefit

#1 Weed seeds are not added to the seedbank unnecessarily.

Key practicalities

#1 Check seed analysis before purchasing seed-lots to avoid importing weed seed.

#2 To reduce the spread of weeds, plan ahead and take due care when retaining seed on-farm for sowing.

#3 Keep good records of seed purchases.

Tactic 5.1b Manage weeds in non-crop areas

Key benefit

#1 Weed management in non-crop areas can prevent 'creep effect' into crops.

Key practicality

#1 Weeds from non-crop areas can impact greatly on farm weed status, but are often easily controlled.

Tactic 5.1c Clean farm machinery and vehicles

Key benefit

#1 Good vehicle hygiene (ie regular cleaning) can reduce the risk of new infestations and weed spread.

Key practicality

#1 Develop and adhere to a clean machinery and vehicle protocol aimed at reducing new additions to the weed seedbank.

Tactic 5.1d Manage livestock feeding and movement

Key benefit

#1 Careful management of livestock will reduce the likelihood of new infestations and weed spread.

Key practicality

#1 Quarantine contaminated fodder in a sacrifice paddock or feedlot so that weeds are contained in a small area.

Introduction

Weeds are estimated to cost Australian agriculture between $2.5 billion and $4.5 billion per annum (Sinden et al 2005). For winter cropping systems alone the cost is $1.3 billion (Jones and Medd 2005), equivalent to around 20% of the gross value of the Australian wheat crop. Consequently, any practice that can reduce the weed burden is likely to generate substantial economic benefits to growers and the grains industry.

Integrated weed management (IWM) is a system for managing weeds over the long term, particularly the management and minimisation of herbicide resistance (HR). Grain growers can no longer rely solely on selective herbicides for effective control of a number of weed species. There is a need to combine herbicide and non-herbicide methods into an integrated control program. Given that there are additional costs associated with implementing IWM, the main issues for growers are whether it is cost-effective to adopt the system, and whether the benefits are likely to be long-term or short-term in nature.

Is integrated weed management cost-effective?

IWM is definitely cost-effective in the longer term. In the short term, many farms don't adopt IWM because of the added costs; however, research and farmer experience have shown that failure to adopt IWM leads to herbicide resistance.

In a survey of Western Australian grain growers Llewellyn et al (2004) identified that the adoption of IWM practices was associated with the HR status of a farm. Although farms without resistance also used IWM, practices were more likely to be used when HR was present. For example, IWM tactics such as crop-topping use was three times greater on farms with resistance than without. On average, farms with HR used a greater number of weed control practices (nine) than farms without HR (six). Thus, for Western Australian farming systems at least, the adoption of IWM is often an outcome of identification of HR.

There are a number of key factors that influence adoption of IWM (Llewellyn et al 2002; 2004; Pannell and Zilberman 2000):

- Expectation of new herbicide technology

Herbicides are regarded as having greater weed control efficacy than non-herbicide controls. Consequently, while current herbicides remain effective there is reduced incentive to adopt alternative control options. The development of HR indicates a reduction in the future effectiveness of herbicide options, and should increase the attractiveness of IWM. However, Llewellyn et al (2002) found that there is a high level of confidence, among Western Australian growers, that new herbicides with different modes of action will become available, thus reducing the incentive to adopt IWM.

These attitudes prevail despite there being no post-emergent herbicides with novel modes of action known to be in the latter stages of development for major crop weeds (annual ryegrass, wild radish and wild oats).

- Regression and mobility of resistance

Llewellyn et al (2002) surveyed growers' perceptions of HR regression (when herbicides are no longer used and the less fit resistant plants fail to maintain their proportion in the population) and HR mobility (via means such as pollen flow, seed movement, and contaminated seed and fodder).

The survey found that:

- up to 46% of growers perceived regression after 5 years to be likely
- nearly 14% thought it to be highly likely
- 54% of growers perceived importation of resistance after 10 years to be likely
- 21% believed it to be highly likely.

These perceptions are an indication that issues of reverse and mobile resistance, within and between farms, can potentially affect resistance management decisions.

Widderick et al (2006) found similar trends in a study of farmers and agronomists in the northern grains region (northern New South Wales and Queensland), where 30% of respondents thought HR lasted up to 5 years and a further 10% did not know.

- Efficacy of alternative IWM options

In the absence of herbicide resistance, post-emergent selective herbicides are perceived by growers as having the highest reliability and efficacy among available IWM options. In contrast, some 'traditional' control methods such as stubble burning and cultivation are regarded as having much lower efficacy and large variances. Although it is recognised that each control tactic has its own impact on weed mortality and/or seed-set, an increasing number of growers realise that very effective weed control can only be achieved with a targeted combination of a wide range of strategies. As control tactics are imposed at different times, their combined impacts are considered to be multiplicative rather than additive. For example, the combined effect of two control tactics each with 40% survival is 16% survival (Pannell et al 2004).

- Growers' attitudes to short-term profit versus long-term returns

IWM is widely regarded as providing a long-term approach to weed management, in which there are likely to be initial up-front costs to achieve longer term gains from reduced weed populations. In some circumstances growers may make suboptimal weed management decisions due to their specific planning objectives. For example, where there are short-term financial pressures (eg debt servicing requirements) growers may make decisions that increase current period profits but that may have negative long-term consequences (eg herbicide resistance).

Returns of an individual enterprise in the short term are usually measured through a gross margin budget, which is determined by factors such as crop yield, price, the costs of both herbicide and non-herbicide weed control, and other inputs such as seed and fertiliser. Crop yield is directly influenced by weed density, which itself is a function of weed control. For short-term decision making the goal of the grower managing a weed problem is to determine the optimal level of herbicide and non-herbicide inputs for a given weed density that will maximise the crop gross margin.

However, this approach to measuring returns from weed management ignores a critically important economic factor – the carryover of the weed seedbank and its impact on returns in future years.

A weed control decision not only has an impact on returns for the current crop, but affects yields in later years (for good or bad) due to its impact on the biological seed stock. Thus, calculating returns over the long term (eg 20 years) is a better approach for determining the value of the economic benefits of IWM.

A longer term approach is also able to account for important economic factors such as changes to weed seedbanks from one year to the next due to weed management actions and the impact of HR. The role of good agronomic practices such as more competitive crops, alternative crops in a rotation, and pasture phases should be valued along with weed management tactics.

The longer term view of weed management can be assisted by adopting the concept of Tactic Groups (see below). This approach coordinates weed control practices with the life cycle of weeds, and emphasises the need to avoid any practices which may add viable weed seeds to the seedbank.

Management of weeds using tactic groups

IWM in Australian cropping systems approaches weed management in a novel manner by introducing the concept of Tactic Groups (TGs). This concept creates new options and opportunities for weed management and has been designed to change the focus of growers and advisors from crop yield to weed life cycle.

Individual weed management tactics are packaged into TGs according to the target growth stage of the weed. The TGs are based on the five key objectives of all weed control strategies (see table below):

Tactic group	Aim of tactic group
1	Deplete weed seed in the target area soil seedbank
2	Kill weed(s) (seedlings) in the target area
3	Stop weed seed-set
4	Prevent viable weed seeds within the target area being added to the soil seedbank
5	Prevent introduction of viable weed seed from external sources

In a well-integrated weed management plan each target weed will be 'attacked' by a number of tactics, each from a different TG. TGs should be combined in the same way herbicides from different mode-of-action (MOA) groups are rotated. Integrating TGs and MOA groups will reduce weed numbers, stop replenishment of the seedbank and minimise the risk of developing populations of HR weeds.

When selecting a tactic, consider the aim of the TG to which each tactic belongs, and evaluate the suitability of the activity to the target weed and the weed's growth stage. Some weed management tactics significantly reduce crop production or yield, producing a dramatic effect. Instead of excluding such tactics, consider the option of using them as a 'one-off' solution in problem situations. Tactics of this kind can be highly effective, reducing weed seedbank numbers by a huge proportion in a single year.

Taking control of weed management

Significant or subtle changes in agronomy can enhance the impact of weed management tactics. Increases in sowing rate, adjustments to fertiliser application rate and changes in crop variety choice can significantly improve crop competition, which in turn improves weed control results. More substantial changes, such as choosing a different crop type, can enable the inclusion of additional tactics and expand the opportunities for highly effective weed control.

Most importantly, get out and have a look. Useful knowledge of the weed species in the target area includes population density, distribution across the paddock, growth cycle and the growth stages when the weeds are most vulnerable to weed management tactics. Knowing the problem to be faced is essential to solving the weed management dilemma.

Contributors

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The IWM Manual

The manual is divided into seven sections, to assist the reader make the development of an IWM plan a simple process.

Section 1 Economic benefits	Outlines the economic benefits of IWM in Australian cropping systems using computer model simulations.
Section 2 Herbicide resistance	A knowledge resource clarifying aspects of herbicide resistance in weed populations. It is crucial to understand the basics of herbicide resistance when managing weed populations that are resistant to one or more herbicide groups, or are at risk of becoming resistant.
Section 3 Agronomy	Discusses a range of agronomic practices that can be used to enhance the results of the specific weed management tactics employed. It includes many simple and cost-effective management changes that can be made to improve the competitive ability of the crop.
Section 4 Tactics	Provides detailed information on available weed management tactics and presents trial results from across Australia. The tactics, sorted by Tactic Group, are addressed individually. Where a tactic can fall into two Tactic Groups because it impacts on two stages of the weed's life cycle, it has been grouped according to its major aim.
Section 5 Implementing IWM	The 'doing' part of the manual, outlining how best to assess the on-farm situation and implement the IWM plan on-farm. The information that should be collected for each paddock is listed, so that an effective weed management plan can be prepared.
Section 6 Weeds	Details the characteristics of 20 key weeds of annual cropping across Australia. Information includes basic identification, distribution and traits that make the weed a significant problem in cropping systems. For each weed there is a recommendation of the most suited weed management tactics for control.
Section 7 Case studies	Includes a number of grower case studies collected from across Australia. These are an invaluable resource highlighting how growers are actually implementing IWM. What made them change? What has been successful? What have been the challenges?