SECTION 4
TACTICS
Tactics for managing weed populations

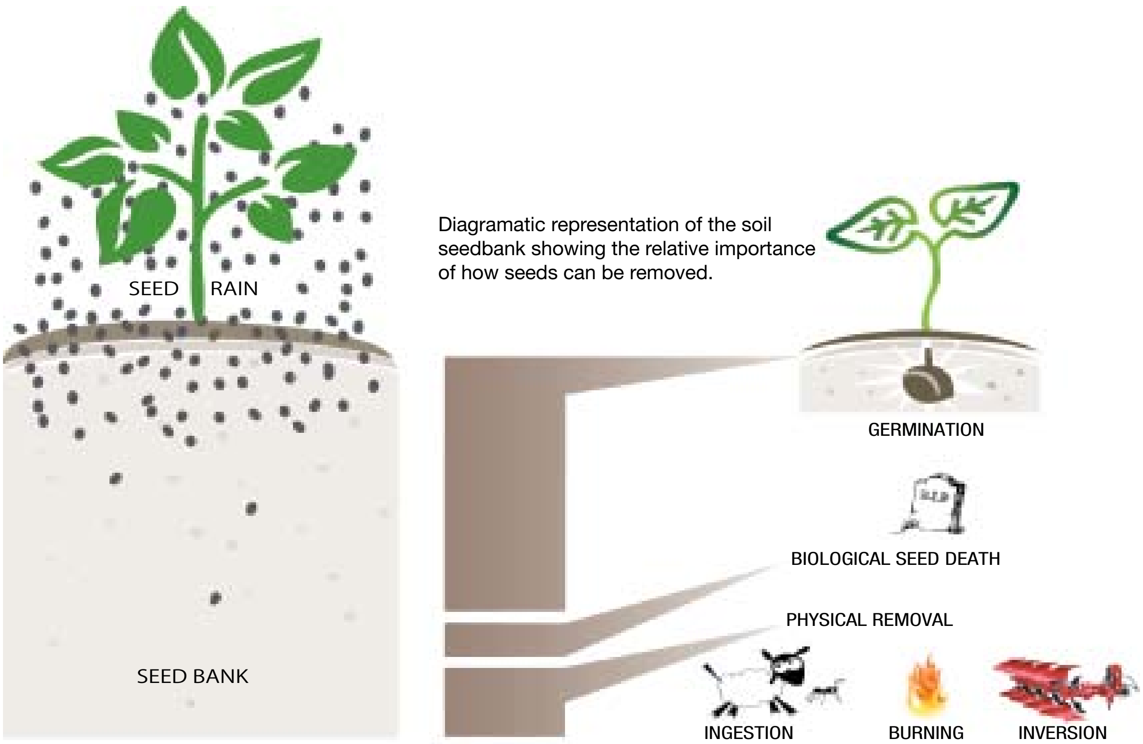
INTEGRATED WEED MANAGEMENT
IN AUSTRALIAN CROPPING SYSTEMS

SECTION 4: TACTICS FOR MANAGING WEED POPULATIONS

'Used singly, none of the currently available cultural techniques provide an adequate level of weed control. However when used in carefully planned combinations extremely effective control can be achieved.' — Gill and Holmes 1997

The above quote is from a research and extension paper written in 1997. The concept of using as many weed control tactics in combination within the one season to prevent the production of new weed seeds still holds true today and will continue to hold for as long as we farm. There are no 'silver bullets' and this section looks at all the tactics that can be used in combination to keep weed numbers down and farming profitable.

The image below shows the relationship between seed rain, the soil seedbank and how seeds are removed or prevented from entering the seedbank. Germination is the largest path where herbicides or cultivation can be used. A small proportion of seeds die through natural causes while we can also bury, burn or eat seeds using a range of IWM tactics.



TACTIC GROUP 1 DEPLETE WEED SEED IN THE TARGET AREA SOIL SEEDBANK

TACTIC 1.1 BURNING RESIDUES

Despite the ability of summer fires to effectively destroy the surface seedbanks of many weeds, including annual ryegrass (*Lolium rigidum*), the environmental hazard of burning at this time of the year in Australia is extreme (Gill and Holmes 1997) and therefore illegal.

Autumn burns are an effective alternative and have been shown to successfully decrease weed seed densities. Strategic late burning (in March) to manage weed seedlings and surface weed seeds is therefore useful for growers on soils with low erosion potential.

PHOTO: ANDREW STORRIE

Chaff dumps can be burnt in autumn, killing a high proportion of seeds present.

PHOTO: WARWICK HOLDING

Narrow windrows being burnt in autumn.

Crop residue burning may challenge the stubble retention principles of many grain growers and advisers. However, when used strategically as a one-off tactic and in conjunction with other management strategies, it can be quite effective in reducing viable weed seed numbers.

Benefits

Key benefit #1

Burning can reduce viable weed seed numbers in the seedbank

The weed management benefits of burning crop residues have been widely researched. Outcomes from a number of research projects where reductions in soil surface seedbanks have resulted from burning are provided in Table T1.1-1 (below).

Burning is more effective at higher temperatures and particularly where there is high levels of stubble. Seeds on or very close to the soil surface are more likely to be killed than seeds buried more deeply (greater than 5 mm) in the soil.

All crop residues (canola, wheat and lupin) can produce a sufficiently hot burn provided that adequate tonnage of residue is present. Hence higher temperature burns will be obtained by concentrating residue into a narrow windrow (see *Tactic 4.1a Narrow header trail*, page 215).

TABLE T1.1-1 Reduction in weed seed numbers following crop residue burning.

Location	Situation	Weed species	Control achieved	Reference
New South Wales	Continuous cropping	Annual ryegrass	97–98%	Fettell 1998
Victoria	Pasture	Annual ryegrass	35–57% control when stubble grazed	Davidson 1992
Victoria	Pasture	Annual ryegrass	35–66%	Reeves and Smith 1975
South Australia	Cereal	Annual ryegrass	60%	Matthews *et al* 1996
Western Australia	Wheat, canola, lupin trash windrows (harvest spreaders removed, trash concentrated with chute)	Annual ryegrass Wild radish	98% 75%	Newman and Walsh 2005
Western Australia	Wheat: straw spread (equivalent to 2.3 t dry matter/ha)	Annual ryegrass	82% control of total annual ryegrass on soil surface	Chitty and Walsh 2003
	Wheat: concentrated trash windrow (equivalent to 15 t dry matter/ha)	Annual ryegrass	99% control of annual ryegrass in the windrow	

Key benefit #2

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

Weed management using burning can be made more effective by combining it with other techniques such as seed collection, windrowing or modifying the header's trash placement (see *Tactic 4.1 Weed seed control at harvest*, page 212).

High density annual ryegrass controlled with clethodim in canola, Eyre Peninsula.

Same paddock as photo to the left, however this section had a full stubble burn in December.

PHOTOS: ANDREW STORRIE

The effectiveness of burning for weed seed destruction is directly related to the amount of residue (fuel) available for burning. Simply removing or disengaging the straw spreaders leaves the straw and chaff in a narrow trail or windrow approximately 1.5 m wide. Alternatively, a chute attached to the rear of the header will concentrate harvest residues into narrow windrows or header trails (Walsh *et al* 2005).

A windrow will burn at a higher temperature for longer than spread stubble, thereby improving weed kill. Burning a narrow windrow also reduces the percentage of the paddock that is burnt, thereby reducing the area prone to wind erosion.

Seed which is not collected in the windrow will not be burnt and therefore remains viable. This could be a problem if large amounts of seed are shattered prior to windrowing or the seeds are below harvest height. For example, over 300 annual ryegrass seedlings/m^2 emerged in the area between the windrows in one study at Mt Barker, Western Australia (Peltzer *et al* 2005).

Key benefit #3

Late autumn burning of crop residues can kill weed seedlings

In addition to reducing weed seed numbers, stubble burning in autumn can be used to kill weed seedlings, including self-sown crop volunteers such as wheat. The effectiveness of the burn will depend on the size and density of the weed seedling population. Cooler ambient temperatures and the presence of non-flammable green material will reduce the temperature of the burn, resulting in lower efficiency of both seed and seedling control.

Key benefit #4

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

While stubble burning can destroy wild oats (*Avena* spp.) seed on the soil surface, it can also stimulate seedling emergence by modifying seed dormancy of the survivors (Nietschke *et al* 1996). Fire can be very effective at stimulating germination of hard or dormant seeds for subsequent control with another tactic.

Experience in southern New South Wales found that plant densities of wild oats, wild radish (*Raphanus raphanistrum*) and vulpia (*Vulpia* spp.) doubled in the year following

PHOTO: WARWICK HOLDING

Stubble can be burnt along narrow windrows creating a hot burn and killing a high proportion of weed seeds in the chaff.

stubble burning compared to stubble retention. This may be due to either stimulation of germination or suppression by stubble (E. Koetz pers. comm. 2004).

Key benefit #5

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

Soil residual herbicides that need incorporation can be more effectively mixed with soil when high stubble loads are removed via burning.

It should be noted, however, that spraying soon after burning can result in binding of herbicide to ash. Ash needs to be dispersed by rainfall or physical incorporation prior to spraying with soil-residual herbicides.

Whole-farm benefits

Burning crop residues has additional benefits including:

- the removal of residues to ease sowing of the subsequent crop
- the management of foliar disease and pests
- the elimination of short-term nitrogen tie-up.

These benefits improve crop health and, therefore, crop competitive ability against weeds and the effectiveness of pre-emergent herbicides.

Practicalities

Key practicality #1

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

Reduction in weed seed numbers due to burning is highly variable and dependent on the exposure of the seeds to high temperatures. This in turn is dependent on the quantity, quality and distribution of residue, the conditions at time of burning, the weed species present and the placement of the weed seeds.

PHOTO: WARWICK HOLDING

Unburned windrows need to be sprayed due to a concentration of weed seeds.

It has been identified that a temperature of 400°C for 10 seconds is required to kill annual ryegrass seed (Chitty and Walsh 2003) and that wild radish pods will be destroyed by 400°C for 20 to 30 seconds or 500°C for 10 seconds (Walsh *et al* 2005). Walsh *et al* (2005) also demonstrated that it was possible to achieve temperatures above 500°C for over three minutes in a lupin trash windrow, where dry matter in the windrow was estimated at 15 t/ha.

Key practicality #2

Prepare the burn area to ensure best placement of seeds

Ideally weed seed should be located on or just above the soil surface. Grazing should be avoided or, at least, reduced in paddocks targeted for a weed management stubble burn to ensure that quality residue remains for the burn.

By reducing the disturbance of harvest residues caused by grazing, the potential for

A FESA grass fire index which can be used to evaluate when to burn windrows and chaff dumps.

maximum burning efficiency will be retained. Additionally, the movement of stock across a paddock frequently pushes weed seed into the soil, where it is unlikely to be exposed to high temperatures during burning.

Key practicality #3

Time burning to suit residue conditions and legislative limitations

Although burning early in the season is likely to achieve best weed seed control, in many instances this is not practical due to weather conditions, the risk of fire spread and the increased risk of erosion to paddocks bared for longer periods. Early removal of stubble in a fallow period also reduces the efficiency of water conservation.

Very high temperatures are required to kill annual ryegrass seed following short exposure periods (Chitty and Walsh 2003). Although a hot burn earlier in the summer reduces seed viability to a greater extent (Pearce and Holmes 1976), there are practical and legislative limitations to burning during summer.

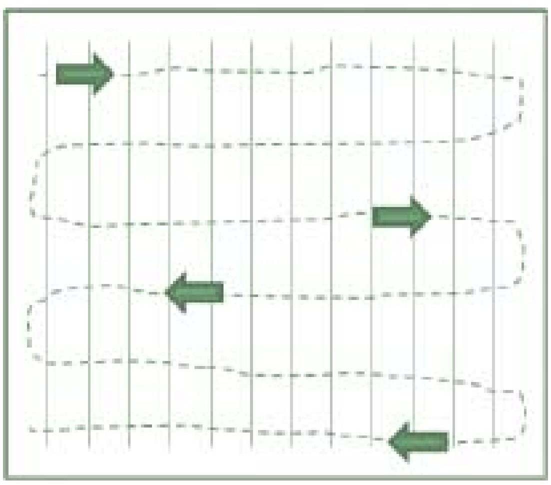
Chitty and Walsh (2003) found that lower temperatures can also be effective if exposure periods are increased. Late autumn (or 'cool') burning of residues reduces the viability of seeds susceptible to heat treatment to some extent. In north-eastern Victoria, for example, Davidson (1992) achieved a 57 per cent reduction in annual ryegrass establishment with a late autumn burn.

Preliminary data from trials on the Darling Downs, Queensland (Walker pers. comm. 2005), found that an autumn stubble burn reduced turnip weed (*Rapistrum rugosum*) seeds by 28 per cent, wild oats seeds by 34 per cent and paradoxa grass (*Phalaris* spp.) seeds by 43 per cent in the top 10 cm of soil.

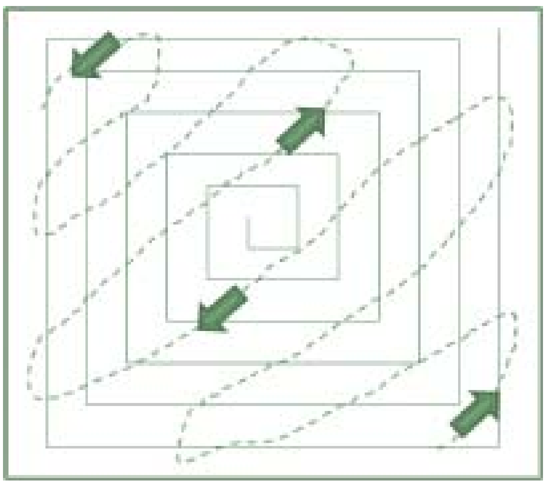
Key practicality #4

The impact of burning depends on residue placement and quantity

An alternative to burning in summer is to concentrate the crop residue into windrows to achieve a slower, hotter burn. It is important to burn windrows in dry conditions with a light wind to ensure that the windrow burns all the way to the soil surface. Burning wet windrows and/or burning in still conditions will often result in a layer of unburnt residue left at the soil surface.



Recommended lighting strategy for up-and-back harvesting.



SOURCE: SALLY PELTZER

Recommended lighting strategy for around the paddock harvesting.

The environment also plays a key role in determining the success of burning to reduce weed seed numbers through the influence it has on the amount of post-harvest residue available. Studies in South Australia found that, in drier environments with less reliable rainfall (Roseworthy, mean annual rainfall 441 mm), burning stubble did not significantly reduce annual ryegrass seed numbers due to the lack of fuel available to generate a destructive fire. However, in more favourable environments (Auburn, mean annual rainfall 596 mm) there was an average 58 per cent reduction in annual ryegrass seed numbers following burning (Matthews *et al* 1996).

Key practicality #5

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

Not all weed seedbanks can be decreased by effective burning (Table T1.1-2, below). Some weeds are not affected by burning and others benefit from burning.

TABLE T1.1-2 Likely impact of burning versus retaining crop residue prior to sowing on autumn weed seedling emergence in southern New South Wales (D. Heenan pers. comm. 2004).

Weed species	Crop residue treatment	
	Burned	Retained
Wireweed (*Polygonum aviculare*)	No change	Decrease
Fumitory (*Fumaria* spp.)	Decrease	Decrease
Brome grass (*Bromus diandrus*)	Decrease	Increase
Barley grass (*Hordeum leporinum*)	Decrease	Increase
Silver grass (*Vulpia* spp.)	Increase	Increase
Annual ryegrass (*Lolium rigidum*)	Decrease	Increase
Wild oats (*Avena* spp.)	Increase	Decrease

Whole-farm considerations

The benefits of burning for weed management must be weighed up against a number of concerns. These include:

- environmental concerns about pollution and carbon dioxide emissions from burning crop residues
- potential respiratory health issues (e.g. asthma)
- the risk of soil erosion following burning, especially after a total residue burn
- adverse effects on soil fertility, organic matter and soil structure, especially if burning is used frequently
- reduced soil water infiltration and increased evaporation and run-off due to crop residue removal
- reduced numbers of macro- and micro-organisms, especially earthworms, and therefore reduced biopores
- a shortened sowing window after rain.

In the past grain growers across Australia have regularly used crop residue burning and so they understand the following practicalities associated with the tactic:

- Burning must be conducted in strict accordance with state rural fire service regulations.
- Chaff dumps can take a long time to burn, creating smell and smoke issues. Extended burning time also heightens fire risk.
- Legislation to ban burning has been introduced in some countries around the world due to concerns over greenhouse gas emissions, global warming and health issues.
- There is public pressure in Australia to ban burning, especially in areas in close proximity to large urban centres.

Contributors

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TACTIC 1.2 ENCOURAGING INSECT PREDATION OF SEED

The contribution that insects make to seedbank reduction is often overlooked, despite weed seeds comprising a major component of many insect diets. This predation of seed is often termed 'natural mortality' to partly explain why less seed is returned to the seedbank than is produced.

Understanding the role that insects play in removing weed seeds could potentially help the development of farming systems that encourage greater removal of seeds from the seedbank. In New South Wales seed theft by ants has commonly caused failure of pastures, so it is feasible that weed seedbanks also could be decreased by encouraging ant predation.

Benefits

Key benefit #1

Insect predation of annual ryegrass can reduce seedbank numbers

Levels of predation can be quite variable, with removal rates ranging from zero to 100 per cent depending on the proximity of the seedbank to ant colonies. Predation by insects was found to be significantly higher for annual ryegrass (*Lolium rigidum*) seed than wild radish (*Raphanus raphanistrum*) seed in a study in the Western Australian wheatbelt. At three months into the study 81 per cent of the original annual ryegrass seed had been removed, compared to 46 per cent of wild radish seed (see Table T1.2-1, below). Original seed numbers were 2000 seeds/m^2 for annual ryegrass and 1000 seeds/m^2 for wild radish.

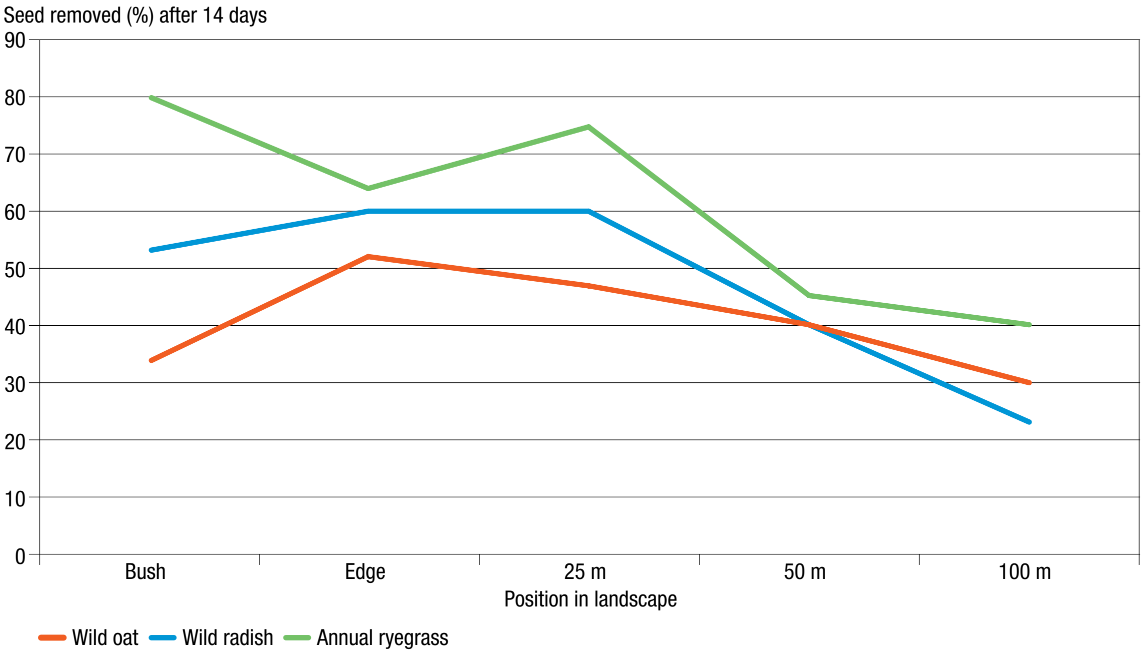
TABLE T1.2-1 Effect of time on cumulative weed seed removal across a 16 ha cropping paddock in Merredin, Western Australia. Figures represent the average percentage of seed removed for annual ryegrass and wild radish (Spafford Jacob *et al* 2006).

	Seed removal %	
	January	March
Annual ryegrass	69	81
Wild radish	21	46

PHOTO: DAVID MINKEY

Pheidole hartmeyri is a seed consuming specialist and can be seen here removing annual ryegrass seed from a cropping field in Merredin, Western Australia.

FIGURE T1.2-1 **Effect of landscape position (distance from fenceline) and environment type on seed removal from seed caches (Spafford Jacob *et al* 2006).**



Practicalities

Key practicality #1

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

Predation appears to be higher for some species such as annual ryegrass and wild radish in situations close to refuge areas (e.g. remnant vegetation or fencelines), and decreases with increasing distance from the refuge (Figure T1.2-1, above).

Although validating studies have not been conducted, it is possible that provision of refuges or 'island' habitats (e.g. remnant vegetation strips and commercial tree planting) within a field may benefit seed predation, as most ant species are opportunistic and will invade disturbed habitats.

PHOTO: ANDREW STORRIE

Grass seeds collected by ants.

Key practicality #2

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

Recent work in Western Australia has suggested that ants are responsible for 75 per cent of total seed losses on the edges, and close to 100 per cent at the centre, of paddocks. Farming practices that affect ant populations therefore have the biggest impact on potential seed predation.

Prolonged broad spectrum insecticide use will decrease the number of 'friendly' insects in paddocks. For example, insecticides used to control the Australian plague locust (e.g. fenitrothion, an organophosphate) may greatly reduce ant populations. Minimising the use of such insecticides and choosing to use more selective products can reduce the impact on the key predating species. This is especially important during the warmer months, when ants are most active.

Key practicality #3

Manage stubble according to the type of seed predator present

Retaining stubble is a two-edged sword. Stubble can provide a refuge for predatory insects but it also discourages heat-loving ant species which prefer open spaces. Most ant species also prefer a perfect line of sight, which is needed for insects (especially ants) to be efficient seed predators.

Stubble type is also important. Compared to cereal, canola stubble can reduce the numbers of some ant seed removal by grain-eating insects.

Key practicality #4

Minimum tillage improves predation of weed seeds

It is thought that a cropping system that employs a minimum amount of soil disturbance is optimal (e.g. using a tined seeder with knife points).

Tillage, especially in heavy clay soils, reduces ant populations. However, zero disturbance encourages dominant, non-seed-preferring species such as the Australian meat ant, which will displace other grain-eating ant species

Key practicality #5

Soil disturbance over summer reduces seed predation

Any soil disturbance over the summer months, including grazing livestock, will dramatically reduce ant species and, consequently, the level of wild radish seed pod removal, particularly early in summer.

Contributor

David Minkey

TACTIC 1.3 INVERSION PLOUGHING

Inversion ploughing is used to fully invert the soil to ensure that weed seeds that were on or just below the soil surface are placed at a depth from which they cannot germinate. This can be practised every 10 to 15 years without detrimental effect to the environment, where zero or reduced tillage is used in the intervening years. This length of time is required for weed seeds to die and non-wetting waxes to break down. Inversion ploughing is particularly effective at resetting the weed seedbank and is very useful if herbicide resistant weeds are a problem.

Inversion ploughing has been adopted in Western Australia using commercial two-way machines, a modified mouldboard plough with skimmers to assist with total soil inversion. The technique is used after the break of season when the soil profile is wet to a depth of at least 40 cm.

The process has been successful on a range of soil types, including duplex sands over clay, loamy clays and deep sands. It should be noted that for self-mulching soils many weed seeds will already be deeply buried in soil cracks and inversion ploughing may not be as effective on this soil type for weeds that can emerge from greater than 100 mm depth.

Although whole paddock inversion ploughing is quite expensive (estimated at the time of writing at \$70 to \$100/ha on deep sands for an owner/operator machine and \$125/ha plus diesel for a contractor), there are long-term benefits for the reduction of the weed seedbank and the amelioration of soil problems such as water repellence and subsurface acidity.

Benefits

Key benefit #1

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

After long-term reduced tillage most weed seed is located in the top few centimetres of soil, where it readily germinates. Nearly all annual weeds of cool season cropping emerge from the top 10 cm of soil and annual grasses have relatively short-lived seeds. However, burial of all seeds at depth extends the longevity of the seedbank. Therefore it is recommended that inversion ploughing for weed management occurs 10 to 15 years apart (see *Tactic 2.1 Fallow and pre-sowing cultivation* – Table T2.1-1, page 117).

PHOTO: PETER NEWMAN

Mouldboard plough working near Geraldton showing skimmers in action.

PHOTO: PETER NEWMAN

Effective depth of mouldboarding to bury weed seeds for the long term.

Weed seeds fail to establish and eventually die when soil is fully inverted to a depth of greater than 20 cm using a specialist mouldboard plough fitted with skimmers (Douglas and Peltzer 2004). The skimmers relocate topsoil to the bottom of the previous plough furrow, thus burying seed at a greater and more uniform depth than the mouldboard plough alone would do.

A single soil inversion event reduced annual ryegrass (*Lolium rigidum*) numbers by over 95 per cent at Katanning and Beverley, Western Australia, for a period of two years (Douglas and Peltzer 2004). This resulted in substantially higher grain yields (Figure T1.3-1, page 103) due to a combination of reduced weed competition and an increase in soil nitrogen (the rate of mineralisation is higher in disturbed soil). Over nine trials in the northern cropping belt of Western Australia between 2007 and 2010 the average control of annual ryegrass and wild radish (*Raphanus raphanistrum*) was 96 per cent and 83 per cent respectively (Newman 2011).

Whole-farm benefits

Additional benefits from inversion ploughing include:

- disease and insect control due to the burial of stubble
- amelioration of non-wetting soils
- nitrogen mineralisation
- removal of any nutrient stratification in the soil (i.e. mixing of nutrients concentrated in one layer of the soil, usually the surface)
- opportunities for soil ameliorant (e.g. lime) application at depth.

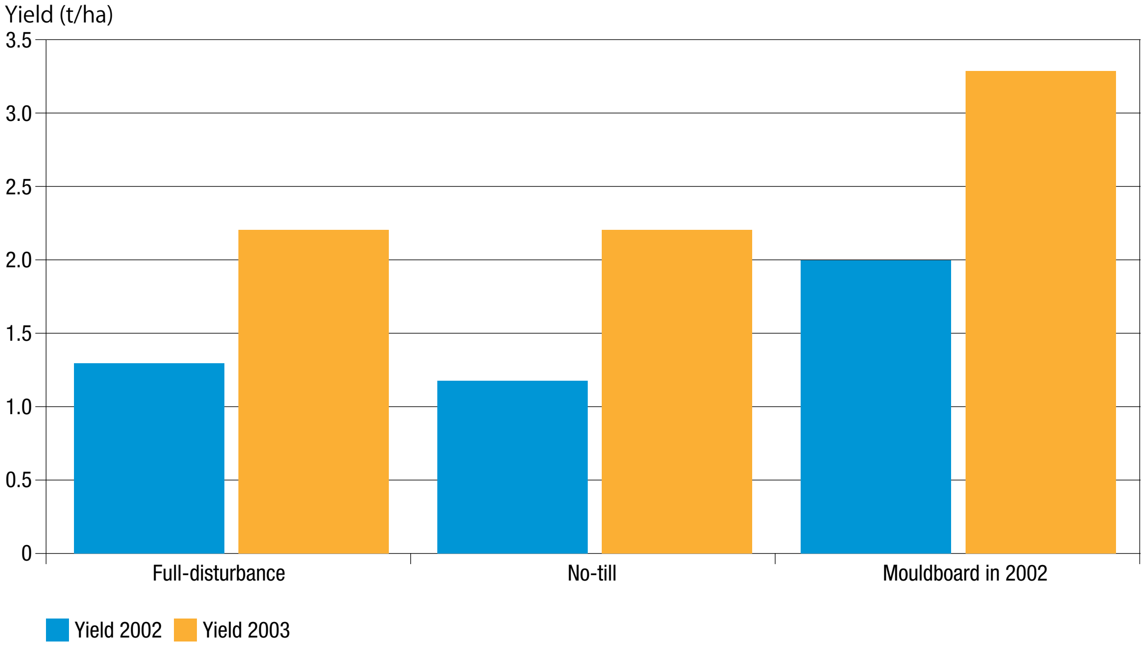
Practicalities

Key practicality #1

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

Soil inversion is not suitable for the control of all weed species. Although most species are unable to emerge from depths greater than 10 cm, a reinversion in later years may bring up viable seed of dormant weed species. Knowledge of the seed survival characteristics of the target weed is important (see *Section 6 Profiles of common weeds of cropping,* page 249).

FIGURE T1.3-1 The effect of three tillage treatments (full-cut cultivation, no-till and mouldboard ploughing in 2002 only) on the yield of barley (mean of four replicates) in 2002 and 2003 at Katanning (Douglas and Peltzer 2004).



Key practicality #2

Appropriate soil type is needed for effective soil inversion

Soil inversion is limited to soil types where there is sufficient topsoil to allow full inversion. Shallow duplex soils where the clay is less than 15 cm deep, for example, are unsuitable. It is also difficult to achieve the complete inversion needed for effective weed control in soils with a large number of rocks and/or stumps. Auto-reset mouldboard ploughs have the ability to plough soils with rocks and/or stumps as the plough jumps the rock or stump. However, soil inversion is compromised when the plough jumps.

In situations where soils exhibit problems at depth (e.g. rocks, clay, sodicity, salinity, boron, magnesium, manganese) soil inversion should be avoided, as it may bring these problems to the surface. Conduct soil tests where problems are suspected.

Key practicality #3

Inversion ploughing of moist soil followed by the immediate sowing of a crop will reduce the risk of wind and water erosion

Inversion ploughing is best performed with a moist soil profile, and is immediately sown to a cereal crop. Cultivation of dry soil will lead to incomplete inversion and increase the draught requirement.

Rolling following ploughing is essential on sandy soils. Cereal crops are less prone to sandblasting compared with broadleaf crops (Newman 2011). Also if a pulse is sown it is highly recommended that the seed is inoculated because much of the soil containing rhizobia from previous crops is likely to be below 20 cm, and may therefore delay or prevent nodulation.

Be aware that yield reductions may be incurred due to the delay in sowing while waiting for the soil profile to become wet; however, yields from later sown crops are higher if serious weed and soil issues are ameliorated.

Key practicality #4

Mouldboard ploughs must be operated and set up correctly to achieve total inversion

Considerations include:

- Eight to 14 furrow ploughs cutting 3 to 6m at a speed of 8 to 8.5 kph equates to 2.5 to 5 ha per hour.
- Ploughs work to a depth of 30 to 35 cm.
- The horsepower required is roughly 35 hp per board and perhaps 40 hp for big machines (12 to 14 furrow) due to the weight of the machine.
- Cost of a new mouldboard plough is approximately $80,000 to $100,000 for an 8 to 10 furrow machine and $120,000 to $150,000 for a 12 to 14 furrow machine.
- Three-point linkage on the tractor is best but alternatively a tool carrier can be used.
- The paddock needs either light rolling prior to sowing or to be sown with lightweight seeding machinery such as an air drill where the weight of the seeding bar is carried by presswheels.

Key practicality #5

Occasional inversion ploughing is unlikely to be deleterious to soil structure

Tillage can have different effects on different soil types. For example, Chan and Hulugalle (1999) found tillage practices to be more deleterious on hard-setting red soil than on self-mulching clays.

One concern with inversion ploughing is the effect it has on both the structure and stability of the soil. Studies in the USA reported that five years after full soil inversion, most soil properties return to the levels of no-tillage systems (Kettler *et al* 2000; Pierce 1994).

Chan *et al* (2001) found that incorporating a pasture phase into a cropping system could improve the soil fertility of a hard-setting red soil in central western New South Wales. If using inversion ploughing, a pasture phase may be useful in repairing any soil structural damage caused by the inversion.

Contributors

Alex Douglas, Sally Peltzer and Andrew Storrie

TACTIC 1.4 AUTUMN TICKLE

Autumn tickling (also referred to as an 'autumn scratch' or shallow cultivation) stimulates weed seed germination by placing seed in a better physical position in the soil (Gill and Holmes 1997). At a shallow depth of 1 to 3 cm the seed has better contact with moist soil and is protected from drying. Because weeds that germinate after an autumn tickle can be controlled, such a process will ultimately deplete weed seed reserves.

An autumn tickle can be conducted using a range of equipment including tyned implements, skim ploughs, heavy harrows, pinwheel (stubble) rakes, dump rakes and disc chains.

Tickling can increase the germination of some weed species but has little effect on others (see *Key practicality #5*, page 107 and *Section 6 Profiles of common weeds of cropping,* page 249).

Tickling needs to be used in conjunction with delayed sowing (*Tactic 1.5 Delayed sowing*, page 109) for the greatest opportunity to control emerging weeds and deplete the seedbank.

Benefits

Key benefit #1

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

Between seed dispersal and the autumn break only 10 to 30 per cent of wild radish (*Raphanus raphanistrum*) seeds will germinate from the seedbank without stimulation (Murphy *et al* 2000). As a result, late germination flushes are common. These affect crop growth and yield, create management problems and further contribute to the weed seedbank.

Weeds that germinate as a result of an autumn tickle (including wild radish) are often subsequently controlled with a non-selective herbicide prior to crop sowing (Cheam *et al* 1998). This reduces in-crop weed pressure as well as reliance on selective herbicides.

Trials in Western Australia (Hashem *et al* 1998) showed that an autumn tickle followed by application of a non-selective herbicide can be very effective in depleting annual ryegrass (*Lolium rigidum*) and wild radish seedbanks (see Tables T1.4-1, below, and T1.4-2, below). The effect of climate on the success of an autumn tickle is also shown in Table T1.4-2, comparing results from the Wongan Hills site (medium) with those from the Merredin site (dry). For best weed seed germination it is important for soil to have adequate moisture.

TABLE T1.4-1 Effect of autumn tickle on wild radish soil seed reserves in Western Australia (Hashem *et al* 1998).

Treatment	Wild radish seedling emergence per m^2 (pre-sowing)	Wild radish density per m^2 (post-sowing)	Wild radish seedbank depletion before sowing (%)
With tickle	160	66	55
Without tickle	3	201	4

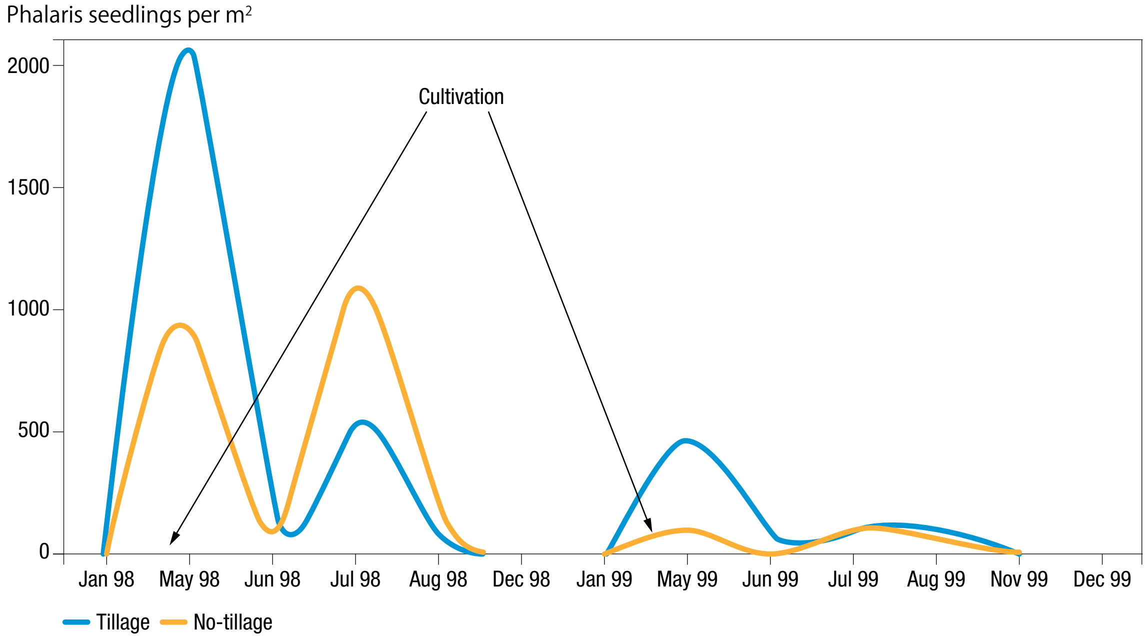
TABLE T1.4-2 Effect of autumn tickle on annual ryegrass seedbank at Wongan Hills and Merredin, Western Australia (Hashem *et al* 1998).

Treatment	Depletion of annual ryegrass seedbank before sowing (%)	
	Wongan Hills (medium)	Merredin (dry)
With tickle	63	51
Without tickle	31	1

Research on paradoxa grass (*Phalaris paradoxa*) in southern Queensland has shown that, compared with uncultivated soil, shallow cultivation in autumn increased overall seedling emergence by 40 per cent (Taylor *et al* 2005). The shallow cultivation also increased emergence of paradoxa grass in May, which would have otherwise reached peak emergence in July (Figure T1.4-1, page 106).

Tactics

FIGURE T1.4-1 **Comparing the effect of presence and absence of cultivation on emergence of paradoxa grass seedlings over two years after sowing in 1997 (Taylor *et al* 2005).**



Practicalities

Key practicality #1

Autumn tickle should be used in conjunction with another tactic

Failure to kill weeds germinated by an autumn tickle may cause transplantation of weeds during sowing and can lead to a significant in-crop weed problem. If the time between tickle, germination and crop sowing is insufficient, a mass germination is likely to occur as the crop establishes.

Key practicality #2

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

Autumn tickle can be performed any time in autumn or winter, but post-cultivation erosion risk will be minimised when cultivation occurs closer to sowing.

Ideal conditions for an autumn tickle are following a rainfall event of 20 mm or more when the topsoil is wet and germination occurs evenly. The top 4 cm of soil must be moist for at least 10 days, and other conditions (e.g. the diurnal temperature) must be conducive to germination for the majority of non-dormant seeds to germinate and emerge. Marginal moisture conditions may result in staggered weed germination.

An autumn tickle is usually only effective after a timely break. Its impact is often greatest in paddocks that are to be sown last (see *Tactic 1.5 Delayed sowing*, page 109) and in situations where a high weed density is expected.

Key practicality #3

Soil type is critical for a successful autumn tickle

Light-textured (sandy) soils, non-wetting soils and those where moisture has trouble penetrating the soil profile are poor candidates for autumn tickling. Where soils wet unevenly, weed seeds may be buried in pockets of dry soil. These pockets may become wet during the season, with seeds subsequently germinating to cause in-crop problems.

On sandy soils even light cultivation can leave the surface exposed to wind erosion, and cultivating dry soil exacerbates the erosion problem. Avoid using an autumn tickle in paddocks prone to sandblasting (e.g. sandhills and sandplains).

Key practicality #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

An autumn tickle is a useful tool to consider in non-crop years because it can increase the proportion of the seedbank that germinates. The use of grazing pressure and non-selective weed management tactics can ensure that minimal weed seed is set. In these paddocks early germination of weeds can provide valuable feed for livestock while newly sown legume pastures in other paddocks establish.

Key practicality #5

The efficacy of an autumn tickle will vary with weed species

Autumn tickling is a tactic best suited to weeds that are easily released from dormancy.

Those seeds that germinate readily in the top layer of soil and in response to changing light exposure are ideal candidates. Annual ryegrass, paradoxa grass, wild radish and fumitory (*Fumaria* spp.) all respond well to an autumn tickle (see *Section 6 Profiles of common weeds of cropping*, page 249).

Dormancy in annual ryegrass and paradoxa grass is affected by light. Movement of seed to the surface or flashes of sunlight during cultivation may be enough to stimulate germination (Steadman *et al* 2004; Taylor *et al* 2004). The autumn tickle will only be an effective weed management tactic if adequate seedset control is applied after stimulation of germination in the first year, preventing further seedset.

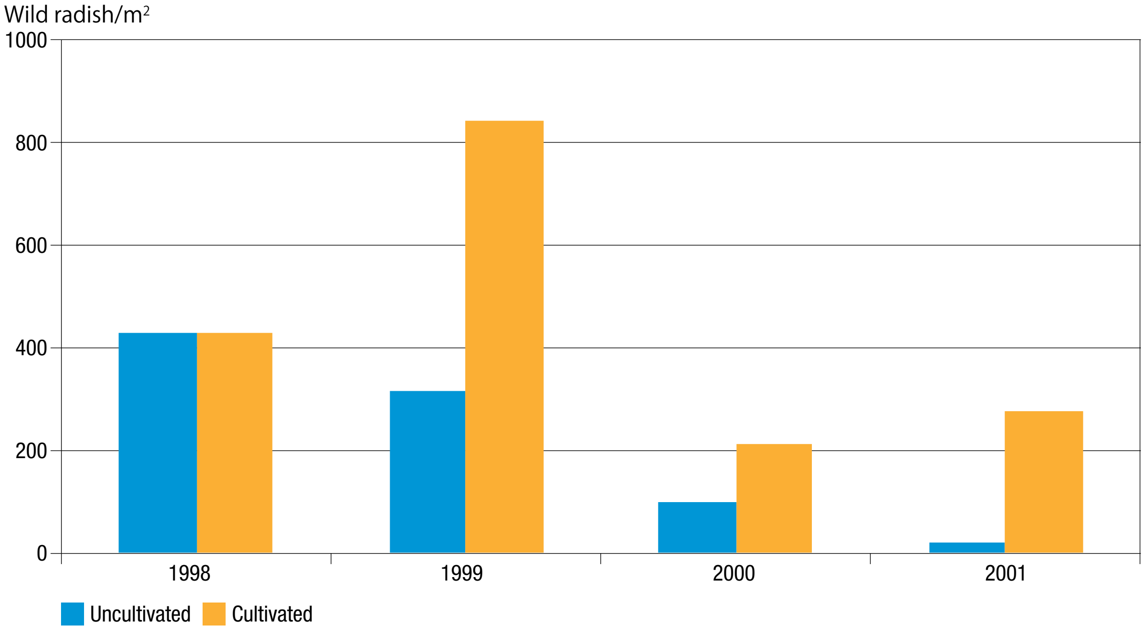
The increased germination of paradoxa grass over two years after cultivation in March in both seasons, compared with no cultivation, is shown in Figure T1.4-1 (page 106). Cultivation stimulated increased germination of paradoxa grass in both years, with an additional response to cultivation in the second year.

A similar response can be achieved with annual ryegrass, although it will be limited to the first year after seedset because dormancy mechanisms are lost as the seed ages in the soil (Peltzer and Matson 2002).

An autumn tickle will increase wild radish emergence, but predominantly in the second year after seedset (Figure T1.4-2, page 108). The seeds of wild radish have seed coat dormancy and are enclosed in a hard pod which also delays germination (Young and Cousens 1999). The suggestion is that a year in the soil in combination with tillage is needed to cause the pod to break down and allow the seed to germinate. The response to autumn tickle in the first year after seedset (Figure T1.4-2) is explained by germination of damaged pods, which occurs when wild radish that has passed through the header is dropped back into the header trail (Peltzer and Matson 2002).

Where weeds such as barley grass (*Hordeum* spp.), great brome (*Bromus diandrus*) and *vulpia* (*Vulpia* spp.) are the main problem, autumn tickling is an unnecessary tactic. These weeds have little or no dormancy and will germinate with the break in the first season without stimulation. However, some populations of barley grass are evolving a cold requirement and germinating l ater than other barley grass populations (see *Section 6 Profiles of common weeds of cropping,* page 249). These populations will be poor candidates for tickling.

FIGURE T1.4-2 The number of tickled (cultivated) and uncultivated wild radish seedlings emerging per year at Mount Barker, Western Australia (Peltzer and Matson 2002).



Whole-farm considerations

Determine the suitability of autumn tickle as a weed management tactic by considering the following points:

- Soil disturbance prior to sowing can reduce soil moisture, placing the sowing operation at risk in a dry season.
- Soil disturbance prior to sowing can incorporate stubble and, as a result, significant amounts of soil nitrogen will be tied up by microbes that proliferate to degrade the stubble.
- In the early stages of no-till adoption, short-term nitrogen deficiencies are likely if stubble levels are high.
- Sowing must be delayed sufficiently after an autumn tickle to enable weeds to germinate and be killed before sowing. Changes to crop type or variety to minimise the downside of a later sowing date will need to be considered.

Contributors

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TACTIC 1.5 DELAYED SOWING

Delayed sowing (seeding) is the technique of planting the crop beyond the optimum time for yield in order to maximise weed emergence. Weeds that emerge in response to the break in season can then be killed using a knockdown herbicide or cultivation prior to crop sowing.

This tactic is most commonly employed for paddocks that are known to have high weed burdens. Paddocks with low weed burdens are given priority in the sowing schedule, leaving weedy paddocks until later. This allows sufficient delay for the tactic to be beneficial on the problem paddock without interrupting the whole-farm sowing operation.

Choosing a crop or cultivar with a later optimum sowing time can reduce the risk of reduced yield.

Benefits

Key benefit #1

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

Delayed sowing can reduce early crop competition via management of early germinating weeds prior to sowing. For this tactic to be successful, sowing must be delayed until the first flushes of weeds have emerged and have been controlled either by knockdown herbicides, cultivation or a combination of the two (see *Tactic 2.1 Fallow and pre-sowing cultivation*, page 113; *Tactic 2.2a Knockdown (non-selective) herbicides for fallow and pre-sowing control,* page 124 and *Tactic 2.2b Double knockdown or 'double knock',* page 128, for information on controlling weeds after they have germinated and prior to delayed sowing).

Up to 80 per cent of annual ryegrass (*Lolium rigidum*) emergence occurs within four weeks of opening rain (Gill and Holmes 1997). Allowing this seed to germinate and providing subsequent control measures will deplete the weed seedbank.

Research in South Australia (Matthews *et al* 1996; Matthews and Powles 1996) clearly demonstrated that a sowing delay of three weeks decreased in-crop annual ryegrass by an average of 52 per cent, and the quantity of weed seed produced by 21 per cent (Table T1.5-1, page 110).

PHOTO: DI HOLDING

Delayed sowing allows use of knockdown herbicides or cultivation to control small weeds prior to sowing and reducing the pressure on selective herbicides.

TABLE T1.5-1 Effect of a three-week delay in sowing on the number of mature annual ryegrass plants in the crop and on the following seedbank (Matthews *et al* 1996).

Crop species	Annual ryegrass plants or seeds/m²			
	Early sowing		Late sowing	
	Plants	Seeds	Plants	Seeds
Field peas	234	15,955	104	12,011
Barley	367	2240	152	1060
Wheat	419	5557	237	5791

In field studies Gill and Holmes (1997) found that 11 to 30 per cent of in-crop annual ryegrass density could be reduced with each progressive week of sowing delay.

Key benefit #2

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

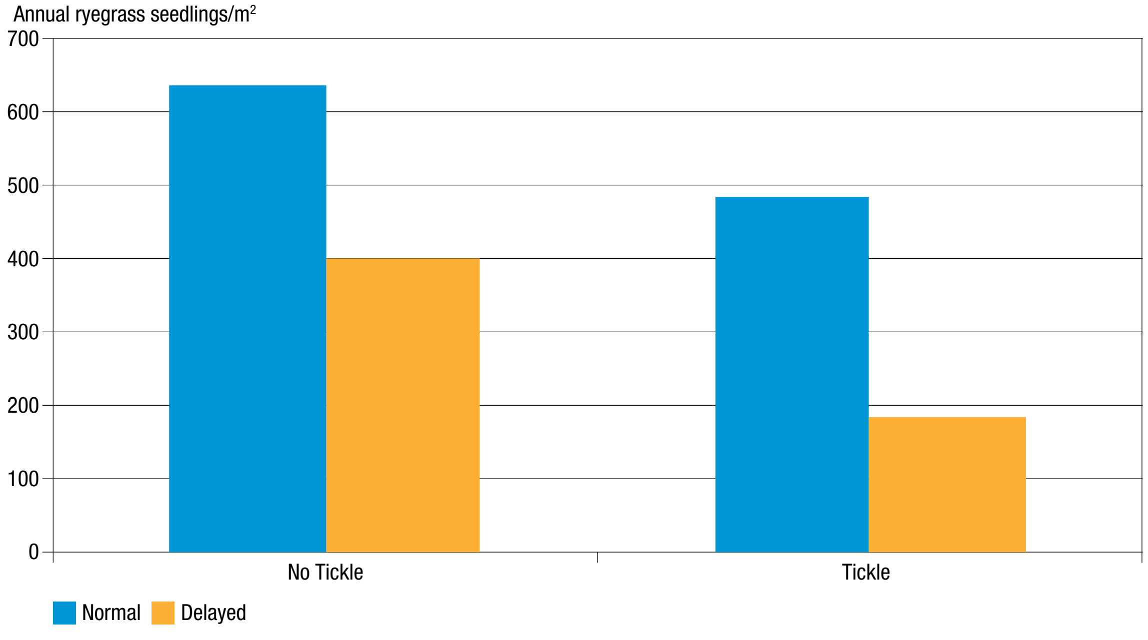
Delayed sowing is most effective when used in conjunction with another tactic. The additional benefit which can be obtained by combining an autumn tickle with a delayed sowing tactic is shown in Figure T1.5-1 (below).

In trials at Wongan Hills, Western Australia, autumn tickling conducted three weeks prior to normal sowing time (equivalent to six weeks prior to late sowing) stimulated emergence of 1700 seedlings/m² of annual ryegrass prior to sowing, compared to 460 seedlings/m² in the 'untickled' treatment.

These seedlings were subsequently controlled using knockdown herbicides. At this stage, two sowing treatments were trialled (normal sowing and delayed sowing) and in-crop annual ryegrass numbers were reassessed three weeks after sowing time in each instance (Figure T1.5-1).

In the crop sown under optimum conditions for crop yield (normal sowing time at 31 May and with 120 kg/ha seed) a weed management benefit was seen in the autumn tickle treatment.

FIGURE T1.5-1 Comparison of delayed sowing versus normal sowing time and the impact of autumn tickling (with follow-up knockdown herbicides used prior to sowing) on reductions in annual ryegrass seedlings in-crop three weeks after sowing, Wongan Hills, Western Australia (Hashem *et al* 1998).



There were 24 per cent less in-crop annual ryegrass plants when compared to the 'untickled' plots (Figure T1.5-1, page 110).

However, the greatest weed management benefit was obtained from the autumn tickle used in conjunction with delayed sowing (three weeks after normal sowing time at 20 June). Compared to the normal sowing time, the density of in-crop annual ryegrass that emerged was reduced by 37 per cent in the untickled and 70 per cent in the tickled treatment. The later sowing time allowed for more weed seedlings to emerge and be adequately controlled prior to sowing of the crop (Figure T1.5-1, page 110).

Practicalities

Key practicality #1

Target problem paddocks first and sow them last

The benefits of delayed sowing for weed control have to be offset against reduced yield potential of the crop. Most crops will experience reduced yields as a direct outcome of delayed sowing.

Use delayed sowing in paddocks with high numbers of a weed that will germinate on the first significant rain, or in paddocks with herbicide resistant weed populations. In these situations a calculated risk of a potential lower yield may be the best option to enable weed seedbank reduction.

For wheat it has been estimated that yield potential declines approximately 4 to 7 per cent for every week that sowing is delayed past the optimum sowing window (Matthews *et al* 2012). The impact of this decline on yield and gross margin for up to 12 weeks' delay in sowing is shown in Table T1.5-2 (page 112). It highlights the importance of choosing a crop and variety suited to later sowing to reduce the costs associated with this tactic.

The impact of delayed sowing on crop yields will be influenced by the type of growing season experienced in the area. Crop variety sowing guides produced by the different state departments of agriculture and primary industry around Australia will give a guide to optimal sowing windows for different crops and their respective varieties.

Key practicality #2

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

Crops such as chickpeas, field peas or barley can be sown later in the cropping program, making them more suited to delayed sowing as a weed management tactic than early sown crops such as canola and lupins.

French and Maiolo (2007) found delaying lupin sowing nine days after the break in Merredin in 2006 did not reduce annual ryegrass numbers due to rapid drying of the soil surface and subsequent lack of weed emergence. Later sown lupins also yielded less than lupins sown on the breaking rain as the weed numbers were the same in both treatments.

When planning delayed sowing with wheat choose a quick maturing variety suited to the later sowing window.

Key practicality # 3

Seasonal conditions will influence delayed sowing opportunities

Delays to the start of the growing season will severely restrict the potential to wait for the first flushes of weed germination and subsequent pre-sowing control. In such seasons good paddock planning will help to identify paddocks that are likely to have high weed burdens.

If the season has a late break, consider omitting very weedy paddocks from the cropping program. This will allow for other weed management tactics to be employed in readiness for the following season.

TABLE T1.5-2 The impact of sowing time on yield and gross margin of short fallow wheat given a yield penalty of 5.5% per week and in the absence of weeds.

Number of weeks delay	Yield estimate (t/ha)	Variable cost ($/ha)a	Gross margin ($/ha)
0	3.5	230	295
4	2.7	220	185
6	2.3	210	135
8	1.9	200	85
12	1.2	190	0

a Variable cost decline with delay due to likely reductions in fertiliser input and lower freight costs associated with lower yield.
Note: Gross margin for 0 weeks delay sourced from NSW Department of Primary Industries crop budgets handbook.

Contributors

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TACTIC GROUP 2 KILL WEEDS (SEEDLINGS) IN THE TARGET AREA

Killing weeds in the target area with cultivation has been the focus of weed management since agriculture was first developed. Since the release of *glyphosate* and Group A and B herbicides in the early 1980s herbicides became a primary tool for controlling weeds due to their cost effectiveness, high levels of control and ease of use. However, as discussed in *Section 2 Herbicide resistance* (page 27), this approach to controlling weeds has led to the development of herbicide resistance. Despite herbicide resistance, herbicides remain an important tool, but require support from a range of non-herbicide tactics to remain effective.

Tactic 2 includes fallow and pre-sowing cultivation, double knock, pre- and post-emergent herbicides, weed detector spraying, wide-row cropping and biocontrol.

TACTIC 2.1 FALLOW AND PRE-SOWING CULTIVATION

Cultivation, as a function of fallowing and pre-sowing operations, can kill many weeds including herbicide resistant populations (see *Section 3, Agronomy 5 Fallow phase,* page 81 and *Tactic 1.3 Inversion ploughing,* page 101). It is useful as a one-off tactic in reduced tillage or no-till operations, and can be used as a non-herbicide component of a 'double knock' system (see *Tactic 2.2b Double knockdown or 'double knock'*, page 128).

Benefits

Key benefit #1

Well-timed cultivation effectively kills weeds

Cultivation destroys weeds via a number of processes, including:

- plant burial
- seed burial, thus reducing the ability to germinate
- root severing
- plant desiccation, where plants are left on the soil surface to die
- breaking seed dormancy
- placing seed in a more favourable environment to encourage germination for subsequent control.

The impact of cultivation will depend on the weed species. Surface germinating weeds such as sowthistle (*Sonchus* spp.), prickly lettuce (*Lactuca serriola*), feathertop Rhodes grass (*Chloris virgata*) and fleabane (*Conyza* spp.) revert to minor problems once cultivation is practised as seed is buried deeper than is ideal for these species. Seed of annual ryegrass (*Lolium rigidum*) will more rapidly lose viability at greater soil depths than when shallowly buried. Strategic cultivation and deep burial of annual ryegrass seed is therefore an ideal one-off tactic to reduce the size of the seedbank (Cheam and Lee 2005). Similar viability reduction responses to burial depth have been noted in feathertop Rhodes grass in limited northern grain region studies (Osten 2011), and current trials are validating this.

Key benefit #2

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

Pre-sowing cultivation following early rain can achieve a weed-free seedbed. Cultivation will also break up remaining weed residues and crop stubble that may impede sowing.

Different cultivation implements cause varying levels of soil disturbance. Selection of suitable equipment will depend on availability, weed species present, soil type, soil moisture and land use.

Key benefit #3

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

Cultivation can control seedlings or mature weeds in situations where herbicides do not provide effective control. This includes situations where weeds are stressed (e.g. dry conditions, nutrient deficiencies) or resistant to available herbicide options, or when herbicide sensitive crops are present nearby.

Cultivation can be a better option in situations where herbicides are perceived as high risk options such as near urban areas and schools.

Key benefit #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

(See *Tactic 2.2a Knockdown (non-selective) herbicides for fallow and pre-sowing control*, page 124 and *Tactic 2.2b Double knockdown or 'double knock'*, page 128.)

Incorporating strategic cultivation into a no-till farming system adds diversity to the weed management options used at sowing. Used in conjunction with stubble burning (see *Tactic 1.1 Burning residues*, page 92), cultivation enables the effective use of pre-emergent herbicides (see *Tactic 2.2c Pre-emergent herbicides*, page 133).

Cultivation prior to sowing, or full disturbance cultivation at sowing, will decrease the reliance on knockdown herbicides for weed control. Although environmental factors such as damage to soil structure and increased erosion risk must be considered when choosing to use multiple cultivations to control weeds in herbicide resistant paddocks, it may be the only option available.

Whole-farm benefits

Weed management can be an additional benefit obtained when cultivation is used for:

- incorporating phosphorus and/or soil ameliorants (e.g. lime or gypsum)
- overcoming nutrient stratification
- breaking up a plough pan
- pupae busting (e.g. breaking the life cycle of *Helicoverpa* spp. in cotton cropping systems).

Practicalities

Key practicality #1

Strategic cultivation must take into account whole-farm practicalities

Avoid repeated cultivation: use it strategically in situations where no suitable alternatives are available. Over-reliance on cultivation can increase weed control costs through increased labour and machinery inputs.

PHOTO: ANDREW STORRIE

Cultivation can be used to disrupt plough pans.

Cultivation should be carried out when weeds are relatively small before flowering commences. The soil should be neither completely dry nor completely wet. A drying profile is ideal. Under moist soil conditions, transplanting of seedling weeds often leads to incomplete weed kill, necessitating a second tillage operation.

The aim of cultivation is to displace plant roots from the soil matrix and leave the weeds to die. Root systems of large weeds may be extensive, making removal difficult. Weeds which are not fully dislodged by the cultivation may re-root if the surface soil remains moist. Some weeds, particularly perennials such as skeleton weed (*Chondrilla juncea*), silver-leaf nightshade (*Solanum elaeagnifolium*) and field bindweed (*Convolvulus arvensis*), can regenerate from roots left in the soil.

Key practicality #2

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

Cultivating when the soil is too wet can cause 'smearing' and compaction. On the other hand, cultivation when the soil is too dry can also destroy soil structure. Both will lead to reduced water infiltration and storage and soil aeration. Travelling faster than the recommended ground speed for a particular implement type will greatly increase the damage to soil structure.

Key practicality #3

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

Choose the right implement for the job. Depending on the target weed species, the best strategy may be to use a disc plough or mouldboard plough to invert the soil and bury a high proportion of weed seed (see *Tactic 1.3 Inversion ploughing*, page 101).

If burial prolongs the life of the weed seed, future cultivations may lead to germination and the problem may resurface (see *Section 6 Profiles of common weeds of cropping*, page 249). For these target weeds, scarifiers and cultivators that cause little soil disturbance (operating at less than 10 cm depth) may be the most suitable implements.

Alternatively a chisel plough fitted with narrow points can be used for deeper cultivation. Fitting of wider sweeps equips the implement for shallow cultivation and weed killing.

Key practicality #4

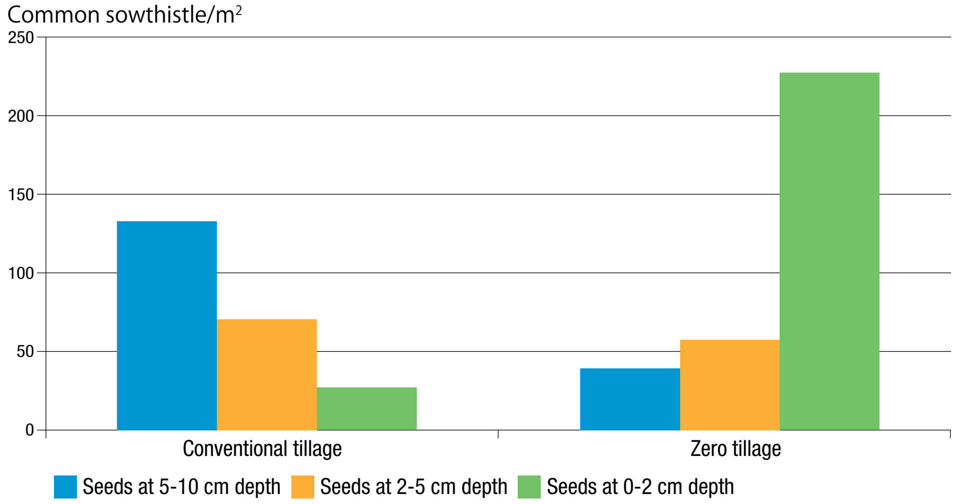
Choice of cultivation practice can influence weed density and spectrum

Knowledge of the target weed's biological traits will assist seedbank depletion. Growth of weeds that reproduce vegetatively (e.g. skeleton weed, nut grass (*Cyperus rotundus*), silver-leaf nightshade and field bindweed) will be encouraged by cultivation. In contrast, zero till and a dependence on herbicides will encourage the growth of weeds such as fleabane, common sowthistle, prickly lettuce and vulpia (Felton *et al* 1994).

PHOTO: ANDREW STORRIE

Cultivation failed to control the turnip weed.

FIGURE T2.1-1 Burial of common sowthistle seed under different tillage treatments. The conventional tillage treatment is a disc plough followed by a chisel plough (Widderick *et al* 2002).



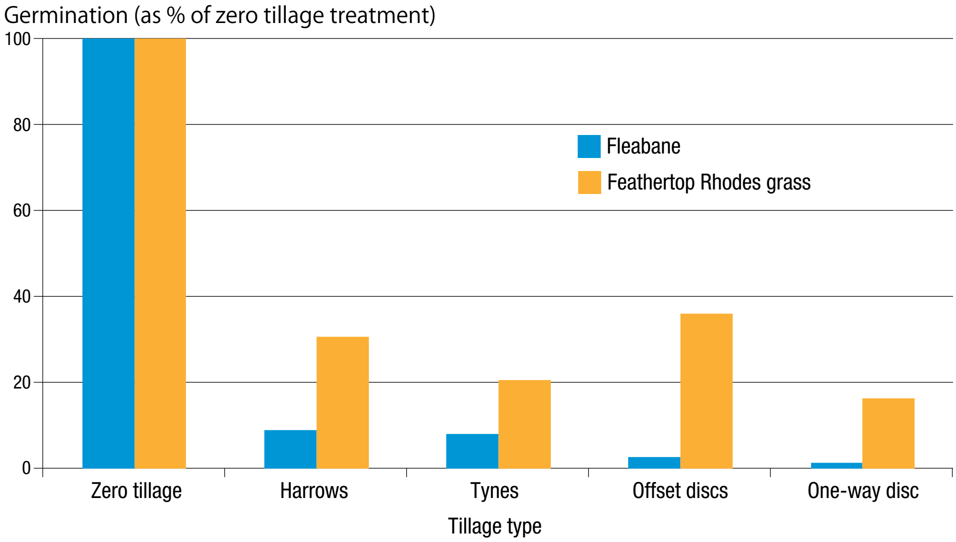
Common sowthistle (*Sonchus oleraceus*) is recognised as a weed of zero and reduced tillage systems. As most seedlings emerge from the soil surface (0 to 2 cm), tillage is often used as a control tactic. However, although it reduces the initial impact from sowthistle, the practice also prolongs the problem as the small seeds are able to survive at a depth of 10 cm for as long as 30 months (Widderick *et al* 2002).

The effect of burying seed of common sowthistle is shown in Figure T2.1-1 (above), comparing conventional tillage (disc plough followed by chisel plough) with zero tillage. As buried common sowthistle seeds are much less likely to germinate than those left at the soil surface, zero tillage may be a beneficial practice to reduce the seedbank, providing that effective management tactics are used to control emerging weeds.

Ongoing research in 2011-12 (unpublished) has also demonstrated the impact of different tillage types on the germination of the zero till favouring weeds, fleabane and feathertop Rhodes grass (Figure T2.1-2, below). Results showed germination for both weeds was significantly reduced by all tillage types but with the greatest impact measured in the one-way disc treatments.

Deep burial of wild radish seed also lengthens its survival. Code *et al* (1987) found that the number of viable seeds remaining after four years was much greater when seed was buried at

FIGURE T2.1-2 Germination (expressed as a % of the zero tillage treatment) of fleabane and feathertop Rhodes grass following different tillage types.



10 cm depth in the soil, compared to shallow burial (1 or 5 cm) or being left on the surface (Table T2.1-1, below). The seeds persist in the soil for a longer period of time because the seedlings cannot emerge from depth (Table T2.1-2, below). Subsequent cultivations following deep seed burial would need to be shallow, to avoid raising the seeds to soil depths where germination would be promoted.

Murphy *et al* (1999) found that wild radish emergence was significantly greater after direct drilling than after tillage using a scarifier, disc plough or mouldboard plough. Emergence was also greatest when the seed was shallowly buried (less than 5 cm).

TABLE T2.1-1 Wild radish survival in the soil (% of total remaining) depending on depth of burial in the soil (Code *et al* 1987).

	Survival in the soil (% of total remaining) Duration of burial (years)					
Depth of burial (cm)	0.5	1	2	3	4	6
0	43	19	5	4	5[a]	0
1	10	12	16[a]	5	3	1
5	55	47	52[a]	27	21	7
10	75	57	53	44	43	0

a Apparent increases in viability with time due to variation between samples.

TABLE T2.1-2 Emergence of wild radish from various depths (% of total seed sown in May 1977) (Code *et al* 1987).

	Emergence (% of total seed sown)					
Depth of burial (cm)	1977	1978	1979	1980	1981	1982
0	33	4	1	0.6	0.1	0.13
1	73	0.5	1	0.3	0.0	0.10
5	16	0.1	1	0.02	0.1	0.02
10	0.6	0.0	0.02	0.0	0.0	0.00

Results indicated that under reduced tillage systems wild radish emergence may be enhanced. Provided that seedlings were effectively controlled and seedset was prevented, reduced tillage systems may achieve a more rapid depletion of viable wild radish seeds in the soil, compared to tillage systems that create a higher degree of soil disturbance (Murphy *et al* 1999).

The outcome of shallow burial, compared to seeds left on the soil surface, will be dependent on the weed species being targeted.

Whole-farm considerations

Cultivation reduces surface stubble cover that would otherwise be maintained for as long as possible to reduce erosion risk and optimise soil moisture storage.

The type of seedbed produced by cultivation will depend on soil type and moisture content. Poorly timed cultivation, resulting in a poor seedbed, can lead to reduced crop emergence, herbicide damage and reduced herbicide performance.

Pre-season cultivation may improve the reliability of sowing time in some environments. In low rainfall environments pre-season cultivation may delay sowing.

Over-reliance on cultivation can:

- reduce soil cover from plant residues and increase the risk of erosion
- degrade soil structure
- reduce available soil water.

Contributors

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TACTIC 2.2 HERBICIDES

Herbicides have been in widespread use since the late 1940s. Western agriculture was significantly changed in the late 1970s when glyphosate, sulfonylureas and grass selective herbicides were released.

In the early years of herbicide use an integrated approach to weed management was seen as an unnecessary inconvenience to an effective and simple solution. The development of herbicide resistance is challenging this oversimplified approach.

Herbicides continue to play a vital role in integrated weed management. Better knowledge of the mechanisms and activity of herbicides will improve the impact and sustainability of the use of herbicides as a weed management tactic.

Development of new herbicides

Development of new herbicides is slow and expensive. To identify a single new compound that may become a potential herbicide, a minimum of 50,000 chemical compounds are screened (Pallet 2000).

Development processes include identification of new molecules, efficacy testing, assessment of crop and environment safety margins, and scoping of potential markets. The entire process can take up to 10 years to complete. Even then, despite proven efficacy levels, many potential herbicides do not continue through to commercialisation because of environmental constraints or limited market potential.

Herbicides are broadly categorised according to their mode-of-action (MOA). This refers to the essential function(s) within the target plant (weed) that suffer disruption when herbicide is used. MOA grouping assists in resistance management by clearly identifying which herbicides belong to the same MOA.

In 2000 there were 270 registered herbicide active ingredients in the world, categorised into 17 different MOA groups. Over 50 per cent of the herbicides lie within three MOA groups: Group B (e.g. sulfonylureas), Group C (e.g. triazines) and Group G (e.g. oxyfluorfen and carfentrazone).

In 1999 nine new herbicide announcements were made, all belonging to existing MOA groups, as follows:

- four Group B herbicides
- two Group C herbicides
- two Group A herbicides
- one Group G product.

In 2012 there was limited commercial release of a new pre-emergent herbicide for use in wheat and triticale, namely pyroxasulfone from the isoxazole chemical family. Despite this being a new herbicide for this use, it is still a Group K MOA. There is a low likelihood of new MOA groups being released, making it essential that current herbicide use is conservative and supported with non-herbicide tactics.

Some definitions

Translocated herbicides

Translocated herbicides move to the site of action via the transport mechanisms within the plant (the xylem and phloem). The xylem transports water and nutrients from the soil to growth sites and the phloem transports products of photosynthesis (sugars, etc.) to growth and storage sites. It may take up to two weeks for symptoms to develop on the target weeds, depending on herbicide rate, conditions and species.

Glyphosate is an example of a foliar applied translocated herbicide. It moves within both the xylem and phloem to the whole plant. This two-way interior movement improves the ability of glyphosate to kill the whole plant, including the roots, even when the plant is well established (although seedlings are often more sensitive).

PHOTO: ANNE DIXON

Melons (*Citrullus lanatus*) about to be sprayed with glyphosate + triclopyr, Kellerberrin, WA.

Soil applied translocated herbicides move within the plant via the xylem and are absorbed by germinating seeds, emerging roots and shoots and established roots. Examples of soil applied translocated herbicides are atrazine and metolachlor. In the case of atrazine, translocation can only occur in an upwards direction. As a result, when used as a post-emergent product, little of the herbicide gets to the roots and the control of established weeds is often very poor.

Contact herbicides

Contact herbicides have limited movement within the plant, so complete coverage of the target is critical. Compared to translocated herbicides (e.g. glyphosate), contact herbicides (e.g. paraquat, oxyfluorfen, diquat and bromoxynil) tend to show symptoms rapidly, usually within 24 hours.

As contact herbicides are not well translocated, they are best suited to controlling very small seedlings. Herbicides such as bipyridyls can also be quite effective at stopping seedset of annual weeds if applied directly to the flowers or soon there afteras a desiccant or 'spray-topping' application.

Selective and non-selective herbicides

Selective herbicides will kill target weed(s) but not desired plants (the crop or pasture) when applied at a specified application rate. The crop or pasture is able to survive this rate of selective herbicide applied because it may:

- have a slower rate of herbicide absorption. However, damage may be caused by the use of inappropriate adjuvants, which modify the leaf surface and thus increase absorption.
- not possess a relevant target site on which the herbicide can act (e.g. a grass selective herbicide used on a broadleaf crop)
- rapidly detoxify the herbicide, usually with enzymes called 'cytochrome P450', before the herbicide can reach the target site (e.g. fenoxaprop or a sulfonylurea used in wheat). However, these herbicides can damage the host crop or pasture if it is under stress or if the rate of application is too high and the plant cannot produce sufficient enzymes to detoxify the herbicide.

Non-selective herbicides (also called knockdown herbicides) such as glyphosate or paraquat will damage most plants they contact. The recent inclusion of genes for resistance to glyphosate into crop DNA can enable a non-selective herbicide to be used selectively in crops that have been specifically bred to be tolerant (see *Agronomy 3 Herbicide tolerant (HT) crops*, section 3, page 74).

Residual versus non-residual

Residual herbicides remain active in the soil for an extended period of time (i.e. months) and can act on successive weed germinations. Residual herbicides must be absorbed through either the roots or the shoots, or through both. Examples of residual herbicides include imazapyr, chlorsulfuron, atrazine and simazine.

The persistence of residual herbicides is determined by a range of factors including application rate, soil texture, organic matter levels, soil pH, rainfall or irrigation, temperature and the herbicide's characteristics. Persistence will affect enterprise sequence (e.g. a rotation of crops such as wheat–barley–chickpeas–canola–wheat).

Non-residual herbicides, such as the non-selective paraquat and glyphosate, have little or no soil activity and are quickly deactivated in the soil. They are either broken down or bound to soil particles, becoming less available to growing plants. They also may have little or no ability to be absorbed by roots.

Post-emergent and pre-emergent

These terms refer to the target and timing of herbicide application. Post-emergent refers to foliar application of the herbicide after the target weeds have emerged from the soil, while pre-emergent refers to application of the herbicide to the soil before the weeds have emerged.

Herbicide mixtures and sequential applications

Herbicide mixtures involve the application of more than one herbicide in a single operation. From a weed management perspective the primary reason for mixing herbicides is to increase the spectrum of weed species controlled. Application costs are also reduced when applying herbicide mixtures in the one tank.

The MOA of every herbicide is clearly stated on the product label. Some pre-mixes of herbicide comprise individual herbicides from different MOA groups. In such situations product packaging will identify which MOA groups are contained within the product.

Using tank mixes or sequential applications of herbicides in the same season may help to delay the development of herbicide resistance if they control the survivors of the other herbicide in the mix. Modelling by Diggle *et al* (2003) has shown that tank mixes (where both mix partners are applied at full label rates) and/or sequential applications are more effective at delaying resistance than application patterns that rotate MOA groups over a number of years. This approach is also more effective than pushing a weed population to resistance to one MOA group before progressing on to another group.

The long-term returns from delaying the onset of resistance will be high, particularly for highly valued herbicides such as glyphosate, and will balance the increased cost of weed management in that season. Tank mixes for resistance management should use the full registered rate of all products included in the mix. This will ensure that there is adequate alternate herbicide to kill those weeds that are resistant to the first product. Note that where the resistant proportion of the weed population is low, there will be little economic gain through inclusion of an alternate herbicide in that season.

Synergies between herbicide groups are uncommon. They are known to exist between some Group C (photosystem II inhibitors) when mixed with Group I (synthetic auxins) or Group H (HPPD inhibitors) herbicides (Hugie *et al* 2008).

Even where synergies are known to exist application rates should not be decreased to levels that are lower than if the products had been applied singularly.

Some combinations of herbicide products cannot be mixed due to antagonism. Mixtures of antagonistic products may damage crops and/or result in reduced weed control because of chemical or biological incompatibility. However, antagonistic herbicides can be applied in split (or sequential) applications, usually after a delay of one day to allow translocation of the first herbicide, but before symptoms appear.

Herbicide labels will contain some information on the compatibility of herbicide mixtures. The quality and amount of information varies between different labels so always seek advice before using unproven or novel mixtures. Use of such mixtures can also occasionally result in physical incompatibility (e.g. undesirable tank or nozzle blockages and sludges).

Herbicide uptake by plants

Foliar applied herbicides

A foliar herbicide's effectiveness is influenced by meteorological conditions, the distribution and composition of the spray droplets and the characteristics of the leaf surface on which it is deposited.

The herbicide enters the leaf either by diffusion through the leaf cuticle and epidermis, or directly through the stomata (although access via the stomata is minor with most herbicides).

The leaf cuticle protects the cells of the plant from desiccation. It is coated in various types of wax and fatty acids, depending on the species and the growing conditions the plant has experienced. The structure of the cuticle will influence herbicide entry into the leaf. The cuticular wax is more like a sponge than a solid layer, and an aqueous and a lipid route provide two means of access through this sponge.

When a plant is actively growing and well hydrated, water soluble herbicides (such as those from Group B MOA) diffuse rapidly via the aqueous route through the cuticular pores. This is possible because the pores are holes in the sponge and are full of water. In water stressed plants the pores form air pockets which disrupt the continuous aqueous path and slow the rate of diffusion.

The lipid route allows oil-soluble herbicides, such as emulsifiable concentrate formulations, to diffuse through the wax layer into the leaf. This route is less affected by moisture stress.

The effect of herbicide formulation and addition of adjuvants on diffusion through these pathways is complex and will not be discussed here.

Herbicides in the soil

Both foliar and soil applied herbicides may be present in the soil and absorbed through plant roots. Some herbicides (e.g. picloram) leak from plant roots (this is also known as herbicide flashback) and can be absorbed by other plants or reabsorbed by the same plant.

Root absorption

Water soluble herbicides (e.g. chlorsulfuron) are absorbed in water through root hairs and the area just behind the root tip.

Coleoptile and young shoot absorption

Some herbicides are primarily absorbed through the coleoptile and new shoots. These herbicides (e.g. triallate and trifluralin), which act mainly through root uptake with some shoot uptake, can be volatile and must be absorbed quickly to be effective. Non-volatile shoot uptake herbicides (e.g. diflufenican and metolachlor) rely on a moist soil surface for highest levels of absorption.

Translocation within the plant

Movement of herbicide within the plant occurs through:

- the cell wall continuum and xylem. This movement (e.g. in most Group C MOA herbicides) occurs with water and nutrients from the roots to the shoots.
- the minute cytoplasmic threads that extend through openings in cell walls and connect protoplasts of adjacent living cells and phloem. This movement (e.g. in 2,4-D and MCPA) occurs with sugars produced in the leaves and to areas of new growth, the roots and storage organs.
- a combination of the above. This movement (e.g. in glyphosate, picloram and dicamba) occurs with circulation within the plant.

Stressed weeds: what level of control can be expected?

Stressed weeds are harder to kill than healthy, actively growing weeds. Plants can be stressed and not show any distinct visual signs. Stress can be caused by:

- lack of moisture due to dry conditions, and physical or chemical impediments to root growth
- lack of oxygen due to waterlogging
- extremes of temperature, e.g. cold (frost) and heat
- nutrient deficiencies
- insect pests, e.g. aphids, wireworms
- disease
- a sub-lethal dose of herbicide from previous applications or soil residues
- mechanical damage, i.e. tillage or slashing.

Moisture stress is one of the most common plant stresses. Translocation and respiration slow dramatically when plants are moisture stressed, restricting the movement of herbicides to their sites of action. When herbicides are applied to stressed crops and pastures, herbicide breakdown via metabolic processes can be slowed, leading to crop or pasture damage.

Weeds that have suffered moisture stress may have limited leaf development but extensive root systems, developed to assist in the search for moisture. This means that the above ground plant biomass does not adequately reflect the true weed size or growth stage.

In the case of summer annual grasses the opposite is often true. A plant of liverseed grass (*Urochloa panicoides*) or barnyard grass (*Echinochloa* spp.) might be well-tillered but only have two or three roots, which means it stresses very quickly.

Plants experiencing high temperatures, low humidity and low soil moisture conditions tend to have a thicker cuticle (the protective cover of the leaf) with more waxy deposits on the surface. This reduces absorption of foliar applied herbicides.

The timing and amount of rainfall not only determines the moisture status of the plant but also removes dust from the leaves and modifies the leaf cuticle. Recent rainfall will therefore improve herbicide absorption.

Weeds may have sufficient soil moisture available but still be stressed by high (greater than 30°C) temperatures. This is a common cause of poor control in summer fallows.

Cold stress can also affect herbicide performance. For example, the efficacy of Group A MOA herbicides on grass weeds is greatly reduced if conditions prior to or just after application are very cold or frosty.

PHOTOS: ANDREW STORRIE

A paddock of wild oats showing moisture stress before sowing, Tamworth, NSW. Herbicide control now will be ineffective. Note the large blue patches of the stressed plants.

Wild oats showing moisture stress prior to cropping, Tamworth, NSW. Notice that the leaves are curled and the leaf colour is blue, not green.

Seasonal environmental conditions determine overall herbicide performance, and conditions on the day of spraying determine the variation around this level.

Once a weed has been subjected to stress it will not be adequately controlled by rates of herbicide that would otherwise be sufficient for unstressed weeds, even when there has been sufficient rainfall to make the weed appear healthy.

Additives such as ammonium sulfate, wetters and oils may help improve the control of stressed weeds by 10 to 20 per cent but can be unpredictable. Performance enhancements are specific to some herbicides or formulations, so always check the label.

How to tell if plants are moisture stressed

Symptoms of moisture stress include wilting, rolling of leaves and a dull blue colour. Photosynthesis and respiration will decline before these symptoms are visible.

Roots can indicate if a plant is actively growing. Carefully dig out the plant and gently wash the soil from the roots. Actively growing plants will have fresh white roots. Leaves of well-hydrated plants will be 'springy'.

To determine the extent to which grass is hydrated:

1. Remove the mid-vein of the leaf.
2. Hold the remaining portion of the leaf horizontally between thumb and forefinger.
3. Flick it down with the other hand.

A well-hydrated leaf will spring back to the horizontal position, while leaves from stressed plants will not return to the horizontal.

Contributors

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TACTIC 2.2a KNOCKDOWN (NON-SELECTIVE) HERBICIDES FOR FALLOW AND PRE-SOWING CONTROL

Knockdown herbicides lack species selectivity and therefore kill all plants when used in sufficient quantities under suitable spraying conditions. For this reason knockdown herbicides are used to control a wide range of weeds, either in a fallow or prior to sowing.

To simplify weed management certain *crop* cultivars (e.g. Roundup Ready® crops: see *Agronomy 3 Herbicide tolerant (HT) crops*, section 3, page 74) have been developed to tolerate some knockdown herbicides.

Knockdown herbicides also represent a key component of other weed management tactics, including:

- controlling weeds before sowing (see *Agronomy 2 Improving crop competition*, section 3 page 61 and *Tactic 1.5 Delayed sowing*, page 109)
- herbicide tolerant crops (see *Agronomy 3 Herbicide tolerant (HT) crops*, section 3, page 74)
- controlling weeds in fallow (see *Agronomy 5 Fallow phase*, section 3, page 81)
- inter-row application (see *Tactic 2.3 Weed control in wide-row cropping*, page 146)
- crop-topping (see *Tactic 3.1b Crop-topping with non-selective herbicides*, page 174)
- use of wiper methods (see *Tactic 3.1c Wiper technology*, page 178)
- crop desiccation (see *Tactic 3.1d Crop desiccation and windrowing*, page 181)
- pasture spray-topping (see *Tactic 3.2 Pasture spray-topping*, page 184)
- brown manuring and hay freezing (see *Tactic 3.4 Manuring, mulching and hay freezing*, page 195).

Since their development knockdown herbicides have become one of the most heavily relied upon weed management tactics. Glyphosate entered the world market in the late 1970s although high pricing initially limited its use. Prior to this, paraquat was more commonly used. Developed to deal with capeweed (*Arctotheca calendula*) in southern Australian farming systems, Spray.Seed® (paraquat + diquat) also improved the control of *Erodium* species and black bindweed (*Fallopia convolvulus*).

Glyphosate dominates the world knockdown herbicide market due to its ease of use and application rate flexibility. Increasing affordability in Australia has played a large part in its increased popularity (Figure T2.2a-1, page 125), allowing no-till farming to become more competitive with standard cultivation systems.

The use of glyphosate is likely to further increase due to:

- enterprise flexibility becoming increasingly important
- legislation aimed at curbing the off-target movement of herbicides leading to a reduction in the use of tank mixes of herbicides and the use of glyphosate at higher application rates
- increased fuel prices making cultivation more expensive.

PHOTO: ANDREW STORRIE

Summer fallow spraying Wickepin, WA

Paraquat and Spray.Seed® are also regaining popularity and are used in managing glyphosate resistance.

Benefits

Key benefit #1

Knockdown herbicides are effective

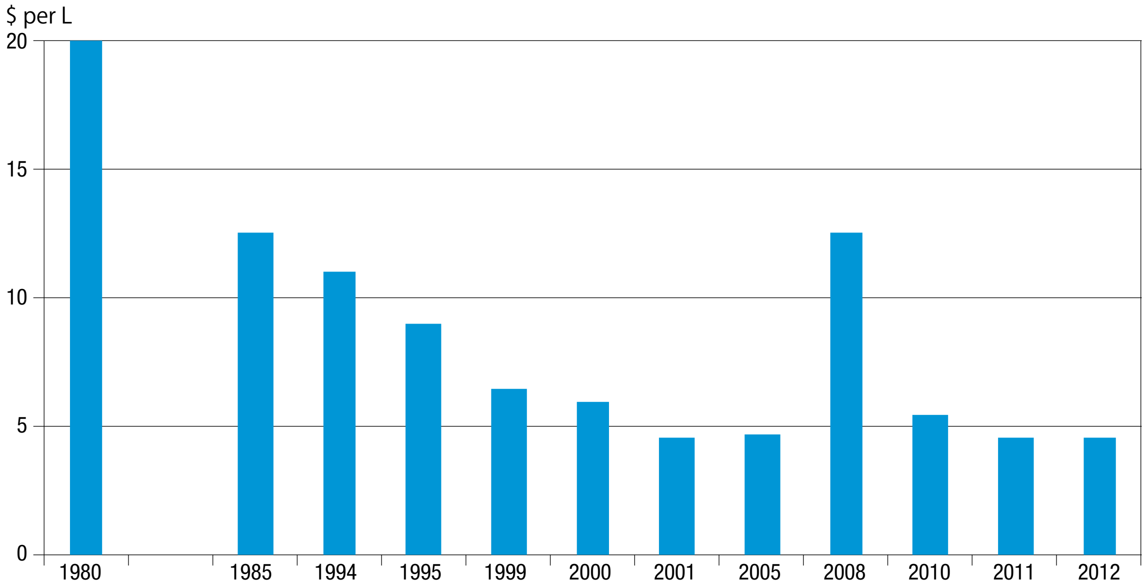
Over 95 per cent control can be expected when knockdown herbicides are applied under suitable conditions (Wallens 1983).

Key benefit #2

Knockdown herbicides are cost-effective

At the time of writing the cost of glyphosate for fallow and pre-sowing spraying is between \$4/L and \$8/L (Figure T2.2a-1, below).

FIGURE T2.2a-1 **The price of glyphosate (450 g/L) in Australia since its release in 1980.**



Spraying is also a quicker operation than cultivation: spraying can cover up to 50 ha/hour compared with about 8 ha/hour for cultivation. This means that one person can control weeds over a much greater area in a given time. The increasing price of fuel will increase the price advantage of spraying.

Key benefit #3

Use of knockdown herbicides can improve the timeliness of sowing

Spraying is usually quicker to conduct than cultivation, and this is particularly important after breaking rains. Minimum tillage paddocks are also able to be accessed more quickly after rain compared with conventionally cultivated paddocks.

As spray machines can be lighter than cultivation equipment, they are less likely to cause large wheel tracks or soil structural problems associated with cultivation of moist soil. Therefore, with less delay, crops can be sown closer to their optimum sowing date into better soil moisture.

Glyphosate can also be applied by air if conditions are too wet to get machinery onto the paddocks.

Whole-farm benefits

Maintaining plant residue cover on the soil for as long as possible will:

- reduce the risk of wind and water erosion
- help improve soil structure
- improve plant available water content (see *Tactic 2.1 Fallow and pre-sowing cultivation*, page 113).

Practicalities

Key practicality #1

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

At the time of writing, there are 411 documented glyphosate-resistant populations of annual ryegrass, 76 of awnless barnyard grass, 57 of fleabane, 11 of windmill grass, three of liverseed grass and three of great brome. See the Australian Glyphosate Sustainability Working Group website (www.glyphosateresistance.org.au) which provides up-to-date information on glyphosate and paraquat resistance.

Non-herbicide tactics must be used in an integrated weed management plan to save the effectiveness of our herbicides.

Key practicality #2

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

There are a number of considerations when choosing between a spray and a cultivation tactic for fallow weed control (Table T2.2a-1, below).

TABLE T2.2a-1 Fallow situations – suggestions for weed control (Somervaille and McLennan 2003).

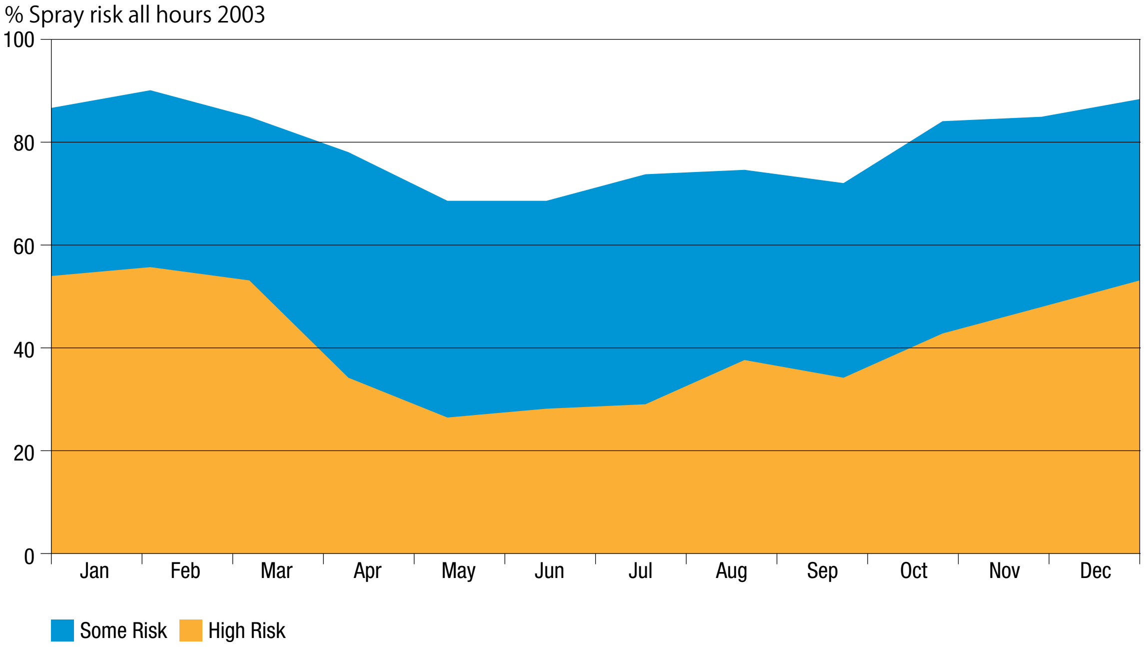
Situation	Cultivate	Spray
Weeds small and fresh		✓
Weeds stressed	✓	
Soil too wet for machinery		✓
Weather unsuitable for spraying	✓	
Weeds grazed but have not regrown	✓	
Excessive wheel tracks after harvest	✓	
Excessive stubble in windrows/disease control	✓	
Soil conditions suitable for planting		✓
Build-up of weeds not well controlled by herbicides – too large and/ or resistant	✓	
Wind erosion – paddock starting to blow	✓	

Key practicality #3

Stressed weeds will not be adequately controlled by knockdown herbicides

Weeds that are stressed do not readily absorb or translocate applied herbicide. As a result, only a sub-lethal dose of herbicide reaches the active sites within the plant, leading to low levels of weed control.

FIGURE T2.2a-2 **Effect of meteorological conditions on the risk of spray loss over an average 24 hours at Moree, New South Wales, during 2003 (Gordon, J., unpublished).**



Key practicality #4

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

Applying knockdown herbicides in unsuitable conditions leads to spray failure because insufficient herbicide reaches the target.

Movement of herbicides off-target (spray drift) can contaminate neighbouring enterprises, communities and native vegetation. The effect of meteorological conditions on the risk of spray loss (drift) at Moree, New South Wales, during 2003 is shown in Figure T2.2a-2 (above). November to March had a greater than 50 per cent risk of pesticide drift due to conditions that were too hot, dry, windy or still. This means that during this period at least 12 hours each day were unsuitable for spraying.

Contributor

Andrew Storrie

TACTIC 2.2b DOUBLE KNOCKDOWN OR 'DOUBLE KNOCK'

'Double knock' refers to the sequential application of two different weed control tactics applied in such a way that the second tactic controls any survivors of the first tactic. Most commonly used for pre-sowing weed control, this concept can also be applied in-crop.

The double knock approach to weed management was first used in the 1960s when direct drilling was still developing. The system comprised an application of knockdown herbicide (paraquat or paraquat/diquat) followed by full disturbance sowing.

Other double knock strategies include application of non-selective herbicide followed by burning or grazing. Although these combinations of tactics are still valid today, the trend towards no-till farming, with minimal disturbance sowing and often with wider crop rows, has led to the double knockdown technique.

The double knockdown technique is the sequential application of two knockdown herbicides from different MOA groups, such as glyphosate (Group M) followed by paraquat/diquat (Group L), at an interval of between one and 14 days. Used prior to sowing, each herbicide in the double knockdown must be applied at a rate which would be sufficient to control weeds if it was used singularly. The second herbicide is applied with the aim of controlling any survivors of the first herbicide application. Control of weeds that germinate during the interval between the two applications of herbicide is an incidental benefit.

It is important to understand that the double knockdown method is definitely not two sequential applications of the same knockdown herbicide. While this practice is used occasionally when there are a number of pre-sowing germination events, it does not include the key characteristic of minimising selection pressure for resistance.

Although double knockdown has primarily targeted annual ryegrass (*Lolium rigidum*) it is an effective tactic for use on a wide range of weed seedlings.

PHOTO: ANDREW STORRIE

Double knockdown treatment of glyphosate followed eight days later with paraquat on glyphosate resistant annual ryegrass, Spring Ridge, NSW.

Benefits

Key benefit #1

Double knockdown delays the development of glyphosate resistance

A 30-year modelling simulation (Neve *et al* 2003) demonstrated that the double knockdown strategy of sequential applications of glyphosate and paraquat in the same year prevented the evolution of resistance in annual ryegrass to either herbicide (Table T2.2b-1, below). To be fully effective the technique must be applied before glyphosate resistance has had a chance to develop.

The model results indicate that the proportion of glyphosate resistant annual ryegrass plants in the population slowly increased over time if either cultivation or an in-crop selective herbicide was used after a glyphosate application.

A more rapid move to glyphosate resistance occurred where there was no tillage at sowing or where a selective in-crop herbicide, to which resistance had already developed, followed the pre-sowing application of glyphosate or paraquat.

TABLE T2.2b-1 Probabilities of glyphosate resistance evolution in annual ryegrass under four knockdown management strategies (Neve *et al* 2003).

Strategy	Probability of glyphosate resistance evolution
Glyphosate every year	0.64
Alternate glyphosate and paraquat each year	0.35
Double knockdown every year	0
Double knockdown three years in five	0.017

Thornby *et al* (2008) demonstrated 30-year-run simulations using the DAFF developed glyphosate resistance evolution model on the likely development of resistance in awnless barnyard grass (*Echinochloa* spp.), the troublesome northern region summer fallow weed, in a high risk system (minimal till, no summer crop, no control of survivors). The various simulations revealed that the double knockdown technique as a 'resistance busting' tactic significantly reduced the risk of evolving glyphosate resistance. The model showed the use of the double knock every year delayed onset completely in the 30 year period. Application every second year delayed onset until the twenty-fourth year, and no application of the tactic had resistance developing 10 years earlier than the previous scenario.

In practice, we have been selecting at varying levels for resistance to glyphosate in most paddocks for many years, and most paddocks have already been moved significantly closer to a resistance problem than had they been 'double-knocked' since glyphosate started to be used. Modelling work also shows that starting to double knock after many years of glyphosate use will not have the nearly the same impact on delaying resistance onset.

Key benefit #2

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

Attempting to control all emergent weeds prior to sowing reduces the number of surviving glyphosate resistant weeds to be controlled by selective in-crop herbicides.

Treating smaller numbers of weeds with selective in-crop herbicides also reduces the selection pressure for the development of resistance to these selective herbicides.

Key benefit #3

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

Although this is not a primary objective of the technique, double knockdown may improve pre-sowing weed control that is particularly important in minimum or zero tillage sowing systems.

In 19 trials in five states over five years, Sabeeney (2006) showed that a double knockdown gave 10 to 15 per cent better control (average 95 per cent weed control) of a range of annual weeds than a single knockdown application (average 80 per cent weed control). The double knockdown used was either glyphosate and bipyridyl or two applications of bipyridyl, with similar results. The single knockdown used was either glyphosate or bipyridyl alone, again with similar results. It should be noted, however, that using two herbicides from the same MOA group is not recommended because of the increased risk of developing herbicide resistance. Studies by Borger and Hashem (2007) have shown the double knockdown of glyphosate followed by a paraquat-diquat mix was more effective at controlling three- to six-leaf annual ryegrass than glyphosate alone.

Numerous double knockdown studies have been conducted in Australia since 2006, not only for managing herbicide resistant populations, but also for fallow management of difficult to control weeds (e.g. feathertop Rhodes grass, fleabane), particularly in the northern grain region (Osten and Spackman 2011; Werth *et al* 2010).

Fleabane (*Conyza* spp.) can be effectively controlled in the early rosette stage by double knockdown where paraquat alone or in-mix with diquat is applied five to seven days after glyphosate or glyphosate mixed with an appropriate Group I herbicide. The double knockdown tactic has also been described as the most consistent and reliable method of controlling feathertop Rhodes grass (*Chloris virgata*) across various growth stages (Osten and Spackman 2011). No herbicides are currently registered for fallow control of feathertop Rhodes grass, however, a permit exists allowing the use of haloxyfop followed by paraquat as a double knockdown prior to the sowing of mungbeans (minor use permit, PER12941, www.apvma.gov.au/permits/). This permit (which expires 31/08/2016) was granted based on unpublished trial work from the Grains Research and Development Corporation Northern Grower Solutions projects.

Practicalities

Key practicality #1

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

Traditionally, the system has been viewed as requiring the translocated herbicide (glyphosate) to be applied first because it is moved to the root system by the plant. Subsequent application of the paraquat/diquat effectively destroys the plant top, while regrowth of glyphosate-susceptible weeds is prevented by glyphosate in the root system. Applying the contact herbicide (paraquat/diquat) first damages the leaf surface and can interfere with the ability of the weed to take up glyphosate.

When targeting glyphosate resistant annual ryegrass, Storrie (2005) found a 10 per cent improvement in control by using glyphosate followed by a bipyridyl compared to using a bipyridyl followed by glyphosate. Field trials by Borger and Hashem (2007) in Western Australia showed a similar response, also to annual ryegrass.

Research conducted by Newman and Adam (2003, 2004) has shown that capeweed (*Arctotheca calendula*) did not survive a double knockdown when glyphosate was applied first. When a bipyridyl was applied first, up to 30 plants/m^2 survived. Wild radish (*Raphanus raphanistrum*) follows a similar trend, with survival decreasing from 13 to three plants per plot, where glyphosate was used ahead of a bipyridyl (Newman and Adam 2004).

Key practicality #2

The time between applications will vary with the main target weed species

Historically, the recommended interval between the two herbicide applications has been a minimum of four days and preferably 10 days. The primary aim of the double knockdown is to allow the second herbicide to control survivors of the first herbicide application, and a longer delay increases the likelihood that weeds germinating after the first herbicide application will be killed by the second herbicide.

Newman and Adam (2004) found that, under good growing conditions, the bipyridyl herbicide could be applied as soon as one day after the glyphosate when targeting glyphosate susceptible annual ryegrass. However, this short timing would limit the ability of the double knockdown to control subsequent germinations.

Borger *et al* (2004) concluded that an interval of at least two days was required before spraying glyphosate following an application of paraquat/diquat. Later studies by Borger and Hashem (2007) defined the effective interval to be between two and 10 days for seedling annual ryegrass.

An application of glyphosate stops glyphosate resistant annual ryegrass growth for approximately seven days. Storrie (2005) found that the bipyridyl application could be extended to 14 days with glyphosate resistant annual ryegrass under good conditions. Longer intervals may be required for broadleaf weeds.

Current research in the GRDC's northern grains region is determining the interval between knocks for Group M followed by Group L herbicides for a range of problem summer grasses and broadleaf weeds, and for Group A followed by Group L for the grasses, particularly the troublesome *Chloris* species (windmill and feathertop Rhodes grasses). Results to date are indicating that intervals are quite specific for each weed and that the intervals may differ within the same weed for the different first knocks. These are currently being validated (Widderick, M., DAFF, Queensland, pers. comm. 2012).

Key practicality #3

Identify the weed species being targeted

In paddocks free of capeweed, *Erodium* species or black bindweed (*Fallopia convolvulus*), paraquat alone as the second knock often gives the most cost-effective result. If any of these species are present paraquat/diquat must be used.

Key practicality #4

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

Maximum control of annual ryegrass results from an application of herbicide at the three- to four-leaf stage. Annual ryegrass sprayed at the zero- to one-leaf stage can potentially regrow from seed reserves (Borger *et al* 2003, 2004).

Later application, when the annual ryegrass is tillering, risks an incomplete control by the bipyridyl application. Paraquat and Spray.Seed® are contact herbicides which result in little translocation taking place within the plants. Excellent herbicide coverage, which is difficult to achieve in the case of tillering plants, is needed for success.

Key practicality #5

Double knockdown is more expensive than a single herbicide application

A double knockdown does not need to be applied every year. Llewellyn *et al* (2005) looked at the economics of introducing the double knockdown system (glyphosate followed by paraquat) in two out of three years to delay glyphosate resistance. They found that this timing resulted in glyphosate resistance in 1.7 per cent of populations over 30 years, which would be economic for growers in high-risk situations such as no-tillage systems.

The higher the cost of weed control after glyphosate resistance has occurred, the longer the break-even period for introducing double knockdown. A paddock risk assessment, involving history of herbicide use and density of weeds to be controlled, should be conducted before using double knockdown.

Key practicality # 6

Seasonal conditions and spraying capacity will influence the scale of on-farm implementation

Pressure to rapidly establish crops restricts the proportion of the cropping program in which double knockdown can be practically implemented. In addition, the way in which seasons unfold can mean limited pre-sowing weed germinations and thus limited scope to use the double knockdown.

The best option is to select paddocks with the highest target weed populations as these are the highest risk for selecting resistance. It also means that a higher number of individuals will survive the first control operation, requiring follow-up control from the double knockdown.

By reviewing farm herbicide application records, it is possible to identify paddocks where there has been long-term use of glyphosate. These paddocks should be targeted first with the double knockdown.

If the tactic is being used to manage difficult to control weeds such as feathertop Rhodes grass, the worst infested paddocks should be targeted first where property size may limit spraying capacity (i.e. where it is physically impossible to cover all of the country in a timely fashion). In summer, feathertop Rhodes grass develops very quickly and timely application is necessary to target pre- to early tillering plants. Also, under hot summer conditions the application window (suitable delta T conditions) for knockdown sprays narrows considerably. Together, these temporal and spatial constraints may limit the use of this very effective tactic.

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TACTIC 2.2c PRE-EMERGENT HERBICIDES

Pre-emergent herbicides control weeds at the early stages of the life cycle, between radical (root shoot) emergence from the seed and seedling leaf emergence through the soil.

Of the 19 herbicide MOA groups, 12 are classed as having pre-emergent activity.

Pre-emergent herbicides may also have post-emergent activity through leaf absorption and some can also be applied to newly emerging weeds. For example, metsulfuron methyl is registered for control of emerged weeds but gives residual control typical of many pre-emergent herbicides. There are also herbicide treatments that are solely applied pre-emergent (e.g. trifluralin).

Benefits

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

The earliest emerged weeds are the most competitive. Therefore, pre-emergent herbicides are ideal tools to prevent yield losses from these 'early season' weeds. The residual activity gives control of a number of cohorts rather than simply those germinating around the time of application.

Ideally, pre-emergent herbicides should be applied either just prior to or just after sowing the crop or pasture. This maximises the length of time that the crop will be protected by the herbicide during establishment.

PHOTO: ANDREW STORRIE

Effect of simazine residues used in a lupin crop on the following wheat crop.

Practicalities

Key practicality #1

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

There are four main factors to consider when using pre-emergent herbicides.

1. Weed species and density
When deciding to use a pre-emergent herbicide it is important to have a good understanding of the expected weed spectrum. Use paddock history and observations of weed species and densities from at least 12 months prior to application. Correct identification of the weed species present is vital.

Pre-emergent herbicides are particularly beneficial if high weed densities are expected. Post-emergent herbicides are often unreliable when applied to dense weed populations, as shading and moisture stress from crowding result in reduced control. Pre-emergent herbicides have the advantage of controlling very small weeds, whereas post-emergent herbicides can be applied to larger, more tolerant or robust plants.

2. Crop or pasture type
The choice of crop or pasture species will determine the herbicide selection. Some crops have few effective post-emergent options. For example, weed control in grain sorghum is strongly reliant on the pre-emergent herbicides atrazine and metolachlor. In chickpeas, faba beans and lentils there are few effective broadleaf post-emergent herbicides available. In these cases it is important to have a plan of attack which is likely to include the use of a pre-emergent herbicide.

The competitive nature of the crop should also be considered. Chickpeas, lupins and lentils are poor competitors with weeds and rely on pre-emergent herbicides to gain a competitive advantage.

In the GRDC's northern grains region, approximately 70 per cent of growers use pre-emergence herbicides in both sorghum and chickpea crops but only 20 per cent utilise pre-emergents in wheat, and double the number (20 per cent) utilise this herbicide type in summer fallow compared to uses in winter fallow (10 per cent) (Osten *et al* 2007).

3. Soil condition
Soil preparation is a critical first step in the effective use of pre-emergent herbicides. The soil is the storage medium by which pre-emergent herbicides are transferred to weeds.

Soil surfaces that are cloddy or covered in stubble may need some pre-treatment such as light cultivation or burning to prevent 'shading' during application.

Too much black ash from burnt stubble may inactivate the herbicide, and therefore must be dissipated with a light cultivation or rainfall prior to herbicide application.

Less soluble herbicides such as simazine need to be mixed with the topsoil for best results. This process, called incorporation, mixes or cultivates the top 3 to 5 cm of soil for uniform distribution of the herbicide in the weed root zone.

Herbicides such as the sulfonylureas and imidazolinones may not need mechanical incorporation as they move into the topsoil with water (rain or irrigation). Some herbicides need to be incorporated to prevent losses from photodegradation (e.g. atrazine) or volatilisation (e.g. trifluralin).

4. Rotation of crop or pasture species
All pre-emergent herbicides persist in the soil to some degree. Consequently, herbicides may carry over into the next cropping period. The time between spraying and safely sowing a specific crop or pasture without residual herbicide effects (the plant-back period) can be as long as 36 months, depending on herbicide, environmental conditions and soil type.

FIGURE T2.2c-1 **Variation in turnip weed control levels with chlorsulfuron is highly dependent on soil type and soil pH (Walker and Starasts 1996).**

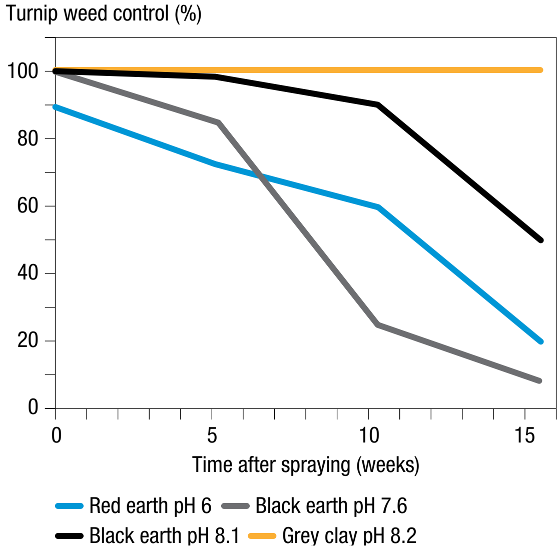
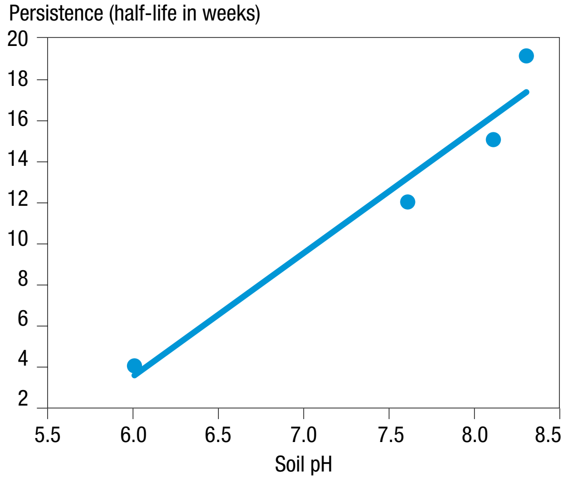


FIGURE T2.2c-2 **Effect of soil pH on the persistence of chlorsulfuron in Queensland soils (Walker and Starasts 1996).**



Key practicality #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

The factors that affect activity and persistence of pre-emergent herbicides are complex. The following nine interacting factors influence the fate of herbicides in the soil:

1. Soil texture
2. Soil pH
3. Organic matter
4. Previous herbicide use
5. Soil moisture
6. Initial application rate
7. Soil temperature
8. Volatilisation
9. Photodegradation.

1. Soil texture

The proportion of clay, silt and sand determines the soil texture. Clay particles bind many herbicides to their surfaces, making them less available to plant roots and shoots. Lighter textured soils, such as sandy loams, have lower clay content, making more herbicide available for plant uptake. Light soils often require lower rates of herbicides than heavy clay soils, which require relatively high rates of herbicide to give the same level of control. Research in Queensland (Walker and Starasts 1996) has shown that different soil types and soil pH affect control of turnip weed (*Rapistrum rugosum*), as seen in Figure T2.2c-1 (above).

Soil texture may also affect the persistence of herbicides. Sandy soils are more prone to herbicides being leached away from weed root zones after rain or irrigation. The herbicide may persist below the crop root zone and move towards the surface with the wetting front later in the season, causing crop damage.

2. Soil pH

Soil pH plays an important role in the longevity of soil active herbicides. Triazine and sulfonylurea herbicides persist longer in alkaline soils and break down faster in acidic soils (Noy 1996; Walker and Robinson 1996; Walker and Starasts 1996) (Figure T2.2c-2, above), whereas the imidazolinones break down faster in alkaline soils. Plant-back periods for many herbicides vary depending on soil pH.

3. Organic matter

Just as clay particles can render herbicides unavailable for plants, organic matter can act in a similar way. Binding of herbicides is caused by the attraction between negative ionic charges on the organic colloids in organic matter and positively charged herbicide particles. The bound herbicides are then either released with the breakdown of the organic matter or degraded by micro-organisms on the colloid. Soils high in organic matter also contain more micro-organisms, increasing the rate of herbicide degradation. Most Australian soils have low organic matter levels; however, the high use of organic amendments (e.g. poultry manure, biosolids) may cause rapid increases in the soil organic matter.

Retained stubble may also affect the soil–herbicide contact by limiting the amount of herbicide reaching the soil; however, research has shown that many water soluble herbicides will wash off crop residue with 5 mm of rain (Shaner 2013). This interception of herbicide by crop residue increases the time for herbicide loss through volatilisation and breakdown by ultraviolet light. Trifluralin binds strongly to crop residues and is lost through volatilisation.

4. Previous herbicide use

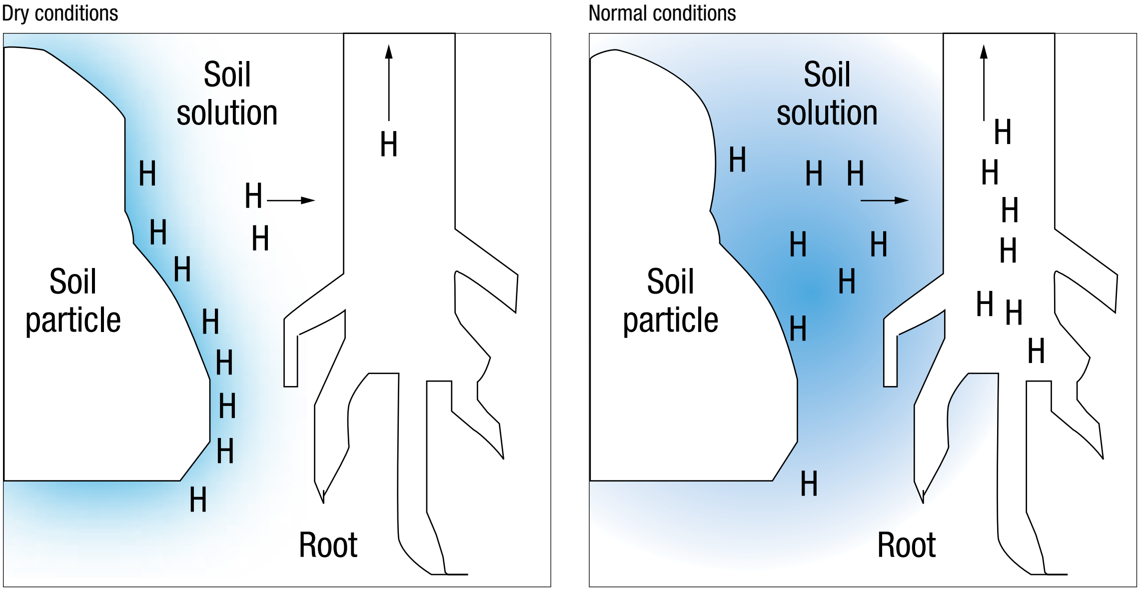
Microbes also break down herbicide in the soil. Soils with a history of use of a particular herbicide are expected to have a higher microbial activity and to break down faster compared to soils with no history of use. Specific microbes that break down active ingredients build up after more frequent use of pre-emergent herbicides (e.g. atrazine, propyzamide) (Rattray *et al* 2007) and Group I herbicides such as 2,4-D.

5. Soil moisture

A diagrammatic representation of the effect of dry soil conditions on the uptake of herbicide through the roots is depicted in Figure T2.2c-3 (below). In the left-hand diagram herbicide molecules are bound to the soil particle in the surrounding thin film. An aqueous bridge is required between the soil particle and the root for the herbicide molecules to move towards the root for uptake (as seen in the right-hand diagram).

In contrast, moist soil conditions can speed up herbicide breakdown, shortening the time interval in which the herbicide is available. Moisture levels at or close to field capacity increase microbial activity and thus increase the rate of chemical degradation. Also, some herbicides are

FIGURE 2.2c-3 Diagrammatic representation of the effect of soil moisture conditions on uptake of herbicide through the roots, contrasting dry soil conditions and normal soil conditions (Cameron 2005).



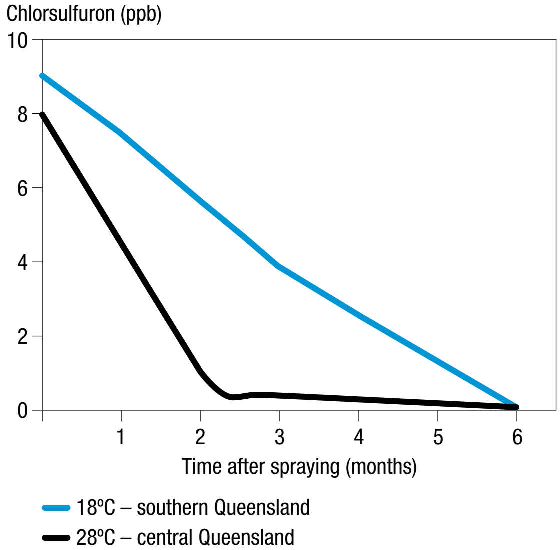
Note: H = herbicide.

degraded by hydrolysis, where water and the active ingredient react to create two new compounds. Triazines and sulfonylurea herbicides are frequently degraded by hydrolysis and break down faster in moist soils than in dry soils.

6. Initial application rate

The half-life of a herbicide is the time taken for half of the herbicide to degrade. The rate of herbicide breakdown is independent of initial quantity applied. For example, if the half-life of a herbicide is assumed to be 6 months and 1 kg/ha is applied, 500 g/ha will be available after 6 months. If 2 kg/ha is applied then 1 kg/ha will remain after the same time. Therefore, the greater the quantity of herbicide applied and the higher the application rate, the greater the quantity that will remain at any particular time.

FIGURE T2.2c-4 Effect of soil temperature on persistence of chlorsulfuron in Queensland (Walker and Starasts 1996).



The Grazon® Extra label reflects the increase in plant-back period for increasing rates. Other labels also infer this rate effect. For example, trifluralin should be used at a lower rate if applied just prior to sowing, whereas a higher rate can be used if applied before planting rain. Most pre-emergent herbicide labels do not state a shorter plant-back period for lower rates.

7. Soil temperature

Many studies have shown that higher soil temperatures result in faster breakdown of pre-emergent herbicides. The rate of most chemical reactions speeds up with increasing temperatures. Microbial activity also increases to specific levels at higher temperatures, dependent on the micro-organisms present. Walker and Starasts (1996) showed that, compared to southern Australia, the higher temperatures experienced in southern and central Queensland led to more rapid breakdown of sulfonylurea herbicides (Figure T2.2c-4, above). Re-cropping trials in central and southern Queensland showed that temperature had the greatest influence on sulfonylurea herbicide (metsulfuron methyl, chlorsulfuron and triasulfuron) dissipation (Osten and Walker 1998).

8. Volatilisation

Herbicides such as triallate, trifluralin and pendimethalin are volatile and must be incorporated to remain active. The herbicide vapour is trapped between soil particles and aggregates after incorporation, preventing volatilisation.

9. Photodegradation

Many herbicides (e.g. atrazine) are subject to degradation by the action of ultraviolet light. They rely on mechanical incorporation or movement with water to prevent inactivation.

Key practicality #3

Both the positive and negative aspects of using pre-emergent herbicides should be considered in the planning phase (Table T2.2c-1, below).

TABLE T2.2c-1 Positive and negative aspects of using pre-emergent herbicides.

Positive	Negative
Relatively inexpensive	Unpredictable efficacy, strongly dependent on soil moisture
Optimises crop yield through control of early weed germinations	As weeds are not yet visible, must have paddock histories and knowledge of previous weeds and weed seedbank
Different modes-of-action to most post-emergent herbicides;	Plant-back periods limit crop rotation
Timing of operation – generally have a wide window of opportunity for application options which can be used to prevent or manage herbicide resistance	Crop damage if sown too shallow or excessive quantities of herbicide move into root zone
Best option for some crops (e.g. sorghum and pulse crops are reliant on good pre-emergent control)	Seedbed preparation – soil may need cultivation and herbicide may need incorporation, which can lead to erosion, soil structural decline and loss of sowing moisture
Effective on some weeds that are hard to control with post-emergent herbicides (e.g. wireweed and black bindweed)	Not suitable when dense plant residues or cloddy soils are present
Extended period of control of multiple cohorts (6–8 weeks); good for weeds with multiple germination times	Varying soil types and soil moisture across paddock can be reflected in variable results

Contributors

Tony Cook, Vikki Osten and Andrew Storrie

TACTIC 2.2d SELECTIVE POST-EMERGENT HERBICIDES

Selective post-emergent herbicides control weeds that have emerged since crop or pasture establishment and can be applied with little damage over the top of a crop or pasture.

The first selective post-emergents to be developed were the Group I MOA herbicides and the first 'modern' herbicide, 2,4-D, became commercially available around 1945. Western industrialised agriculture changed with the release of Group A and B herbicides in the late 1970s.

Selective post-emergent herbicides belong to herbicide MOA Groups A (e.g. diclofop), B (e.g. metsulfuron), C (e.g. diuron), F (e.g. diflufenican), G (e.g. carfentrazone), H (e.g. pyrasulfotole), I (e.g. 2,4-D, dicamba, picloram), J (e.g. flupropanate), R (e.g. asulam) and Z (e.g. flamprop). Some predominantly pre-emergent herbicides also have registrations for some selective post-emergence activity, e.g. dithiopyr (Group D) and chlorpropham (Group E).

There have been no new MOA groups released for nearly 25 years, and it is unlikely that any additional groups will be released in the foreseeable future.

Benefits

Key benefit #1

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

Selective post-emergent herbicides give high levels of control (often greater than 98 per cent) when applied under recommended conditions. When used early in crop development selective post-emergents also result in optimum yield and significant economic returns.

Post-emergent herbicides are often more reliable than pre-emergent herbicides. This is particularly true under low rainfall conditions, as pre-emergent herbicides rely on moist soil conditions to achieve high levels of weed control.

Early removal of grass weeds (e.g. annual ryegrass and wild oats) reduces competition with the crop for resources. McNamara (1976) found that the later the time at which wild oats (*Avena* spp.) were removed from a wheat crop, the higher the resultant yield loss (Figure T2.2d-1, page 140).

PHOTO: ANDREW STORRIE

Post emergent herbicides being sprayed on a wheat crop, Cummins, SA.

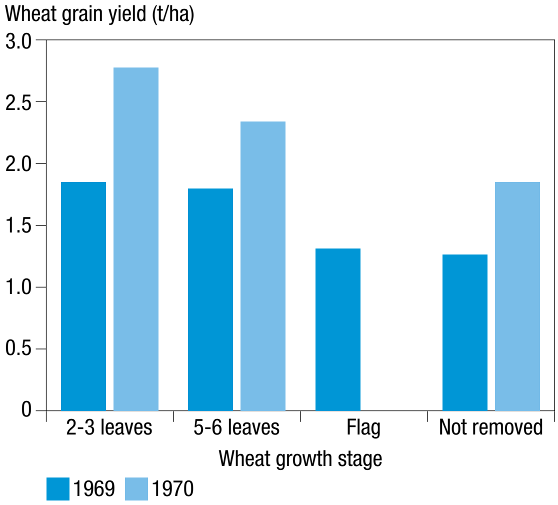
Crop yield benefitted most dramatically when wild oats were removed from the paddock in the earlier stages (two to three leaves) of crop development. Delaying control of wild oats until the flag leaf stage of the wheat crop was found to be not much more effective than a zero weed control treatment.

Key benefit #2

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

Unlike pre-emergent herbicides, post-emergent herbicides are applied after the weeds have emerged. This allows flexibility in choosing the best herbicide, or combination of herbicides, to control the particular suite of weeds in the crop and identification of the most appropriate rate of application. It is important that the weeds are identified correctly to ensure that the correct herbicide is selected.

FIGURE T2.2d-1 Effect of time of removal of wild oats (using selective post-emergent herbicide) on wheat (cv Gamut) yield over 2 years at Tamworth, northern New South Wales (McNamara 1976).



Key benefit #3

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

Dry conditions following sowing often delay weed emergence. Post-emergent herbicides can be applied after the majority of weeds have emerged, at a time when they are most susceptible to the herbicide being applied.

Many post-emergent herbicides (e.g. bromoxynil and metsulfuron on wheat) have a long timing-of-application window due to a wide margin of crop safety, allowing flexibility in the management of the farm.

Key benefit #4

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

Depending on the rate of application, some post-emergent herbicides have some pre-emergent or residual activity on susceptible weeds, thus extending the period of weed control. This is particularly the case with some Group B MOA herbicides (e.g. metsulfuron methyl) and Group I MOA herbicides such as 2,4-D and dicamba.

Often this is related to the application rate: the higher the rate, the longer the residual effect. Additionally, soil moisture, organic matter, clay content, temperature, pH and microbial activity are factors that can greatly influence the longevity or availability of these herbicides in the soil.

FIGURE T2.2d-2 **Effect of wheat and barley population and herbicide rate on the dry matter production of turnip weed and black bindweed at crop anthesis (Marley and Robinson 1990).**

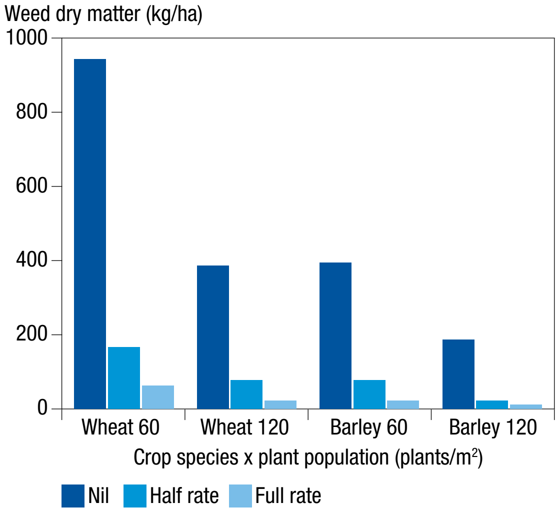
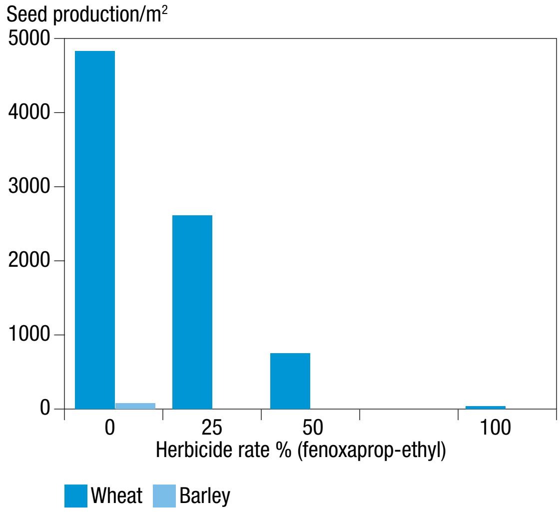


FIGURE T2.2d-3 **Effect of crop type and herbicide rate on paradoxa grass seed production (Walker *et al* 1998).**



Practicalities

Key practicality #1

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

When choosing a selective post-emergent herbicide for a particular situation, consider the following factors:

- target weed species and growth stage
- herbicide resistance status of target weeds
- crop safety (variety, environmental conditions, effect of previously applied herbicide on crop)
- grazing and harvest withholding periods and plant-back periods (minimum recropping intervals after application)
- cost
- spray drift risk
- mix partners
- crop rotation and the effect of residual herbicides.

Unfortunately, herbicide cost often becomes the second consideration after target species to be controlled, but the cheaper treatments can be associated with poor control, unsuitable residues and crop damage.

Key practicality #2

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

Environmental conditions prior to spraying influence the absorption ability of foliar herbicides due to the effects they have on leaf structure (Gerber *et al* 1983). Hot and dry conditions increase the waxiness of leaves, thereby reducing herbicide absorption. Plants suffering any kind of stress will have lower rates of translocation and the herbicide will take more time to reach sites of action.

Normally tolerant crops can be damaged when stressed due to waterlogging, frost or dry conditions because they cannot produce sufficient levels of the enzymes that normally break down the herbicide into harmless compounds.

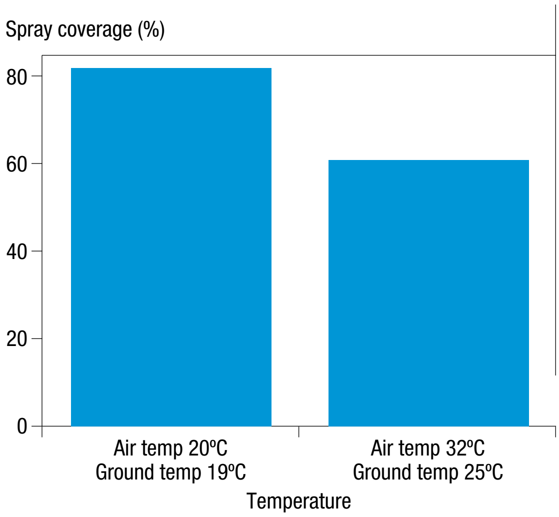
Key practicality #3

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

Good crop competition improves the efficacy of post-emergent herbicides. Marley and Robinson (1990) found that barley was more competitive than wheat against black bindweed and turnip weed (*Rapistrum rugosum*) and that higher crop populations improved the effectiveness of herbicides against these species (Figure T2.2d-2, page 141).

In a study by Walker *et al* (1998) on the effect of crop type and herbicide rate on paradoxa grass (*Phalaris paradoxa*) seedset, it was shown that barley was more competitive than wheat at all rates of herbicide (Figure T2.2d-3, page 141).

FIGURE T2.2d-4 Effect of air temperature on spray coverage using a fine droplet spectrum (Hughes 2004).



Key practicality #4

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

When using selective post-emergent herbicides it is important to use the correct application technique, paying particular attention to:

- equipment (nozzles, pressure, droplet size, mixing in the tank, boom height, ground speed) to maximise the efficiency of herbicide application to the target
- meteorological conditions. Better spray conditions are indicated by Delta T <8°C when air movement is neither excessively windy nor still (Delta T is an indication of evaporation rate and droplet lifetime and is calculated by subtracting the wet bulb temperature from the dry bulb temperature).

PHOTOS: ANDREW STORRIE

Upper (left) and lower (right) surfaces of capeweed showing trichomes.

Droplet of rainwater left compared with rainwater with 0.1% non-ionic surfactant on a waxy leaf (Nasturtium) showing the need for effective adjuvants on plants with waxy cuticles

It is preferable to spray when temperatures are less than 28°C. The effect of temperature on spray coverage using a fine droplet spectrum is shown in Figure T2.2d-4 (above). In this trial only 60 per cent of the applied herbicide reached the target when the air temperature was 32°C (Hughes 2004).

Adoption of medium to very coarse droplets reduces herbicide loss and drift due to higher temperatures and lower humidity.

See ‘Further reading’ for more detailed information (page 163).

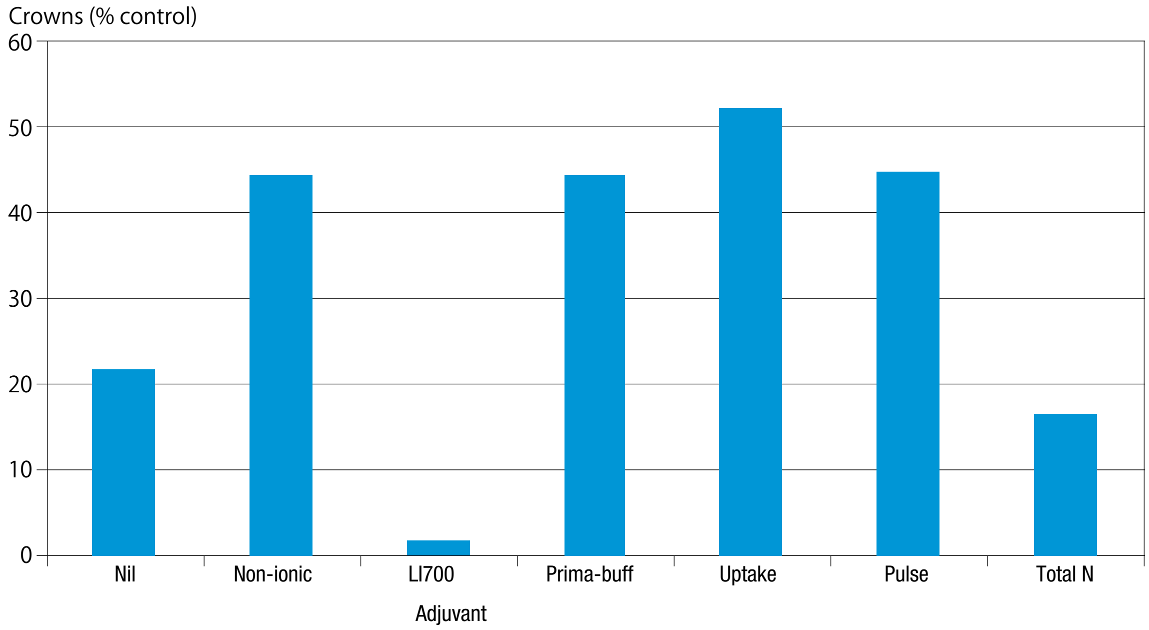
Key practicality #5

Always use the correct adjuvant to ensure effective weed control

Use the adjuvant recommended on the herbicide label to get the best performance from the herbicide being applied. As plants have different leaf surfaces, an adjuvant may be needed to assist with herbicide uptake and leaf coverage. Adjuvants can also increase performance lowered by pH, hard water, compatibility, rainfastness or drift. For more detailed information on adjuvants, see items (Hazen 2000 and Somervaille *et al* 2012) listed under 'Further Reading' (page 163).

Work conducted by Storrie and Cook (2004) on the control of lucerne for fallow commencement showed significant differences between adjuvants on the efficacy of 2,4-D amine (Figure T2.2d-5, below). One adjuvant reduced weed control while others gave varying levels of weed control greater than using 2,4-D amine alone (i.e. nil treatment). The rate of 2,4-D applied was half that recommended for the control of lucerne.

FIGURE T2.2d-5 Effect of different adjuvants on the control of lucerne by a sublethal rate of 2,4-D d.m.a. (Storrie and Cook 2004).



Key practicality #6

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

Early post-emergent herbicides are aimed at maximising yield by removing weed competition in crop establishment stages. Any weed that germinates after, or survives, this application will set seed that will return to the seedbank, thus maintaining weed seedbank numbers and ensuring continuation of the weed problem.

Work through the 1990s by Cook (1998) and others showed that by preventing seedset of wild oats, the seedbank and therefore the problem can be run down to very low levels in three to five years.

As shown in Table T2.2d-1 (page 144), stopping the seedset each year with post-emergent herbicides and a selective spray-topping leads to a 96 per cent decline in the seedbank over five years, compared to using post-emergent herbicides alone, which resulted in only a 40 per cent decrease in wild oats seedbank numbers.

In this trial initial seedbank numbers were high (approximately 1600 seeds/m^2). The 'post-emergent herbicide alone' treatment would have reduced the number of seeds to 960/m^2, an unsatisfactorily high density, and seedbank decline would have stabilised at this point.

By contrast, the 'post-emergent and selective spray-topping' treatment reduced seedbank numbers to 64 seeds/m^2, with a strong indication for continued seedbank decline after the trial had been completed.

TABLE T2.2d-1 Effect of annual applications of different herbicide treatments on wild oats seedbank numbers after 5 years (Cook 1998).

Herbicide treatment	Percentage change in wild oats numbers over 5 years
Pre-emergent alone	+15
Post-emergent alone	-40
Post-emergent + selective spray-topping	-96

Notes: Pre-emergent – Avadex® BW @ 2.1 L/ha
Post-emergent – Puma® S (fenoxaprop) @ 500 mL/ha
Selective spray-topping – Mataven® L @ 3 L/ha

Key practicality #7

Choose the most suitable formulation of herbicide for each particular situation

The correct formulation of herbicide needs to be chosen to take into account efficacy, compatibility and drift. For example, although 2,4-D ester is compatible with most other herbicides and is very efficacious, it should not be used near susceptible crops during summer. In Queensland, use of 2,4-D ester formulations requires a special permit since most broadacre cropping areas sit within defined hazardous zones (Biosecurity Queensland, DAFF).

Weak acid herbicides (e.g. glyphosate) are affected by hard water containing high levels of soluble salts such as calcium and magnesium. If better quality water is not available for use, an ester or suspension concentrate formulation should be substituted.

PHOTO: ANDREW STORRIE

Spraying post-emergent herbicides on lupins, Ouyen, Victoria.

Key practicality #8

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

Inactivation of herbicides can occur due to:

- leaf and cuticle structure
- dust particles
- rainfall
- dew

Key practicality #9

Match herbicide mode-of-action (MOA) to its use

It is important to match the MOA of a herbicide to its intended use. For example, when considering weed size, if weeds are large a herbicide that is poorly translocated (e.g. a bipyridyl) or only upwardly translocated (e.g. atrazine) will be a poor choice. Glyphosate, a fully systemic herbicide, is a better choice for larger weeds.

Droplet coverage and water quality are also important considerations when choosing a herbicide.

Contributors

Tony Cook and Andrew Storrie

TACTIC 2.3 WEED CONTROL IN WIDE-ROW CROPPING

In northern New South Wales and Queensland wide-row cropping has been used for some years as a means to improve yield reliability in grain sorghum production. Wide rows are also used in wheat and chickpea cropping in central Queensland to improve stubble handling and moisture seeking abilities of sowing operations (Reid *et al* 2004).

Wide-row cropping has also been widely adopted in Western Australia as a strategy to overcome herbicide resistant wild radish (*Raphanus raphanistrum*) and, to a lesser extent, annual ryegrass (*Lolium rigidum*).

In response to escalating herbicide resistance and to maintain cropping programs, growers and researchers are developing shielded spraying tactics for wide-row winter crops. This tactic uses non-selective (knockdown) herbicides to control weeds in the inter-row space of the crop. In some circumstances inter-row cultivation may be applicable.

Inter-row cultivation, band spraying and, to a lesser extent, shielded spraying are not new techniques. The innovation is to use them in winter growing broadacre crops.

Pulse crops have been the initial driver and subsequent emphasis for much of the wide-row research aimed at herbicide resistance management across Australia. The wide-row planting configuration has a distinct advantage, particularly when using non-selective herbicides for inter-row weed control.

Research has indicated that weeds (e.g. annual ryegrass) in the crop-row space can be problematic even when the inter-row weeds have been controlled. Depending on the weeds present and their herbicide resistance status, selective herbicides can be band sprayed over the rows, targeting the crop-row weeds. As well, overseas research is currently addressing innovative mechanical treatment of crop-row weeds through the development of ‘intelligent’ weeders that use advanced sensing and robotics (Van der Weide *et al* 2008).

A comprehensive review of weed management in wide-row cropping systems (Peltzer *et al* 2009) identified some potential risks in Australian farming systems with continual use of herbicide and tillage on the inter-row zone. These risks include herbicide resistance, species and/or dominance shifts, crop damage, increased costs, yield reductions and more expensive weed management technology.

Glossary

Wide rows: crop rows which are 50 cm and wider in summer crops and greater than 30 cm in winter crops

Inter-row: the strip of soil between the crop rows

Crop row: the strip of soil taken up by the crop

Shielded spraying: the practice in which shields are used to protect the crop rows while weeds in the inter-row area are sprayed with a non-selective herbicide (see *Tactic 2.3a Inter-row shielded spraying and crop-row band spraying*, page 150)

Band spraying: the practice in which a given area (band) of selective herbicide is applied to weeds in either the crop row or inter-row (see *Tactic 2.3a Inter-row shielded spraying and crop-row band spraying*, page 150) only

Inter-row cultivation: the practice in which weeds in the inter-row space are controlled using tillage equipment (see *Tactic 2.3b Inter-row cultivation*, page 153).

Benefits

Key benefit #1

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

Weed management benefits, particularly for herbicide resistant weeds, may outweigh the risk of crop yield loss when using wide-row cropping. Research to evaluate the impact of increasing row spacing in pulses and other winter crops in the absence of weeds has been conducted across Australia. Reduction in yield was found to be negligible in broadleaf winter crops up to 50 cm spacings. However, summer crops such as sorghum, sunflower, cotton, mungbean and soy bean have been grown on rows at least 1 m wide or in skip-row configurations. Wide row spacings have become more common as the adoption of conservation farming has increased (Peltzer *et al* 2009).

As shown in Table T2.3-1 (below), the yield of two chickpea cultivars in central western New South Wales was not affected when row spacing was increased from 17 cm to 65 cm (Fettell 1998). In this experiment the effect of sowing rate on row spacing and yield was also investigated. Fettell found that there was no difference in yield with different sowing rates (recommended sowing rate and 30 per cent above and below recommended) and also no interaction between sowing rate and row spacing on yield. Sowing rate could therefore be ruled out as a factor affecting yield.

TABLE T2.3-1 Impact of row spacing on the yield of two chickpea varieties at Condobolin, New South Wales (Fettell 1998).

Row spacing (cm)	Amethyst yield (t/ha)	Kaniva yield (t/ha)
17.5	1.2	0.9
26	1.4	1.2
35	1.2	1.0
50	1.4	1.2
65	1.1	0.9

Widderick (2002) investigated the effect of plant population and row spacing on the dry matter production of sowthistle (*Sonchus* spp.) and found that at a narrow row spacing of 25 cm there was minimal dry matter production of sowthistle. As row spacing was doubled to 50 cm the dry matter production of sowthistle increased. As the density of wheat was increased in the wide rows the dry matter production of sowthistle decreased (Figure T2.3-1, below).

The impact of row spacing was studied, in the absence of weeds, over a three-year period in wheat, canola, faba bean and chickpea at Tamworth, New South Wales (Felton *et al* 2004). In that environment, increasing the row spacing from 32 cm to 64 cm had very little effect on crop yield (Table T2.3-2, page 148).

In a similar study at Mullewa, Western Australia, Riethmuller and McLeod (2001) showed that there was no impact on the yield of chickpea (cultivar Sona) by increasing the row spacing from 19 cm to 76 cm. Similarly, work at Wagga Wagga, New South Wales

FIGURE T2.3-1 The effect of plant population and row spacing on the dry matter production of sowthistle (Widderick 2002).

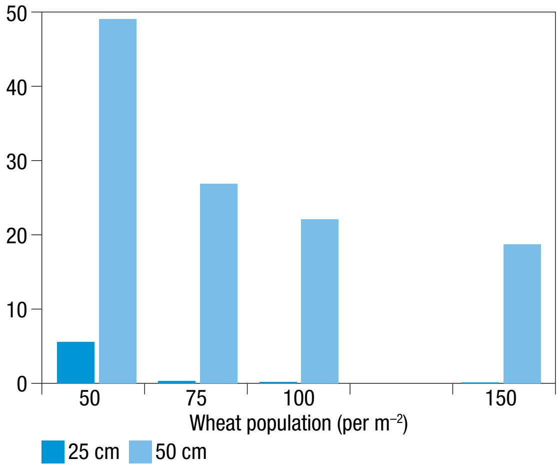


TABLE T2.3-2 The effect of crop row spacing on grain yield (t/ha) at Tamworth, New South Wales, over 3 years (Felton *et al* 2004).

Crop	Grain yield (t/ha)					
	2001		2002		2003	
Row spacing (cm)	32	64	32	64	32	64
Wheat	3.6	3.6	2.8	2.2	4.4	4.0
Canola	1.9	2.0	1.1	1.1	2.3	2.5
Chickpea	3.0	3.2	2.2	2.1	4.1	3.9
Faba bean	2.3	2.8	1.6	1.9	4.5	4.2

TABLE T2.3-3 Effect of two row spacings on annual ryegrass density and field pea (cv Excell) yield at Wagga Wagga, New South Wales (Lemerle *et al* 2002).

Row spacing(cm)	Annual ryegrass in July (plants/m^2)	Field pea yield (t/ha)
23	98	2.5
46	57	2.3

(Lemerle *et al* 2002), showed a relatively small impact of wider rows on the yield of field pea (cultivar Excell) despite higher annual ryegrass numbers in July at the narrow row spacing (Table T2.3-3, above).

In Western Australia Jarvis (1992) found an average lupin yield increase of 3.6 per cent in wide rows (36 cm) compared to standard rows (18 cm) across a range of environments.

Key benefit #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

Careful selection of the most appropriate tactic allows cropping rotations to continue, even where resistance to some herbicide MOAs has already evolved. Options to use herbicides via inter-row shielded sprayers is limited to a few crops and products only as very few products are registered for this use pattern. See the following section (*Tactic 2.3a Inter-row shielded spraying and crop-row band spraying*, page 150) for more information and data relevant to this key benefit.

Whole-farm benefits

Additional benefits from use of wide rows include the following:

- Wide-row cropping enables increased quantities of crop residues to be retained, thus reducing the potential for erosion and improving soil characteristics.
- Wide-row cropping enables easier sowing into retained crop residues.
- There is an option to use smaller tractors with less tynes per sowing width, thus reducing costs.
- Wide rows can reduce crop foliar fungal disease incidence by allowing better airflow within the crop canopy.
- Wide rows work well with tramlining and controlled traffic farming, adding benefits associated with reduced soil compaction and more accurate and timely application of inputs.
- Wide-row cropping provides opportunities for precision fertiliser placement such as side dressing.

Practicalities

Key practicality #1

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

Crop competitive ability will reduce as row spacing increases and crop density falls. Minkey *et al* (2000) reported that in wheat, in the absence of selective herbicide, the total number of annual ryegrass seed-heads was reduced as row spaces were narrowed and crop density increased. Therefore, at increased row spacing the need for weed control by herbicide or mechanical means is also increased.

Due to slow canopy closure of the crop, the timing and effectiveness of weed management becomes critical to prevent yield loss and reduce the impact of weeds.

The competitiveness of wide-row sorghum and sunflower also reduces as row spacing widens, resulting in increased weed growth and seed production. In the absence of weed control in low weed densities, sunflowers grown on 1 m row spacing can suffer 11 per cent yield loss (Osten *et al* 2006).

Key practicality #2

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

Although excellent specialised row-planting equipment is available, wide rows may be sown using modified air-seeders and combines.

In central Queensland, many growers also made the move to wide-row winter crops to reduce the capital outlay on zero till planting equipment. It was deemed more cost-effective to modify existing summer crop planters (with 1 or 1.5 m row set-ups) to sow winter crops on 0.5 m rows than to purchase separate planting equipment for the winter opportunities (Reid *et al* 2004).

Key practicality #3

Precision farming technologies fit well with wide rows for weed management

Technologies such as GPS guidance and controlled traffic farming easily fit with wide-row cropping and weed management.

Contributors

Warwick Felton, Di Holding and Andrew Storrie

TACTIC 2.3a INTER-ROW SHIELDED SPRAYING AND CROP-ROW BAND SPRAYING

The trend towards wide-row planting for a range of crops risks greater reliance on herbicide control to balance declining crop competition. This in turn poses serious problems for the development and management of herbicide resistant weeds. Work with resistant weed populations (Storrie, unpublished) has shown that inter-row spraying with lower risk herbicides is a useful tool for the management of resistant or hard-to-kill weeds. However, this practice increases the herbicide resistance risk to those herbicides being used and needs to be carefully managed.

Despite farmers seeing benefits in inter-row spraying using shields with knockdown herbicides and trialing a range of techniques, its use at the time of writing is limited to glyphosate in cotton and paraquat in row crops.

Benefits

Key benefit #1

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

The use of non-selective herbicides in-crop has the potential to control weeds that are difficult to manage with selective herbicides, while minimising spray costs.

In Western Australia research investigating methods to control a range of weeds, particularly in the pulse phase of a rotation, identified inter-row spraying as an effective option. Hashem *et al* (2004) showed that paraquat + diquat used in the inter-row area of narrow-leaf lupins sown in 55 cm wide rows effectively controlled two weeds, blue lupin (*Lupinus cosentinii*) and wild radish (*Raphanus raphanistrum*) (Table T2.3a-1, below). Inter-row spraying of the lupin crop at the seven-leaf growth stage with a bipyridyl herbicide at a rate of 2 L/ha gave the best lupin yield and a high level of control for both broadleaf weed species.

TABLE T2.3a-1 Effect of controlling blue lupin and wild radish in narrow-leaf lupins in Western Australia with Spray.Seed® at 1 L/ha and 2 L/ha at two application times (Hashem *et al* 2004).

Lupin growth stage	Spray.Seed® (L/ha)	Blue lupin (% control)	Wild radish (% control)	Lupin yield (t/ha)
Untreated control	–	0	0	0.9
7-leaf	1	60	24	1.48
7-leaf	2	93	88	2.29
Flowering	1	83	93	1.88
Flowering	2	83	93	1.50

Key benefit #2

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

By limiting the use of higher resistance risk herbicides to the crop-row band, only 30 to 50 per cent of the field is being treated, and less selection pressure is therefore placed on the whole weed population. The remaining portion of the paddock (inter-row) is treated with either a lower risk (knockdown) herbicide or by inter-row cultivation.

Crop-row weed control is important, particularly in reducing additions to the weed seedbank. Band spraying over the crop row allows selective herbicides to control weeds that the shielded sprayer or inter-row cultivation techniques cannot reach. Hashem *et al* (2008a) found a 70 per cent yield increase in wide-row lupins when the crop row was band sprayed with a residual herbicide to control ryegrass. In addition, band spraying effectively reduces the total amount of herbicide used on a per hectare basis, which in turn reduces costs and minimises the potential for herbicide carryover as well as reducing the risks of potential off-site movement (because less is available to move) .

In the GRDC's northern grains region Osten and Lotz (2008) demonstrated similar responses in wide-row sorghum and chickpea crops. Crop yields were unaffected and weed control was not compromised when residual herbicides were banded (50 cm) over the crop row with either tillage or non-selective herbicide applied to the inter-row (75 cm swath) by either a shielded sprayer or the Irvin boom (an unshielded but directed spray).

In similar but later studies in central Queensland, Osten and Cattell (2011) showed that WeedSeeker® technology could be safely utilised in-crop when fitted to hooded or shielded booms. In these studies atrazine or simazine were banded over the sorghum or chickpea rows while non-selective herbicides were applied via shielded boom with and without WeedSeeker® fitted. High levels of weed control were achieved across all treatments and crop yields were unaffected. On a unit area basis, residual herbicide use was reduced by 50 per cent while the amount of non-selective herbicide applied was reduced by up to 90 per cent with WeedSeeker® but this was dependent on weed density.

Practicalities

Key practicality #1

Timing of shielded spraying is important

It is important to spray small weeds in order to maximise control.

Shielded spraying also needs to be done before the crop canopy begins to close in to avoid physical damage from the passage of the shields.

Key practicality #2

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.

The set-up and operation of shielded sprayers is as important as the design of the shield (Rochecouste and Burgis 2003).

Small amounts of a translocated herbicide such as glyphosate can damage most crops. Cotton growers using glyphosate through shields in 2001 and 2002 reported yield losses of up to 30 per cent.

Any drift from paraquat onto crop rows can cause damage, but also can leave unacceptable levels of residues that will remain until harvest.

Drift from shields is decreased by reducing shield height to less than 5 cm, by using coarse droplets – the British Crop Protection Council [(BCPC) developed an international classification system using a set of reference nozzles for comparison with manufacturers' nozzles – and by travelling at lower speeds (Nicholls *et al* 2003).

TACTIC 2.3b INTER-ROW CULTIVATION

Benefits

Key benefit #1

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

Inter-row cultivation was used in grain sorghum crops in the Northern Territory in the 1950s (Phillips and Norman 1962). They found that with 18 inch and 36 inch row spacings, one inter-row cultivation was beneficial for yield whereas two cultivations removed too much soil moisture.

Research conducted in northern New South Wales in the 1970s (Holland and McNamara 1982) indicated that inter-row cultivation reduced weed growth in dryland sorghum to about half that of the unweeded controls.

Buhler *et al* (1995) reported weed control using inter-row cultivation in the range of 50 to 75 per cent to be common in the USA, and many North American growers find inter-row cultivation highly effective in wide-row summer crops.

Research in the USA also found that inter-row cultivation used in combination with residual herbicides can reduce the quantity of herbicide required for high levels of control (Buhler *et al* 1995; Forcella 2000). Despite this, there is some uncertainty regarding the level of effective weed control resulting from inter-row cultivation (Forcella 2000).

Practicalities

Key practicality #1

Timing of inter-row cultivation is critical to ensure maximum levels of weed control with minimal damage to the crop

Best weed control is obtained when the majority of the target species population has emerged and the weeds are small. In Minnesota, USA, Forcella (2000) found that to obtain maximum control of three *Setaria* species by cultivation it was necessary to wait for 60 per cent emergence.

PHOTO: VIKKI OSTEN

Inter-row cultivation can be effective for controlling small and stressed weeds.

In the Australian cotton industry it is recommended that inter-row cultivation is carried out when the soil is drying out. With this timing, more weeds are killed and any damage from tractor compaction and soil smearing from the tillage implements is minimised (Roberts and Charles 2002).

Studies in Western Australia with inter-row tillage in narrow-leaf lupin showed crop stand losses to range from 39 to 55 per cent depending on the timing and type of tillage employed (Hashem *et al* 2008).

In sorghum trials in central Queensland (Osten and Lotz 2008), inter-row tillage with sweep tynes set 100 mm from the crop rows and applied at crop mid-tillering stage provided 91 to 100 per cent weed control with only slight crop injury levels of up to 2 per cent, and in three of four trials the tillage caused less damage than shielded spraying with paraquat.

Key practicality #2

Weed control is reduced if the soil is too wet or weed densities are too high

With any cultivation, weeds will successfully transplant if the soil is too wet. Soil structure can also be damaged when cultivating soil that is too wet.

Inter-row tillage is often not as effective as herbicides for both weed control and crop yield maintenance under high weed densities (Amador-Ramirez *et al* 2001). Collins and Roche (2002) also showed failure of inter-row tillage to control dense (5000 plants/m^2) annual ryegrass in Western Australian grown narrow-leaf lupins.

Key practicality #3

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

Where retained stubble is dense, it may not be physically possible to carry out inter-row cultivation.

Key practicality #4

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

Some cultivation implements move sufficient soil from the inter-row to the crop row to smother some weeds, but this is only effective either on very small weed seedlings or if the crop is tall enough to avoid being covered. In many situations band spraying is required for crop-row weed control.

Holland and McNamara (1982) found that inter-row cultivation combined with a band spray of pre-emergent atrazine over the crop row was as effective in weed control as, and used less chemical than, an overall spray of pre-emergent atrazine.

Key practicality #5

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

Mulching the soil surface has been shown to have benefits in retaining soil moisture and suppressing weeds.

Inter-row cultivation reduces the opportunity to maintain the mulch, and therefore is not a complementary tactic with mulching.

In the central Queensland sorghum trials described above, while the inter-row tillage was effective and safe to the crop, it did cause an 85 per cent reduction in the standing carry-over wheat stubble (i.e. shifted it out of the treated area) and the 15 per cent that remained was no longer standing (Osten and Lotz 2008).

Key practicality #6

Inter-row cultivation can stimulate emergence of some weed species

Cultivation is known to stimulate fresh germination of weeds. An understanding of the likely impact of cultivation on the weed species in the paddock is essential. This allows for a management plan to be put in place to control the expected weeds that do germinate.

Peltzer *et al* (2007) showed a mid-season inter-row tillage operation in wide-row lupins stimulated an emergence of wild radish producing weed numbers 50 per cent greater than the control treatment.

Contributors

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TACTIC 2.4 SPOT SPRAYING, CHIPPING, HAND ROGUING AND WIPER TECHNOLOGIES

Where new weed infestations occur in low numbers eradication may be possible. In such situations more intensive tactics to remove weeds can be used in addition to ongoing management tactics which aim to minimise weed impact. The term 'wiper technologies' refers to the many versions of wipers available (e.g. wick wipers, rope wipers, carpet wipers, weed wipers).

Benefits

Key benefit #1

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

Targeted control will ensure that all target plants are removed along with any seed or plant parts that allow future propagation. Key steps include the following:

- Correctly identify the plant.
- Understand the plant's biology – when does it actively grow, is it annual or perennial, and how and when does it reproduce?
- Identify which control tactics are best suited to the plant and at what growth stages these should be implemented.

Practicalities

Key practicality #1

Instigate accurate future monitoring by marking isolated infestations

Monitoring is a key part of weed management and is essential if eradication is to be attempted.

Use of a physical marker (e.g. steel post) or a GPS will ensure that the correct area can be regularly checked and additional weeds removed prior to setting seed.

Key practicality #2

Isolate the area of infestation to reduce the risk of further spread

Fences to exclude livestock or markers so that the area can be avoided when carrying out paddock operations (such as cultivation, sowing or harvest) will avoid spreading the weed within the paddock and to other areas of the farm.

Key practicality #3

Control of new weed infestations and low density weed populations requires only simple measures

A number of simple measures may be used:

'**Roguing**' refers to hand pulling or chipping of weeds prior to flowering or seedset. It is also used in seed crops to reduce the chance of spreading weeds in the seed and when other options of controlling the weed are limited. If roguing is carried out after seed is physiologically mature, both the plants and their seeds should be contained and carefully disposed of. Roguing is an effective method of eradicating a new infestation in annual crops, despite being labour intensive and expensive. Many growers carry a chaff bag on all farm machinery and utility vehicles, just for the purpose of disposing of hand pulled weeds.

'**Spot spraying**' is a quicker alternative to hand roguing and can be used to sterilise weed seed. Spot spraying usually involves the application of a non-selective herbicide to individual weeds using a sprayer in a back-pack or mounted on an all-terrain vehicle. The sprayer should have a single nozzle on a wand attached to a flexible hose. A boom sprayer fitted with weed detector units may also be used for applying non-selective herbicides to low density infestations in fallows.

'**Wick wiping**' with a hand-held rope-wick wiper is an alternative to spot spraying when there is the possibility of herbicide drift on to sensitive adjacent plants. It is particularly useful if the weed is taller than the crop canopy (see *Tactic 3.1c Wiper technology,* page 178).

Key practicality #4

Timing of control is important to avoid seedset

Ensure that weed management is extremely thorough while weed numbers are low. Timing control measures according to the development of the weed will avoid seedset. Remember, seedset from a single year can easily result in many years and dollars spent on weed control measures.

Contributor

Di Holding

TACTIC 2.5 WEED DETECTOR SPRAYERS

Weed detector sprayers are low volume spot spraying technology for the control of scattered weeds in crop fallows. The 'weed detector-activated' sprayer consists of detector units mounted to a boom which detect the presence of weeds using infra-red reflectance. When each individual unit passes over a weed it activates a solenoid which in turn switches on an individual even-fan nozzle, spraying the weed.

This technology is currently reducing the per hectare fallow spray application rates by 80 to 95 per cent depending on the density of the fallow weeds.

Benefits

Key benefit #1

Only 10 to 15 per cent of the field is being treated, reducing fallow management costs and encouraging higher levels of weed control

Up to 95 per cent reductions in the area sprayed are possible depending on weed density. This reduces the total amount of herbicide being used and encourages better weed control in fallows due to reduced costs or a higher rate of herbicide applied per plant.

Key benefit #2

A range of herbicide modes-of-action (MOAs) can be used to combat herbicide resistance

This technology allows the use of a range of herbicide MOAs, making it an effective tool in herbicide resistance management programs. At the time of writing six weed species have been identified as having populations resistant to glyphosate (MOA Group M), the most widely used fallow herbicide. Weed detector sprayers enable cost effective control of scattered (low density) weeds in fallows.

A national APVMA minor use permit for the WeedSeeker® (PER11163 - expires 28/02/2015) allows seven different MOAs to be used in fallows. The permit is available from www.apvma.gov.au/permits/search.php

PHOTO: CROP OPTICS

WeedSeeker® spraying large sowthistle in a fallow, northern NSW.

PHOTO: WEED-IT

Weed-it rig spraying large spear thistle in a Victorian fallow.

Key benefit #3

Using a weed detector sprayer reduces the risk of herbicide drift

Herbicide drift risk is reduced as the nozzles activate for short periods and a coarse spray quality is used. This reduction in risk assumes a dual (conventional) spray line is not being used in conjunction with the weed detector sprayer.

Key benefit #4

Using a weed detector sprayer enables spraying in the evening

Since many weed detector technologies emit an infra-red signal and collect the reflectance off weeds and other material, the units can operate at night. This may allow greater opportunities to undertake more time consuming activities such as double knocking that requires two applications of herbicide. The second knock often requires the use of a bipyridil herbicide (MOA Group L) on patchy survivors from the first spray, and this group of herbicides tends to be more effective if sprayed late afternoon or evening.

Practicalities

Key practicality #1

Weeds must be large enough to be detected

Weeds must be larger than 5 cm in diameter (in wheat stubble) to be reliably detected at recommended travel speeds.

Key practicality #2

Travel speeds are limited

Due to time required for the solenoids to switch on the nozzles, sprayer ground speeds should be limited to approximately 16 kph (refer to APVMA permit PER11163 for recommendations). The maximum recommended speed is 20 kph to maintain sufficient spray coverage of the target weeds.

Key practicality #3

Strong winds can reduce coverage and control

Winds greater than 15 kph can move the spray away from the target weeds, reducing the effective dose applied. Strong winds can be a more significant problem for weed detector sprayers compared with normal broadcast spraying. There is unlikely to be spray from adjacent nozzles moving across with the wind and covering the target weeds, because only nozzles directly above the weed switch on and off when a weed is detected.

Key Practicality 4

More night spraying

With increased options to spray at night and with inversion conditions more common at night, great care must be taken to avoid spraying during inappropriate conditions, such as a temperature inversion.

Contributors

Andrew Storrie and Tony Cook

TACTIC 2.6 BIOLOGICAL CONTROL

Biological control (or 'biocontrol') for the management of weeds uses the weed's natural enemies (biological control agents). These natural enemies include herbivores such as insects, but also include sheep (see *Tactic 3.5 Grazing – actively managing weeds in pastures*, page 202) where there is direct consumption of the weed. They also include micro-organisms such as bacteria, fungi and viruses which can cause disease, change weed vigour and competitiveness relative to the crop and decay the weed seed in the seedbank. Other plants which can be included under biological control are those which release substances that suppress weed growth (known as 'allelopathy').

There are three basic types of biological control strategies: 'classical', 'inundative' and 'conservation'.

Classical biological control

Classical biological control, the most widely known approach, is the intentional introduction of an exotic (non-native) biological control agent.

- Low numbers of the exotic organism are introduced which then spread through reproduction.
- The aim is for permanent establishment, where the organisms are released for long-term control without additional releases.
- Natural enemies of the host weed are identified in the plant's region of origin.
- Potential control agents are tested to ensure they attack only the target weed, before importation and clearance through quarantine.
- The most successful example of classical biocontrol in Australia is the cactoblastis moth to control prickly pear (*Opuntia* spp.). The moth was introduced in 1926 and within six years had destroyed much of the infestation that covered 23 million hectares of land in Queensland and New South Wales.

Inundative biological control

Inundative biological control is where weeds are overwhelmed with massive numbers of a naturalised pathogen that is already found in low numbers.

- Biological control agents are mass produced and then released in big numbers to produce an epidemic against the weed.
- The agent is not expected to reproduce or persist in the environment.
- Agents used for inundative releases, especially micro-organisms, are also commonly called biopesticides or bioherbicides. A commonly used biopesticide in Australia is the bacteria, *Bacillus thuringiensis* (Bt), marketed as Dipel® and used to control caterpillars in vegetables.
- An example of a bioherbicide is the formulation of the fungal pathogen *Colletotrichum gloeosporoides* (Collego®) to control northern jointvetch (*Aeschynomene virginica*) in rice and soybeans in the USA. There have been no bioherbicides released in Australia.
- A potential bioherbicide was investigated in Australia using deleterious rhizobacteria (DRB). DRB are non-parasitic bacteria that are associated with plant roots (in the rhizosphere or area just around the roots) and can inhibit or reduce the growth of specific plants (or the weed). This reduction in growth gives the crop the competitive edge. In the USA, one DRB strain (isolated from winter wheat roots) reduced the growth of downy brome and increased yields of winter wheat by up to 35 per cent (Kennedy *et al* 1991). In Australia, DRB strains were investigated for their ability to reduce annual ryegrass (*Lolium rigidum*) but the study failed to find strains that consistently reduced growth and was abandoned.

Conservation biological control

Conservation biological control, the most readily available biocontrol practice and one which is distinguished from other strategies in that natural enemies are not released, is the modification of the environment or existing practices to protect and enhance natural enemies.

- Managing both the crop and the weed can favour the presence of naturally occurring biological control agents that attack or reduce the weed.

PHOTOS: ANDREW STORRIE

Patersons curse leaf showing blisters containing *Dialectica scaleria* caterpillars.

- One example of conservation biocontrol is given in *Tactic 1.2 Encouraging insect predation of seed* (page 98). Ants have been shown to remove large quantities of weed seed over summer. The ants can be 'conserved' by reducing the use of broad spectrum insecticides and minimising tillage.
- Another example is allelopathy, whereby crops are planted that release chemicals to suppress the germination and/or growth of other plants including weeds. Many crops including rice and wheat release chemicals that can suppress other plants. Wu *et al* (2001) reported that residue extracts from a range of wheat varieties suppressed root growth of annual ryegrass by over 60 per cent. This may have implications where retained stubble could be used to suppress weeds. Allelopathy can also work in reverse where the weed suppresses the growth of the crop. For example, degraded residues of silver grass (*Vulpia* spp.) can reduce crop establishment and growth, and toxins released by green wild radish (*Raphanus raphanistrum*) pods can substantially reduce the viability of crop seed in storage.

Benefits

Key benefit #1

The effectiveness of biological control can be increased when used in conjunction with other methods

Biological control is most effective as one element in an integrated weed management approach in combination with herbicides, grazing and cultivation. Biological control rarely controls the weed completely but can reduce its vigour. Optimising the competitive ability of the crop, for example, at the same time can reduce the weed growth further. This is particularly pertinent for the conservation biological control strategy.

Key benefit #2

Biocontrol agents, particularly bioherbicides, have an advantage over chemical herbicides in situations where the latter may be ineffective (e.g. due to herbicide resistance) or inappropriate (e.g. near sensitive wetlands or in organic agriculture)

Practicalities

Key practicality #1

The biology of the weed influences how well a classical biocontrol agent will work

Short-lived annual weeds of cropping are less suitable targets than longer-lived weeds of pasture or native vegetation. For a classical control agent to work in cropping, it must survive hot and dry summers and/or periods of non-cropping then multiply rapidly at the beginning of the season in order to sufficiently reduce the weed. Usually the presence of the biocontrol agent is dependent on the presence of the weed, which is unlikely for annual cropping species.

Key practicality #2

The success is dependent on the existence of suitable agents and their degree of host specificity

Usually it is difficult to find safe biological control agents for weeds that are closely related to crops (e.g. wild oats and cultivated oats, or wild radish and canola).

Key practicality #3

Bioherbicide technology is limited by the need for a large-scale market to make the product viable and by environmental constraints

In most cases the Australian market is too small to warrant bioherbicide development. Other limitations are that bioherbicides are usually less tolerant than chemicals to the extremes of temperature and humidity commonly found in storage and transport conditions. Bioherbicides can also be more sensitive than chemicals to unfavourable environmental conditions during application (e.g. the low humidity in Australian cropping conditions can prevent the bioherbicide from persisting). There is also the possibility of the weed becoming resistant to the bioherbicide.

Contributors

Sally Peltzer and Aaron Maxwell

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TACTIC GROUP 3 STOP WEED SEEDSET

Seedset control tactics include spray-topping with selective herbicides, crop-topping with non-selective herbicides, wick wiping, windrowing and crop desiccation, and techniques such as hand roguing, spot spraying, green and brown manuring, hay and/or silage production and grazing.

Tactic Group 3 (TG3) tactics can be loosely termed 'seed kill' tactics because each aims to reduce weed seed production. The goals are to reduce the weed seedbank, obtain future benefits from depleted weed populations and reduce grain contamination.

Weed seedset management is most applicable to weeds that are expensive to control and/or resistant to herbicides and when weed densities are low. Seedset control tactics are particularly effective when weed populations have already been reduced to low levels through use of fallowing, pasture or other specific crop rotation or weed management practices.

TACTIC 3.1 IN-CROP WEED MANAGEMENT FOR SEEDSET CONTROL

In-crop management of weed seedset is used to minimise the replenishment of seedbanks and/or reduce grain contamination. This is achieved by intercepting the seed production of weeds that have escaped, survived or emerged after application of weed management tactics (see *Tactic Group 1 Deplete weed seed in the target area soil seedbank*, page 92 and *Tactic Group 2 Kill weed (seedlings) in the target area*, page 113) earlier in the cropping season.

Controlling weed seedset contrasts with early in-crop weed management tactics (TG1 and TG2), which aim to maintain or maximise crop yield by reducing weed competition. Generally, there is no grain yield benefit from seedset control tactics, as most competition from weeds occurs earlier during the vegetative stages of the crop. For this reason TG3 tactics should always be used with tactics from other Tactic Groups.

In-crop seedset control advice

- Before sowing decide if seedset control has a role in the paddock in question.
- Choose crop and variety to suit timing of the seedset control tactic selected (i.e. short-season cultivars).
- Choose a competitive crop and variety to improve efficacy of the tactic.
- Choose the most suitable seedset control tactic for the situation and business.
- Check for herbicide(s) registered for seedset control in the crop and target weed(s).
- Look at past records of crops and herbicides used in rotation and assess the risk of herbicide resistance.
- Monitor in-crop weeds and assess the feasibility of seedset control.
- Adopt a strategically timed tactic implementation. Before or after the optimal window the technique will be less effective and may cause unacceptable crop damage.
- Be prepared: the timing window to obtain maximum effect is short. If using contractors ensure that they can be there at the critical time.
- Seek advice if unsure about any aspect of the seedset control tactic to be used.
- Always read and follow the herbicide label.
- Always check and adhere to harvest and grazing withholding periods.
- Seedset control is not a remedy for rampant weed problems. Pursue other options and use seedset control in conjunction with tactics from other tactic groups.
- Seedset control should not be solely relied upon to manage herbicide resistance. It is part of an integrated approach to herbicide resistance management.
- Do not apply herbicides from the same mode-of-action group more than once in the same season.
- Do not apply unregistered or non-permitted herbicides.

Benefits

Key benefit #1

The use of in-crop weed seedset control tactics can dramatically reduce future expenditure on weed management

Weed control is beneficial in the short term because the weed problem is removed. Long-term benefits arise when the weed is prevented from setting seed as there are no increases to the seedbank and, as a consequence, fewer weeds in the future. Annual ryegrass (*Lolium rigidum*), for example, has a relatively short-lived seedbank, so if seed production is prevented in the spring there will be fewer weed seeds to germinate in the subsequent crop (Gill and Holmes 1997).

Research has shown that one wild radish (*Raphanus raphanistrum*) seed/m^2 is enough to replenish the seedbank and incur ongoing economic losses. For wild oats (*Avena* spp.) which do not have the dormancy characteristics of wild radish, six seeds per m^2 will replenish the seedbank and incur economic losses (Murphy *et al* 2000).

Managing weed populations with a long-term approach has shown economic benefits of up to $50/ha/year for major weeds such as wild oats and wild radish (Jones and Medd 1997, 2000). Non-adoption of weed seedset control into an integrated weed management program will incur a high risk of seedbank population increase (Jones and Medd 2005) and lead to future economic costs.

For low density seedbanks (up to 100 seeds per m^2) there is a future cost of approximately $1.50 or $0.63 respectively for each new wild oats or wild radish seed added to the seedbank (Jones *et al* 2002). The cost of adding more seeds of either species to the seedbank diminishes to negligible levels with high density seedbanks as the damage from existing weed populations is already significant.

Key benefit #2

In-crop seedset control reduces levels of weed seed contamination in grain samples at harvest

Weed seedset control can assist in meeting grain receival standards. For example, zero or low seed tolerances apply to several weeds and certain crop seed contaminants, as well as ergot of annual ryegrass (see relevant grain receival standards for targeted market). In such instances hand roguing of paddocks or the application of other seedset management options prior to harvest may help avoid or minimise delivery rejection, downgrading or dockage penalties or the need to clean seed before delivery.

Practicalities

Key practicality #1

Plan weed seedset management in advance

Weed seedset management needs to be planned as it is most successful when crop or variety choice is made with the specific aim of implementing a particular tactic for a known weed problem. Forward planning of this kind will maximise weed seed kill, with minimal reduction in crop performance.

Spot spraying and hand roguing are feasible for scattered weed patches, very low weed densities or new incursions. On the other hand, selective spray-topping works best on densities of weeds up to 50 plants per m^2. Above this density, or where herbicide resistance problems are encountered, crop salvaging options should be considered. Crop-topping, windrowing and desiccation are mostly applicable to pulse and oilseed crops where the crop matures early enough to harvest and prevent weed seedset before seed becomes viable.

Annual ryegrass, wild oats and brassica weeds (especially wild radish) have been the targets of research into weed seedset management techniques. However, registered herbicides are only available for crop-topping of annual ryegrass in pulses and selective spray-topping of brassica weeds in cereals. Harvest and grazing withholding periods must be observed.

Contributors

Richard Medd, Andrew Storrie and Michael Widderick

TACTIC 3.1a SPRAY-TOPPING WITH SELECTIVE HERBICIDES

Selective spray-topping is the application of a post-emergent selective herbicide to weeds at reproductive growth stages to prevent seedset of certain weeds. The technique is aimed at weed seedbank management (i.e. reducing additions to the weed seedbank) but with minimal impact on the crop.

Selective spray-topping is suited to a crop situation and largely targets broadleaf weeds (especially brassica weeds). The tactic should not be confused with pasture spray-topping which occurs in a pasture phase, involves heavy grazing, uses a non-selective herbicide and largely targets grass weeds (see *Tactic 3.2 pasture spray-topping*, page 184).

The strategy can be used to control 'escapes', as a late post-emergent salvage treatment or for managing herbicide resistance.

The rapid spread of Group B resistance in brassica weeds and Group A and Z resistance in wild oats (*Avena* spp.) has significantly reduced the potential application of this tactic.

Benefits

Key benefit #1

Correctly executed selective spray-topping will result in a 90 per cent reduction in weed seedset in herbicide susceptible populations

A range of herbicides can produce high levels of seedset control in a number of brassica weeds. The effects of selective spray-topping on seedset of wild radish (*Raphanus raphanistrum*) and turnip weed (*Rapistrum rugosum*) are shown in Table T3.1a-1 (below).

TABLE T3.1a-1 Seedset of herbicide susceptible wild radish and turnip weed after the application of selective spray-topping herbicide at flowering (Madafiglio *et al* 1999).

Herbicide	Reduction in seedset (%)	
	Wild radish	Turnip weed
Logran®	100	99
Logran®+ MCPA	100	100
Broadstrike®	96	83
MCPA amine	95	86
2,4-D amine	96	91
Untreated weed density (plants/m^2)	36	<1
Seedset in untreated (seeds/m^2)	7736	254

Note: Check chemical selected is registered for this purpose in appropriate state. Weeds in the above trial were susceptible to Group I and B herbicides. Reduced levels of control or spray failure would be expected in weed populations that are resistant to the products being used.

Practicalities

Key practicality #1

Know the herbicide resistance status of weeds before using selective spray-topping

Herbicide resistance testing has shown significant levels (25 to 33 per cent) of cross resistance from clodinafop and fenoxaprop (Group A 'fop') herbicides to Group Z. The development of multiple resistance in wild oats will severely limit the use of this technique (see *Section 2 Herbicide resistance*, page 27). At least 50 cases of resistance to flamprop-M-methyl (Group Z) have been identified in Australia (Broster 2012; Boutsalis pers. comm. 2012). Flamprop-M-methyl resistance has been recorded in wild oats in Canada and the United Kingdom since 1994 (Heap 2013). These weed populations are also resistant to Group A and Group B ('imi') herbicides.

Widespread Group B resistance in brassica weeds will limit the effectiveness of this group of herbicides for selective spray-topping.

Contributors

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TACTIC 3.1b CROP-TOPPING WITH NON-SELECTIVE HERBICIDES

Crop-topping is the application of a non-selective herbicide (e.g. glyphosate or paraquat) prior to harvest when the target weed is at flowering or early grain fill. Crop-topping aims to minimise production of viable weed seed while also minimising yield loss. The selectivity of the crop-topping process is dependent on a sufficient gap in physiological maturity between crop and weed.

Currently, non-selective herbicide crop-topping registrations are limited to use in pulse crops and predominantly target annual ryegrass (Table T3.1b-1, page 175).

Alternative pre-harvest non-selective herbicide applications for crop desiccation are outlined in *Tactic 3.1d Crop desiccation and windrowing* (page 181).

Benefits

Key benefit #1

Crop-topping can reduce annual ryegrass weed seedset, reducing additions to the seedbank

A well-timed application of a non-selective herbicide can significantly reduce the seedset of annual ryegrass (*Lolium rigidum*) and other weeds. A reduction of more than 90 per cent of seedset in annual ryegrass can be achieved if the herbicides are applied at the correct stage of development (Gill and Holmes 1997; Newman 2003).

Balancing annual ryegrass control with potential crop yield loss is important, so in-paddock control results are commonly in the range of 75 to 80 per cent.

Key benefit #2

Reductions in seedset achieved by crop-topping can be increased if used in conjunction with selective herbicide treatments

In South Australia the application of a pre-emergent herbicide (see *Tactic 2.2c Pre-emergent herbicides*, page 133) in combination with crop-topping reduced annual ryegrass seedset by 99 per cent of the untreated control, compared with a 71 per cent reduction when crop-topping was used alone (Matthews *et al* 1996).

Combining controls from different tactic groups is important. In this case the crop-topping was used to control annual ryegrass that had escaped the use of pre-emergent herbicide.

Whole-farm benefits

Crop-topping can deliver a number of benefits in addition to reducing weed seedset, including:

- improved harvest due to even maturity of crops (particularly pulses)
- improved harvest, grain quality and storage by desiccating late weed growth in seasons with late rain.

PHOTO: ERIC ARMSTRONG

Germination of field peas can be affected by application of glyphosate at maturity. The earlier the application the higher the likelihood of seed damage.

TABLE T3.1b-1 Crop-topping label registrations 2013.

Herbicide	Crop	States	Use	Rate
Paraquat (e.g. Gramoxone®)	Chickpeas Faba beans Field peas Lentils Lupins Vetch	NSW, Vic, SA, WA, ACT	Spray-topping to prevent annual ryegrass seedset	400 or 800 mL/ha
Glyphosate 570 g/L glyphosate present as potassium salt (Roundup Ultra®MAX)	Field peas Faba beans	All states	Pre-harvest application to prevent seedset of annual ryegrass	300–645 mL/ha

Disclaimer: The information contained in this table has been compiled as a guide only. Registrations can and do change regularly. All users of herbicide products must read the label of the product they are using and follow the directions printed on that label.
Note: Currently (2013) a very limited number of glyphosate products have a registration for crop-topping. Consult product label prior to use.

Practicalities

Key practicality #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

Plan crop-topping at the start of the season so that suitable crop species and variety can be carefully selected to minimise yield loss. The tactic works best with early maturing pulse varieties.

The best weed control will be achieved if crop-topping takes place when the weed is flowering and/or at the soft dough stage of seed development (Table T3.1b-2, below).

TABLE T3.1b-2 Crop-topping results from a range of farmers' paddocks tested in 2001, Geraldton, Western Australia (Newman 2003).

Lupins (% leaf drop)	Annual ryegrass development stage	Per cent reduction in annual ryegrass seed viability
90	Late flower/ milky dough	90-95
90-100	Milky to soft dough	96
90-100	Firm dough	52
100	Hard	7

Unfortunately, the window of physiological difference between crop and weed is not always as wide as required, and yield losses may occur or weed control may not be as effective as desired. Crop-topping applied prior to crop maturity can significantly reduce crop grain yield and quality. A physiologically mature crop (or later stage) will not be damaged by crop-topping.

The impact on yield and grain size of desi chickpeas treated with a range of herbicides when the crop was at the last flowering stage and at maturity (when pods had changed colour) is shown in Table T3.1b-3 (page 176).

Key practicality #2

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

When the crop is sprayed prior to physiological maturity, grain viability is likely to be reduced. For this reason, glyphosate is not registered for use on seed crops or on pulse crops intended for the sprouting market. Use diquat on seed crops and, if crop-topping occurs before the crop seed is mature, find an alternative seed source.

TABLE T3.1b-3 Effect of herbicide on desi chickpea yield and grain size at two crop-topping times of application, North Star, New South Wales, 1996 (Storrie and Cook 2000).

Crop maturity	Herbicide	Rate/ha	Yield % of untreated	% of total grain with diameter >6 mm	Comment
Chickpeas at last flower	Glyphosate 450 – T1	1L	98	46	Yield loss, significantly smaller grains
	Basta® – T1	2L	83[a]	41[b]	
	Spray.Seed® – T1	2L	90[a]	36[b]	
Physiological maturity, 90% pods changed colour	Glyphosate 450 – T2	1L	105	51	Yield stable, grain size unaffected
	Basta® – T2	2L	103	47	
	Spray.Seed® – T2	2L	101	54	

a >10% yield reduction, b significantly < untreated
Note: Information presented in this table includes results from non-registered herbicide uses. However, the presentation of this research data does not imply a recommendation for non-registered herbicide use. All herbicide use should be in accordance with the directions printed on the herbicide product label.

Key practicality #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

The ideal time to apply non-selective herbicides to reduce the seed production of wild radish (*Raphanus raphanistrum*) and other brassica weeds is when they are at the early flowering and pod development stage. The pod is still very thin and the seed has not reached the embryo stage. The pod will be squashy and watery when pressed between thumb and finger (Cheam *et al* 2004).

For crop-topping to be effective at reducing wild radish seedset, the weed must be treated prior to embryo development. If crop-topping is delayed in order to preserve lupin yield, the weeds will have sufficient time to reach embryo development stage and become more tolerant of the herbicide treatment.

Rule of thumb: brassica weeds must be sprayed or slashed within 21 days of the first flowers opening to maximise control of seed. Level of seed control will decline with delays in treatment after this time.

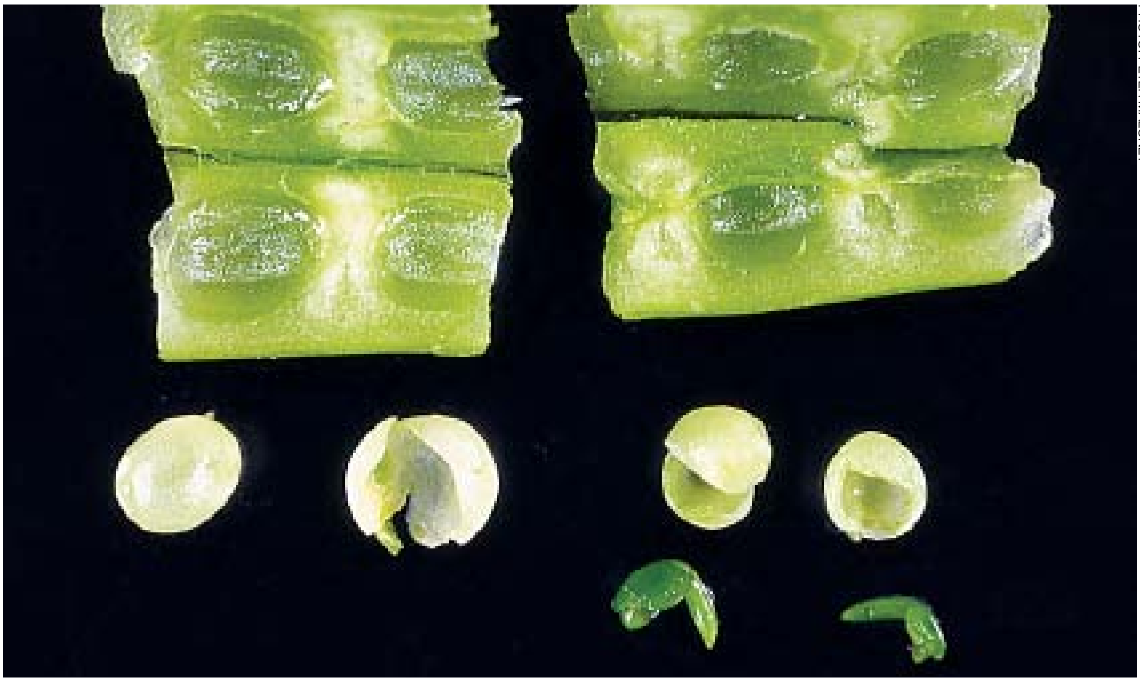

PHOTO: PETER MALONEY

Dissected wild radish pod showing pre-embryo stage (left) and embryo stage (right).

In the trial results summarised in Table T3.1b-4 (below), 92 per cent of the wild radish present in the crop had already reached the embryo stage before the lupins had achieved sufficient physiological development to be sprayed without significant yield loss. The delay caused by waiting for physiological maturity of the lupin prior to spraying is reflected in the poor wild radish seedset reduction seen after the 50 per cent lupin leaf-fall stage.

Different herbicide treatments are also contrasted in Table T3.1b-4. The early application of glyphosate (at the zero lupin leaf-fall stage) resulted in a complete kill of the crop. However, the lupins managed to partially recover from the early (zero lupin leaf-fall) Gramoxone® treatment. Evidence from the later spray timings also indicated that glyphosate has a more damaging effect on lupins than Gramoxone®.

Desirable weed seedset reduction is only achievable in lupins with significant crop yield loss. Work by Storrie *et al* (2006) in northern New South Wales showed similar trends for crop-topping turnip weed (*Rapistrum rugosum*) and charlock (*Sinapis arvensis*) in chickpeas.

TABLE T3.1b-4 Reduction in wild radish seedset (%) and grain yield losses of lupin cv Belara (%) compared to untreated control following crop-topping of lupins at various maturity stages, Western Australia (adapted from Cheam *et al* 2004).

Herbicide	Lupin growth stage – measured as leaf-fall							
	Zero lupin leaf-fall		50% lupin leaf-fall		80% lupin leaf-fall		100% lupin leaf-fall	
	Yield loss	Seedset	Yield loss	Seedset	Yield loss	Seedset	Yield loss	Seedset
Paraquat (250 g/L) at 800 mL/ha	65	100	7	13	4	16	0	17
Glyphosate (450 g/L) at 1 L/ha	100	100	15	32	12	20	1	26

Note: There are currently no non-selective herbicide registrations for crop-topping wild radish in pulse crops.

Contributors

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TACTIC 3.1c WIPER TECHNOLOGY

Wick wiping, blanket wiping, carpet wiping and rope wicking are all forms of weed wiping technology that aim to reduce weed seedset by using a range of devices to wipe low volumes of concentrated herbicide on to weeds that have emerged above the crop.

Benefits

Key benefit #1

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

The technique allows the use of a non-selective herbicide such as glyphosate at the late post-emergent stage to control seedset of weeds growing above the crop canopy. The use of paraquat in weed wiping technology has just been approved for use overseas, but at the time of writing its use was not approved in Australia.

Weed wiping is most effective on individual plants or small populations of weeds growing 20 to 30 cm above the height of the crop. Larger infestations result in more contact between weeds and crop, causing transfer of herbicide which can lead to crop damage and yield penalties.

Weed wiping is used extensively in lentils (a short stature crop) to control the seedset of hard-to-manage muskweed (*Myagrum perfoliatum*).

Rayner and Peirce (1996) found that one- and two-leaf cape tulip (*Moraea flaccida* and *M. miniata*) could be controlled in pastures with no damage to the subterranean clover (Table T3.1c-1, below).

TABLE T3.1c-1 Control of one- and two-leaf cape tulip 1 year after using a wiper in a subterranean clover pasture (Rayner and Peirce 1996).

Treatment	Rate ha^{-1}	% reduction 1-leaf	% reduction 2-leaf
Metsulfuron	0.5 g	88 bcd	52 b
Metsulfuron	5 g	97 d	94 cd
Metsulfuron + glyphosate (450 g/L)	5 g + 250 mL	89 cd	90 cd
Metsulfuron + glyphosate (450 g/L)	5 g + 500 mL	89 cd	94 cd
Untreated		0 a	0 a

Values followed by the same letter do not differ significantly (P<0.05)

PHOTO: ANDREW STORRIE

Blanket wipers use a sheet (blacket) moistened with herbicide to wet the weeds above the crop.

Key benefit #2

Weed wiping is an effective method of reducing seedset in weeds which have not been controlled by tactics used earlier in the growing season.

Weeds that have survived other tactics used earlier in the season can be targeted with weed wiping if the weeds are not dense and rise above the crop canopy. Effective seedset reduction can be achieved (Table T3.1c-2, below).

Practicalities

Key practicality #1

Care is needed to ensure that excess herbicide does not drip on to the crop and cause damage

Hashem and Devenish (2001) showed that up to 48 per cent crop yield loss is possible if there is insufficient height difference between the crop and the target weeds, or if the herbicide drips on to the susceptible crop.

Keys to successful application include:

- controlling herbicide flow to avoid dripping on to the crop
- stabilising broadacre weed wipers to avoid contact with the crop canopy
- targeting areas of low weed density. Dense patches of weeds tend to be knocked into the crop, causing transfer of herbicide from the treated weeds to the crop.
- wiping in two different directions for optimal herbicide application
- applying only to target weeds which rise more than 25 cm above the crop canopy
- consulting product labels for application rates. At the time of writing only some formulations of glyphosate have been registered for use through a weed wiper.

Research was conducted by the Cooperative Research Centre for Australian Weed Management investigating the use of translocated herbicides and synergistic mixtures of non-selective herbicides for use in weed wiping, aimed at controlling seedset and minimising crop damage (Storrie *et al* 2006).

Failure to observe caution with the technology may still reduce seedset but there can be detrimental effects on the crop.

TABLE T3.1c-2 Seedset reduction of charlock and wild radish using blanket wiping in chickpeas and barley (Hashem and Devenish 2001).

Situation	Target weed	Herbicide	Seed-set reduction
Chickpeas at flowering[a]	Charlock	Glyphosate or 2,4-D amine + chlorsulfuron	74–91%
Barley[b]	Wild radish	2,4-D amine + chlorsulfuron	98%

a In this trial there was insufficient height difference between target weed and crop.
b The treatment in barley resulted in an 89% reduction in wild radish emergence in the following crop.

Key practicality #2

Timing of weed wiping is the key

The best time to use weed wiping is when the target weed is most vulnerable. For musk weed, wiping at flowering to early pod fill stages will achieve the greatest reduction in seedset (Stuchbery 2002; Table T3.1c-3, page 180). The degree of weed control decreases after the weed reaches mid pod fill.

The best control of wild radish (*Raphanus raphanistrum*) in lupins and chickpeas is achieved when the weed is at early to mid flowering and has soft squashy pods (Cheam *et al* 2004).

Research at Wagga Wagga showed glyphosate was more effective than paraquat in killing wild radish (98 per cent compared to 94 per cent) at the pre-embryo stage of the seed. Paraquat only controlled 12 per cent of wild radish seed production compared to glyphosate which gave 33 per cent control at the post-embryo seed stage (McGillion and Koetz 2005).

The seedset of annual ryegrass (*Lolium rigidum*) is greatly reduced when weed wiping occurs at or prior to flowering (Stuchbery 2002).

Key practicality #3

A special applicator is required for weed wiping

Weed wipers apply herbicides at a concentrated rate, usually between 1 L of chemical to 2 L of water down to 1 L of chemical to 40 L of water.

Weed wipers have developed significantly since the early days of the single rope, gravity-fed models of the late 1970s to early 1980s. Currently there are models with multiple ropes, carpets, sponges, revolving cylinders and pressurised supply. At least one manufacturer has a system that senses the wetness of the pad and automatically switches on the pump to maintain pad wetness.

A grower group in the Victorian Wimmera region has designed and developed a broadacre wick wiper which can apply concentrated chemicals while travelling at up to 18 kph. This allows areas as large as 400 ha to be wiped in one day. Individual farmers are modifying existing booms with the addition of a line of porous hose which is a quick and inexpensive solution for problem weeds such as muskweed in lentils.

TABLE T3.1c-3 Seed production and seed viability of muskweed in eight commercial paddocks following glyphosate application with a weed wiper (Stuchbery 2002).

Paddock #	Growth stage of musk weed	Seeds per plant		Germination %	Comments
		Total	Viable		
1	Flowering – early pod fill	134	0	0	Small pods, 50% seed shrivelled
2	Flowering – early pod fill	292	3	1	Small pods, 50% seed shrivelled
3	Flowering – very early pod fill	43	9	22	Low seed number, seed plump but green
4	Mid pod fill	326	33	10	Plump and shrivelled seeds
5	Mid pod fill	335	47	14	Plump and shrivelled seeds
6	Late pod fill	265	56	21	Plump seeds
7	Late pod fill	439	97	22	Large pods, green and plump
8	Late pod fill	489	176	36	Mixture of seed types

Work on turnip weed (*Rapistrum rugosum*) in northern New South Wales with a Weed Swiper™ produced good control on charlock (*Sinapis arvensis*) and turnip weed. Chlorsulfuron applied at the pre-embryo stage (soft squashy pods) reduced turnip weed pod set by 95 per cent (Storrie *et al* 2006). Glyphosate applied at the same timing reduced pod set by 60 per cent. Late applications (post-embryo) of glyphosate and 2,4-D achieved 50 per cent pod reduction. Chlorsulfuron was ineffective at the later stage. In experiments involving charlock chlorsulfuron and glyphosate gave 80 per cent reductions in pod set. While some crop damage and yield loss occurred, especially when the crop to weed height differential was less than 20 cm, weed wiping in chickpeas with glyphosate only produced 2 to 8 per cent yield losses.

The introduction of weed wiper technology as part of an integrated weed management plan for charlock and turnip weed has seen numbers remain low and slowed the development of herbicide resistance, particularly to Group B herbicides (Cheam *et al* 2008).

Contributors

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TACTIC 3.1d CROP DESICCATION AND WINDROWING

Crop desiccation and windrowing (also called swathing) are harvest aids which ignore the growth stage of any weeds present, so they are not true weed seedset control tactics. However, in certain conditions windrowing and crop desiccation can provide significant weed management benefits.

The tactics are defined as the termination of crop growth by physical (windrowing) or chemical (desiccation) means at physiological maturity or a later stage.

Benefits

Key benefit #1

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

In conjunction with trash burning and the collection of residue at harvest, windrowing can minimise the addition of weed seeds to the seedbank (see *Tactic 1.1 Burning residues*, page 92 and *Tactic 4 Weed seed control at harvest*, page 212).

Weed seeds that would otherwise be shed prior to harvest are cut and concentrated into windrows. Seed remaining in the weed seed-heads in the windrow are likely to be processed by the header, with the option of being removed in a seed collection system. Seeds that drop out of the seed-heads will generally fall through the windrow to the ground but will remain concentrated in a narrow band.

Key benefit #2

There is a chance that crop desiccation or windrowing will reduce weed seedset

Used on an early maturing crop and variety, desiccation can reduce the seedset of many weeds, including annual ryegrass (*Lolium rigidum*), without reducing crop yield or quality.

Because crop desiccation is timed according to crop maturity, it will only be effective as a weed management tool if its use coincides with the period when weed seed development is sensitive to the chemical used. Crop desiccation or windrowing can reduce the quantity of seed produced by later germinating weeds.

PHOTO: WARWICK HOLDING

Raking stubble (following crop windrowing and harvesting without spreaders) concentrates the stubble into a narrower windrow which gives a hotter burn that kills more seeds.

As illustrated in Table T3.1d–1 (below) windrowing can be an effective means of reducing the seedset of wild radish (*Raphanus raphanistrum*), particularly if the crop matures prior to completion of weed seed development. The earlier maturity of the barley and canola, compared to wheat and lupin, resulted in greater reduction of pod numbers. In the poorly competitive lupins, windrowing greatly reduced wild radish seed production compared to the control treatment, which was not windrowed.

Key benefit #3

Windrowing or desiccation can assist the management of late germinating weeds

Spring rain promotes the germination of a range of weeds that become a problem in summer fallow. Desiccation or windrowing of winter crops removes a potential harvest nuisance and a summer fallow problem.

TABLE T3.1d-1 Wild radish seed production levels in wheat, lupin, barley and canola crops as influenced by windrowing at crop maturity, Goomalling, Western Australia (Walsh 2001).

Treatment	Wild radish (seeds/m²)				Wild radish seed and pod reduction (%)			
	Wheat	Lupin	Barley	Canola	Wheat	Lupin	Barley	Canola
Control	5565	10,220	4873	7974				
Windrowing	4787	4901	1849	2932	14	52	62	63

Whole-farm benefits

Windrowing and desiccation can:

- assist harvest schedule
- encourage even ripening of crops
- increase harvest speed and efficiency
- minimise yield loss from shattering or lodging
- enhance seed quality
- overcome harvest problems caused by late winter or early summer weed growth
- minimise weather damage during harvest by increasing the speed of drying, while protecting the crop in the windrow
- improve the yield of following crops by halting water use by the current crop. Crops can continue to use soil water when past physiological maturity.

Practicalities

Key practicality #1

Timing is the key to maximum yield and quality

Yield and quality will be optimised at crop physiological maturity (see Table T3.1d-2, below).

TABLE T3.1d-2 Optimum timing for windrowing of different crops (compiled from Metz 2004).

Crop	When to windrow
Canola	At 45 to 60% seed colour change in cool weather. Hot weather can increase shattering losses.
Barley	From 30% moisture or lower. It is better to windrow early in varieties susceptible to head loss and lodging.
Wheat	1 to 2 days prior to harvest, to reduce grain moisture content
Lupins	When cotyledons from the primary spike pods are yellow and the cotyledons from the tertiary branch pods are yellowish-green and past the firm dough stage
Faba beans	When the hilum on the seed has just turned black and the pods are still leathery to touch
Field peas / vetches	When the seeds from the least mature pods are firm and moisture cannot be squeezed from the pod with pinched fingers

Key practicality #2

Weed and crop regrowth (post-windrowing) must be controlled to stop seedset.

Apply a non-selective herbicide to manage any regrowth and seedset in-crop or in weeds following windrowing or desiccation.

Some windrowing machines have been adapted by mounting a spray line behind the windrowing front. A non-selective herbicide is sprayed prior to the windrow being laid back on to the paddock surface. This can be an effective means of preventing regrowth and controlling seedset in tillers below the windrow height. Note that only herbicides that are registered as desiccants for the crop in question can be used due to grain maximum residue level (MRL) issues. Observe harvest withholding periods.

Key practicality #3

Weeds and tillers below cutting height will not be incorporated into the windrow

There is a practical limitation to the lowest height at which crops can be cut. Any weeds that grow below this height will escape this management tactic.

Key practicality #4

Check herbicide labels

Crop desiccation is registered in a limited number of crops. Tables outlining registrations for desiccation can be found in weed control guides produced by state departments of agriculture and primary industries. Always check herbicide labels, follow the directions on the label and adhere to harvest and grazing withholding periods.

Key practicality #5

Windrowing in hot weather can increase losses due to shattering

Hot weather can cause the rapid desiccation of standing crops and windrowing of such crops can lead to significant shattering losses.

Contributors

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TACTIC 3.2 PASTURE SPRAY-TOPPING

The composition of a medium-term ('phase') pasture dominated by annual legumes and grasses (a three- to five-year pasture phase between crop phases in a rotation) changes over time. A pasture may be legume dominant in year 1 but often by year 3, without intervention, it will be dominated by annual weeds, often a result of low intensity set stocking. In some regions (and paddocks) the dominant annual weeds are broadleaf, but predominantly they are annual grasses.

Typical grass species that build up in pastures include ryegrass (*Lolium* spp.), silver grass and other *vulpia* grasses (*Vulpia* spp.), barley grass (*Hordeum* spp.) and brome grass (*Bromus* spp). It is worth noting that prior to the advent of widespread herbicide resistance problems, annual ryegrass (*L. rigidum*) was often sown as a component of pastures throughout large areas of the Western and Southern Australian wheatbelt.

Problems caused by annual grass weed build-up in the pasture include:

- a build-up of weed seeds in the seedbank (often herbicide resistant types) that will pose a threat to future crops
- reduced availability of nitrogen from pasture legume input as weeds use the nitrogen reserves
- a build-up of cereal root diseases
- an increased risk of eye and hide injury, meat contamination in sheep and increased vegetable faults in wool.

One of the tactics for reducing annual grasses and retaining desirable species in pastures is pasture spray-topping (see *Tactic 3.1a Spray-topping with selective herbicides,* page 172, to understand the difference between the terms 'pasture spray-topping' and simply 'spray-topping'). This involves application of a non-selective herbicide at a critical time (flowering of the weeds) followed by heavy grazing, to target weed seedset.

Pasture spray-topping is possible because annual grasses become more sensitive to non-selective knockdown herbicides during flowering. This increased sensitivity allows low rates of herbicide to be used to prevent the formation of viable grass seeds, with limited or no effect on desirable pasture species.

'Mechanical topping' refers to slashing or mowing activities late in the season to prevent

PHOTO: SALLY PELTZER

Strip of pasture dominated by barley grass and capeweed spray-topped (right) and untreated (left).

PHOTO: ANDREW STORRIE

Anthers (yellow pollen sacs) about to emerge from the ryegrass flowers. An ideal time to spray-top with paraquat.

development of viable weed seeds. It can be used as an alternative to pasture spray-topping, especially if weeds are resistant to knockdown herbicides. Mechanical pasture topping is slower and more expensive than pasture spray-topping (Table T3.2-1, below) and there is greater likelihood of the plants regrowing to produce seed.

An integration of multiple methods of seedset control in pastures may be useful if the problem is resistance to knockdown herbicides.

Targeted grazing can be very effective as a mechanical pasture topping tactic provided that sufficient numbers of dry sheep are available (see *Tactic 3.5 Grazing – actively managing weeds in pastures*, page 202).

TABLE T3.2-1 Pasture spray-topping compared with mechanical management and targeted grazing for seedset control in pastures.

Tactic	Advantages	Disadvantages
Pasture spray-topping with paraquat or glyphosate	Quick Economical Pasture can be grazed afterwards (check withholding period) Efficacy on target weed can be ≥90%	Desirable species can be affected (glyphosate can be more of a problem than paraquat) if timing is poor (e.g. pasture legume seed production reduced)
Mechanical topping (see Note 1)	Non-selective Can be used on organic farms Used in conjunction with grazing	Time-consuming Plants often regrow, especially if rain falls soon after cutting Can have profound effect on species balance
Targeted grazing (see *Note 2*)	Non-chemical option for organic farms Small positive income stream from wool production	Large numbers of dry (see Note 2) sheep needed Difficult to treat large areas Stock may increase density of some species (e.g. vulpia) Can have profound effect on species balance

Note 1: Non-herbicide methods can be highly effective in changing the species balance in annual pasture (see Table T3.3-2). While mechanical topping and grazing may not be as time efficient as pasture spray-topping, they are viable alternatives where herbicide use may not be possible or desirable.
Note 2: The grazing technique required to alter pasture grass composition generally involves placing a lot of stress on the sheep involved, and excessively stressed ewes and lambs will exhibit reduced performance. Unless sufficient grazing pressure is applied, sheep will ignore the targeted grasses.

Benefits

Key benefit #1

Strategically timed pasture spray-topping significantly reduces the production of viable weed seed in pastures

Pasture spray-topping of annual ryegrass has resulted in a 30 to 80 per cent decrease in seed production (Gill and Holmes 1997). The variation between spray-top trials is due to a number of factors, including the development stage of annual ryegrass, grazing pressure and rainfall events after treatment. There have been reports of an 85 per cent decline in annual ryegrass density after spray-topping (Gill and Holmes 1997).

Dowling (1997) collated data for several experiments that showed large decreases in grass species following pasture spray-topping (Table T3.2-2, page 186).

Variations between experiments may often be explained by differences in timing of application. In addition, some *Vulpia* species never extend their heads fully from the boot (Dowling 2005, pers. comm.), which may partly explain some of the low control of *Vulpia* species in the above data. Leys *et al* (1991) investigated the effect of time of application of pasture spray-topping with paraquat and glyphosate on the regeneration of vulpia. Their results showed that for both herbicides the timing of application was critical for the level of regeneration of vulpia obtained. Pasture spray-topping at heading and flowering (anthesis) gave better reduction of vulpia than pasture spray-topping at grain fill (Figure T3.2-1, page 186).

Research in Western Australia (Stewart and Mann 1988) has shown that the number of viable seeds or tillers of barley grass is low when spray-topping is conducted before anthesis is complete. Once anthesis ends, pasture spray-topping in barley grass is not as effective for seedset control (Figure T3.2-2, page 186).

FIGURE T3.2-1 **The effect on growth stage of vulpia at time of pasture spray-topping with paraquat 250 g/L and Roundup CT on the regeneration of vulpia: average of three replicates by two rates (Leys *et al* 1991).**

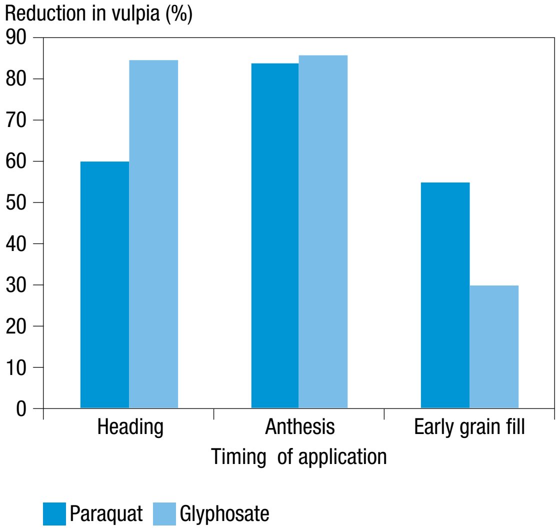
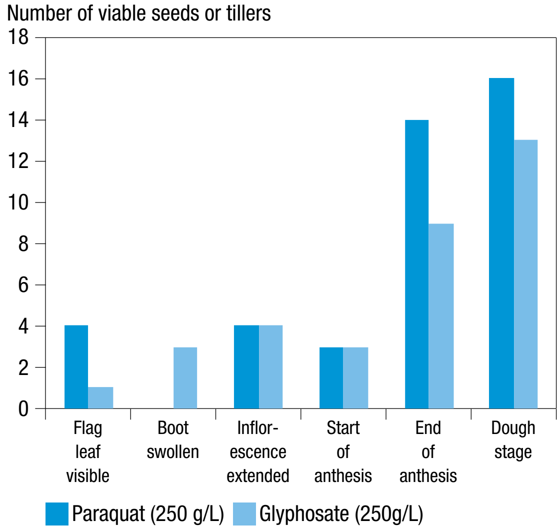


FIGURE T3.2-2 **The effect of pasture spray-topping on barley grass seedset control using paraquat and glyphosate (Stewart and Mann 1988).**



Key benefit #2

Both paraquat and glyphosate can be used for pasture spray-topping

The availability of both paraquat and glyphosate for pasture spray-topping allows for flexibility in mode-of-action rotation, particularly in situations where either herbicide has been used regularly in past seasons or where resistance to a selective herbicide has developed in the target weed.

TABLE T3.2-2 **Effect of pasture spray-topping in the previous spring on percentage reduction of seedling numbers in the following autumn compared to untreated control (Dowling 1987).**

Grass species % control				Source of data
Lolium spp.	*Hordeum* spp.	*Bromus* spp.	*Vulpia* spp.	
94	98	94	98	Blowes *et al* 1984
-	88	87	69	Depts of Ag. Vic and WA
-	85	85	85	England 1986
96	77	97	97	Dowling (unpublished data)

Key benefit #3

Pasture spray-topping is a cost-effective tactic to reduce weed seedset and the weed seedbank

Pasture spray-topping uses one third to half the rate of knockdown herbicide compared with a fallow application herbicide rate. This makes pasture spray-topping a low cost operation compare to mowing, fallow and winter cleaning.

Whole-farm benefits

Additional benefits gained from pasture spray-topping include the following:

- The proportion of legume in the pasture is increased, resulting in improved feed value of the pasture and increased livestock production from grazing.
- Well-planned pasture spray-topping can be used to set up pastures for high-quality forage conservation (hay or silage) in the following spring.

- Pasture spray-topping is ideally used in the season prior to fallow initiation, reducing grass weeds and the risk of cereal disease carryover into the next winter crop.
- Pasture spray-topping can be effective against grass seed injuries to lambs' eyes and skin and damage to carcasses.

Practicalities

Key practicality #1

The timing of herbicide application is critical to the success of pasture spray-topping

Pasture spray-topping must be timed according to the growth stage of the target grass weed. This period extends from when the seed-heads are fully emerged from the boot until the seeds reach the dough stage.

Timing varies slightly between glyphosate and paraquat. In general, the application window for both herbicides begins when all the seed-heads have been extended from the boot. However, the application window for glyphosate ends at the milky dough stage, whereas the window for paraquat application ends a little later, when the most mature seed-heads begin to hay off.

Seed-heads that are still partly enclosed by the upper (or 'flag') leaf may not be 'topped' and viable seed is likely to develop. The seed-heads of some grasses (e.g. *Vulpia* spp.) never fully emerge from the flag leaf.

As a result, the level of seedset control obtained from pasture spray-topping these species may be less than for those species where the majority of seed-heads fully emerge.

An example of the control given in a broad-leaf weed by pasture spray-topping is shown in Figure T3.2-3 (below), which illustrates control of saffron thistle (*Carthamus lanatus*) by pasture spray-topping at four different growth stages.

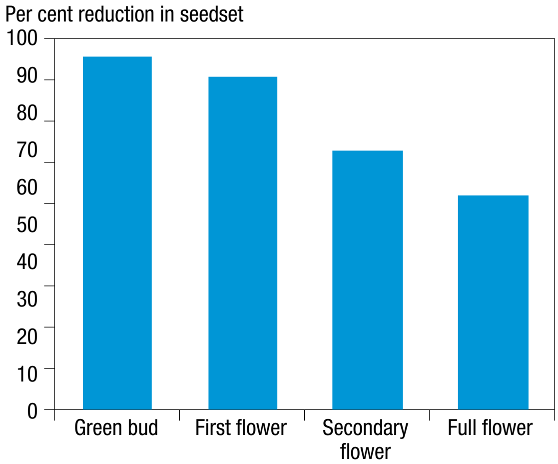
Key practicality #2

Pasture spray-topping is not an alternative to fallow spraying

Pasture spray-topping aims to alter pasture composition by suppressing seedset in a targeted grass weed, while fallow spraying aims to kill all species present, thus initiating the fallow period.

The application window for pasture spray-topping is much narrower than for fallow spraying. Fallow spraying can be carried out much earlier than pasture spray-topping, although the latest time to successfully employ either technique is similar. Furthermore, the herbicide application rates for fallowing are much higher than that for pasture spray-topping as the aim is to kill all plants outright.

FIGURE T3.2-3 Reduction in saffron thistle seedset, after pasture spray-topping, at various growth stages. Pasture spray-topping used paraquat 250 g/L at 400 mL/ha and BS1000 at 60 mL/100 L (Watson 1990).



Key practicality #3

Pasture spray-topping as a lone tactic cannot control a wide range of grass species simultaneously

The success of pasture spray-topping depends on the application of herbicide at flowering. It therefore cannot be successfully used to control seedset in more than one species with one application unless the sensitive growth stage of both species occurs simultaneously. Alternatively, more than one application can be made to target different growth stages but this greatly increases the cost of the pasture spray-topping technique. This is a particular issue for barley grass which flowers over an extended period when compared to annual ryegrass.

Key practicality #4

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

Grass weed density increases in response to increasing nitrogen. Typically a legume dominant pasture will be invaded by grass weeds in the second or third year of the pasture phase, depending on a range of factors such as grazing management and soil fertility.

Pasture spray-topping can be used to manipulate grass weed density to extend the pasture phase an extra year or two.

Key practicality #5

Winter cleaning or fallow spraying may be a better option to finalise the pasture phase before cropping commences

In the final year of a perennial and/or subclover-based pasture phase the pasture should be winter cleaned if a cereal crop is to follow, or fallow sprayed if canola or another non-cereal crop is to be sown.

Winter cleaning is the practice of using non-selective or certain selective herbicides for the complete control of all annual weeds during their vegetative stage in winter. Pasture spray-topping, on the other hand, targets seedset in spring and uses lower herbicide rates than winter cleaning or fallow.

Management options to follow pasture spray-topping are presented in Table T3.2-3 (below).

TABLE T3.2-3 Management options in the year following pasture spray-topping.

Year 1	Year 2 options	Advantages	Disadvantages
Spray-topping	Fallow spraying	Ideal preparation for canola or other non-cereal crops sown in year 3. Stock can graze sprayed forage. Quick and economical.	May not be early enough to control cereal diseases such as take-all.
	Winter cleaning (pasture manipulation)	High levels of take-all suppression likely. A good technique when targeting high yield and grain quality wheat in year after pasture.	Only feasible if legume content is high. Pasture needs to be managed carefully before spraying. All herbicide options will suppress annual legume dry matter production.
	Fodder conservation	Hay or silage production will further reduce weed content of pasture. Best for managing resistant weeds.	Only feasible if the conserved fodder can be used economically (tends to preclude large areas).

Key practicality #6

Spray-topping can reduce seedset in annual pasture legumes if the stage of development of the legume pasture coincides with the development stage of the target annual grass

There is some discussion about the effect of pasture spray-topping on the desirable pasture species, particularly subclover and medics. Evidence suggests that using paraquat for pasture spray-topping has a less detrimental effect on the legume component of pastures than using glyphosate (Milne 1990). Blowes *et al* (1984) reported that when glyphosate was used for pasture spray-topping, some reductions in legume seedset were expected even though the legumes were much more tolerant to glyphosate than grasses at the time.

Other work has shown that repeated use of pasture spray-topping may be detrimental to the seedbank of desirable legumes (e.g. subclover and medic), requiring pasture to be resown (Ferris 1998).

Where pasture legume seedbank numbers are low (e.g. in newly sown pastures) pasture spray-topping should be used with caution. Pasture legume seedset plays a critical role in maximising early competition with weeds and pasture dry matter production during the following autumn.

Practicality #7

Weeds already resistant to glyphosate or paraquat will not be controlled by pasture spray-topping with these herbicides

Despite the fact that pasture spray-topping is targeting a different plant growth stage (i.e. flowering and seedset), a plant already resistant to that herbicide mode-of-action will exhibit little or no effect.

Contributors

Steve Sutherland and Andrew Storrie

TACTIC 3.3 SILAGE AND HAY – CROPS AND PASTURES

Silage and haymaking can be used to manage weeds by:

- reducing the quantity of viable seedset by target weeds
- removing viable weed seeds so that they are not added to the soil seedbank.

Benefits

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

Hay and silage each offer the chance to significantly reduce the return of weed seeds to the seedbank. Research has demonstrated that pasture hay production in spring can decrease annual ryegrass (*Lolium rigidum*) density by 84 per cent in the following wheat crop (Gill and Holmes 1997).

Silage followed by application of paraquat can also successfully reduce annual ryegrass seed-head numbers by 95 per cent (from approximately 900 seed heads per m^2 to 40 seedlings per m^2) in the following season (Roy 2005).

Both hay and silage tactics are most valuable to growers when the weeds, crop and/or pasture are nutritious.

Wild oats (*Avena* spp.) and annual ryegrass are excellent fodder species and can be included in either silage or hay for domestic markets, provided annual ryegrass toxicity (see *Weed 1 Annual ryegrass Lolium rigidum*, section 6, page 250) is not present. On the other hand, the spikelets on barley grass (*Hordeum* spp.), brome grass (*Bromus* spp.) and vulpia (*Vulpia* spp.), when close to maturity, make them unsuitable for hay or silage.

PHOTO: ALEX DOUGLAS

Paddock showing hay cutting (left) and brown manuring (right) – two options to stop weed seed set.

Practicalities

Key practicality #1

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

Hay and silage production are better suited to farms with a livestock enterprise, as the product can be used on-farm. However, there is a limit to the area of pasture or crop that can be cut for hay or silage simply because too much of either can create a problem of over-supply.

As the portability of hay is much better than that of silage, hay is preferred when the product must be transported to a market.

Key practicality #2

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

Timing the cut and the management of regrowth is critical for hay and silage production to be successful as weed control tactics. Cutting too late means that mature weed seed is likely to have already been shed, adding to the weed seedbank in the paddock. In the case of hay production, a high proportion of seeds may also remain viable within the hay, becoming a vector for the spread of weed seeds.

Seedset management must be timed according to stage of weed physiological maturity. Hay must be cut when weeds are flowering and before any embryos have developed in the seeds.

The timing of silage production (cut earlier than hay) usually means there are no viable seeds present. Although we assume the ensiled seeds are no longer viable, this has yet to be proven for many common Australian weeds. A Canadian study (Blackshaw and Rode 1991) identified low levels of viability in ensiled broad-leaf weeds. They showed that 3 per cent of black bindweed (*Fallopia convolvulus*) seed remained viable following ensiling, compared to no viable wild oats seeds.

A pasture trial conducted by Bowcher (2002) demonstrated that, although appropriate timing of cutting is important to reduce target weed seed production, the control regrowth after cutting is critical to reduce weed seed entering the soil seedbank (Table T3.3-1, below). After an early October cut, annual species such as Paterson's curse (*Echium plantagineum*), annual ryegrass and subclover (*Trifolium subterraneum*) were able to regrow. With sufficient growing season remaining, this regrowth set seed and contributed to seedling numbers in the following year (Table T3.3-1).

Therefore it is essential when using hay or silage for weed management that a post-cutting control of regrowth by knockdown herbicide or heavy grazing is planned. If the spring turns dry it may not be required.

TABLE T3.3-1 Effect of cutting times on weed seed production (seeds/m^2) of a mixed annual grass/subclover/perennial grass pasture with no regrowth control (adapted from Bowcher 2002).

Time of cut	Annual weed seed production					
	Annual ryegrass		Vulpia		Paterson's curse	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Early October	980	830	1000	56	970	880
Late October	95	7	210	30	300	90
Early November	240	2900	2250	13,650	7	220
Late November	990	6880	11,990	29,900	210	2150

Key practicality #3

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

Introduced hay or silage has the potential to transport weed seeds. Feed out in dedicated areas to allow for monitoring and control of any germinated weeds. Hay in particular has the potential to contain high proportions of viable weed seed if it has been cut when weeds have already set seed.

A study of weed seeds in hay bales conducted during the 1980 and 1981 drought (Thomas *et al* 1984) found that almost all the sampled bales in the Yass, Young and Gundagai districts of New South Wales contained viable seeds of prohibited or restricted weeds. There were 233 different seed types identified in the 38 bales sampled, and the number of seed types and seeds per bale varied considerably. The study detected one to 30 types of seed per bale, with an average of 21. The number of seeds per bale ranged from 104 to 364,000, with an average of 68,700. The hay had been imported from other areas of New South Wales, Victoria and South Australia.

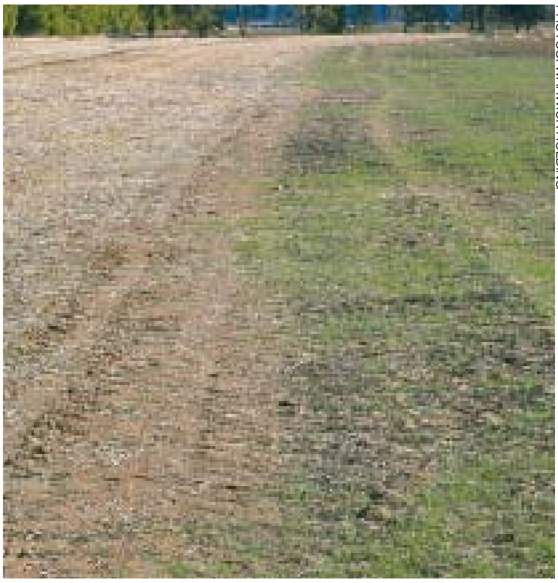
Contamination also determines marketing options. Certain weeds such as doublegee (*Emex* spp.) are prohibited in oaten hay exports to Japan, which must be 95 to 97 per cent pure oats (Carpenter 1999).

Key practicality #4

Understand the biological traits of the target weed to improve efficacy of the tactic

Individual species' responses to cutting, in terms of subsequent regrowth and seed production, will be determined by the stage of maturation of the weed at the time of defoliation. Understanding species differences allows for more suitable timing and can thereby improve the effectiveness of the hay or silage tactic (see *Section 6 Profiles of common weeds of cropping*, page 249).

The impact of cutting and baling pasture infested with Paterson's curse can be seen two years later. Here only the left side of the paddock was cut for hay in 2003. Photo was taken in spring 2005.



The effect of cutting a portion of a crop and making silage (left) compared with harvesting grain (right) on ARG seedling numbers the following autumn.

PHOTOS: WARWICK HOLDING

A study in southern New South Wales showed that early November was the most effective time to cut annual ryegrass and Paterson's curse (Kaiser *et al* 2004). This timing was too late for effective management of vulpia as it had matured earlier than the annual ryegrass and Paterson's curse, and had produced and shed vast quantities of viable seed before the defoliation occurred (Table T3.3-2, below). In contrast to annual ryegrass and Paterson's curse, it was an early October cut that greatly reduced vulpia seed production and vulpia content in the following year.

The key is to identify the target weed species and to strike a balance between the problem weeds and other species which contribute to the pasture mix. In the trial presented in Table T3.3-2 the optimum stage for seedset control of annual grass weeds was found to be when the majority (e.g. 75 per cent) of the most advanced seed-heads were between post-flowering and very early seed fill. For Paterson's curse the optimum cutting time was found to be when the majority of the earliest flowers (lowest on the stem) had started to form green seeds on the most advanced flowering heads. However, the introduction of follow-up controls such as heavy grazing or a knockdown herbicide would negate this issue.

TABLE T3.3-2 Effect of grazing by wethers (10 DSE*/ha) and cutting times on species composition of a mixed annual grass/subclover/perennial grass pasture the third spring (year 3) after cutting or grazing in each of the two previous springs, Wagga Wagga, NSW (Kaiser *et al* 2004).

			Grazed then cut in spring (no control of regrowth)			
	Initial pasture composition (%)	Grazing only	Early October silage	Late October (late silage or early hay)	Early November hay (Wagga district practice)	Late November (late hay)
Species	Percentage of species in pasture in year 3					
Phalaris and cocksfoot	16	15	18	14	14	17
Subclover	316	18	37	12	16	20
Naturalised clovers	4	<1	4.5	<1	4	7
Annual ryegrass	25	18	28	53	10	9
Vulpia (e.g. silver grass)	16	26	2	10	53	41
Great brome	1	14	2	<1	1	4
Barley grass	<1	5	<1	0	<1	<1
Paterson's curse	4	<1	7	4	1	2
Other broad-leaf weeds	2	3	1	6	<1	<1

* DSE = dry sheep equivalents. This trial was conducted at Wagga Wagga and the timing of when weeds flower will vary with district and seasonal conditions.

PHOTOS: ANDREW STORRIE

Regrowth of weeds following silage or hay-cutting must be controlled to prevent seed set.

Key practicality #5

Regrowth can produce enough seed to keep the seedbank topped up

Regrowth monitoring is important because late cutting of hay may not reduce seedbank numbers. Roy (2005) showed that where paraquat was not used to control regrowth, and hay was cut two to three weeks after the silage production, there was an increase in annual ryegrass numbers from 900 seed-heads/m^2 to 1200 seedlings/m^2 the following year, whereas silage followed by paraquat produced 42 seedlings the next year.

A knockdown herbicide or intensive grazing used after an early cut is a reliable way of controlling weed regrowth.

Cutting silage to target forage quality is often too early for weed management. Regrowth will occur and require subsequent additional management.

A summary of issues to be considered when deciding whether to cut for silage or hay is outlined in Table T3.3-3 (below).

TABLE T3.3-3 Considerations to be made when choosing between hay and silage as a weed management tactic.

Issue	Hay	Silage
Prevention of viable seed addition to the weed seedbank in the paddock	Similarly effective, assuming no target weed seed production has occurred before the cut and regrowth is controlled to prevent further weed seed production	
Potential for weed seeds to be spread to other areas during feed out	Moderate to high	Low if ensiled properly
Potential for weed regrowth	Depends on growth stage of weed at time of cut and follow-up rainfall	
Feasibility	Depends on the scale of the operation, livestock enterprises within the business, distance to end-use point and demand for the product	

Contributors

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TACTIC 3.4 MANURING, MULCHING AND HAY FREEZING

Crops and pastures can be returned to the soil with the key aims of reducing weed seedbanks, improving soil fertility and maintaining soil organic matter. Crops and pastures may be returned to the soil by burial, mulching or chemical desiccation.

Green manuring incorporates green plant residue into the soil with a cultivation implement. Most commonly conducted with an offset disc plough, cultivation aims to kill weeds and control seedset while building soil organic matter and nitrogen status. Green manuring has a very long history of managing weeds and building soil fertility in systems where herbicides are either not an option or not available, such as organic farming systems.

Brown manuring is simply a no-till version of green manuring, using a non-selective herbicide to desiccate the crop (and weeds) at flowering instead of using cultivation. The plant residues are left standing. This may also be a preferred option on lighter soils prone to erosion. Prior to spraying, the crop or pasture can be 'opened up' by grazing, followed by a recovery period, to enable better coverage with the herbicide. This might preclude the need for a double knock to control any regrowth. The standing residues can be grazed post-spraying after appropriate withholding periods have been observed.

Lupins are preferred for manuring in the northern Western Australian wheatbelt, while field peas are preferred in the south. Biomass production is the key to successful manuring. In Western Australia there is a trend towards manuring weeds such as wild radish (*Raphanus raphanistrum*) when there is an early break to the season due to their high biomass. Manuring peas and lupins would cost $70 to $100/ha more than a fallow (Fosbery pers. comm. 2012).

In southern New South Wales there is a resurgence in interest in brown manuring over fallow because a manure crop competes with weeds, requires less use of knockdown herbicides and improves accumulation of soil nitrogen and maintenance of soil cover (Patterson 2012). Weed management outcomes of green and brown manuring are contrasted in Table T3.4-1 (page 196).

Mulching is similar to brown manuring but involves mowing or slashing the crop or pasture and leaving the residue laying on the soil surface. This enables more soil contact with the crop residue and might help reduce soil moisture loss through evaporation. Residues may break down more rapidly as plant pieces are likely to be smaller than in brown manuring.

PHOTO: WARWICK HOLDING

Aerial photo of section of a crop that has been brown manured to control herbicide resistant ryegrass and wild oats.

Hay freezing is similar to brown manuring with the additional aim of creating standing hay. In this case herbicide is applied earlier than if the crop was to be mown for conventional haymaking. Hay freezing is a more reliable tactic for controlling weed seedset than conventional haymaking, with the added advantage that existing boomsprays are used rather than specialised haymaking equipment. The protein content and digestibility of standing hay are similar to those of conventionally baled hay.

Benefits

Key benefit #1

Manuring, mulching and/or hay freezing (all with regrowth control) reduce viable weed seedset, thereby controlling high weed numbers and managing herbicide resistant weeds

Manuring or hay freezing can greatly reduce seedset of all plants treated, including desirable pasture legumes. Pasture regeneration will be substantially reduced in the following year, depending on the size of the seedbank and the extent of seed dormancy, although it is unlikely you would use this tactic if wanting to go back to pasture the following year.

One of the advantages of hay freezing is that reduction in weed seedset is much more reliable than with hay production, as the grower is tempted to maximise hay yield and cut later, allowing some weed seeds to be set. Hay bales also need removing from the paddock before spraying of regrowth can occur. In addition, specialised haymaking equipment is not required and existing farm equipment (e.g. a boomspray) can be used. This can be a useful tactic to employ when changing from one pasture species to another, or when moving from a pasture to a cropping phase.

TABLE T3.4-1 Contrasting green and brown manuring.

Weed management outcome	Green manuring	Brown manuring
Effectiveness in preventing seed return to paddock	Depends on weed regrowth. A secondary cultivation or heavy grazing is often needed to ensure complete success	Tall, dense or tangled herbage may interfere with herbicide coverage and a double knock treatment is advised to control survivors. This may not be necessary if the paddock is grazed to open up the sward before spraying.
Ability of viable seeds to germinate	Burial can induce dormancy in many species. Ideally, the manuring occurs before seeds are mature, so this should apply only to existing seeds in the seedbank	Herbicides at recommended rates generally have little effect on the ability of viable seeds to germinate. The sward should be sprayed before weeds set viable seed. Existing seeds will be left on the soil surface.

As a number of legumes are relatively competitive with annual ryegrass (*Lolium rigidum*), green manuring of high density plantings of legumes (e.g. arrowleaf, Persian and berseem annual clovers) can reduce the seedset and subsequent germination of weeds in the following season (Table T3.4-2, page 197). The 'no tactic' treatment in the table indicates that field peas are a more competitive crop than lupins.

The level of reduction of annual ryegrass will depend on the timing of tactical manuring and control of any regrowth. In Table T3.4-2 (page 197) tactics are presented in chronological order of timing of activity. Green manuring takes place early in the season as yield is not a target, and so the seedset of annual ryegrass is effectively controlled. By contrast, the silage activity commences a little later in the season, with the result that some annual ryegrass can escape the tactic and set seed unless regrowth is controlled (107 weeds/m^2 with no control of regrowth versus 16 weeds/m^2 with grazing of regrowth). In this example haymaking was performed too late in the season to significantly reduce annual ryegrass seedset, and subsequent germinations were high. Also the introduction of grazing prior to treatment will improve herbicide coverage by opening the sward and might negate the need for a second control treatment (Condon 2000).

In a trial at Wongan Hills, Western Australia, Hoyle and Schulz (2003) found that the reduction in annual ryegrass numbers in a wheat crop was 94 per cent following green manuring, 79 per cent following brown manuring and 82 per cent following mulching.

In Western Australia hay freezing pink serradella (cultivar Cadiz) resulted in the lowest density of annual ryegrass and the highest wheat yields in the year after treatment, compared to green manuring with an offset disc plough or physical pasture topping with a mower. The average reduction of in-crop weed numbers following green manuring, hay freezing and mowing of serradella pasture was 90 per cent (Revell and Hudson 2001).

Key benefit #2

Costs (income loss) from the tactic can be offset by improved yield in subsequent cereal crops and/or by fattening trade stock

Income loss from manured crops can be mitigated in successive seasons by benefits such as increased canola or wheat yields, improved grain quality and reduced weed control costs. These benefits may in some instances outweigh and exceed the loss of income.

Grazing competitive forage or pulse crops with stock prior to imposing the treatment can also create significant income from the manured paddock.

TABLE T3.4-2 Annual ryegrass germination (plants/m^2) in autumn following green manuring, silage or hay production of forage break crops compared to pulses harvested for grain. Initial annual ryegrass population was 100 plants/m^2 (Condon 2000).

Weed management tactic	Crop and treatment	Annual ryegrass plants per m^2
Green manuring	Vetch	44
	High density legume	29
Silage	Vetch	44
	High density legume	107
	High density legume, regrowth grazed	16
	Field peas	401
Hay	High density legume	634
	High density legume, regrowth grazed	549
No tactic	Lupins harvested for grain	1145
	Field peas harvested for grain	721

Key benefit #3

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

Weed infestations (resistant or otherwise) often begin in patches. Killing heavily weed-infested patches prevents production of viable seed and eliminates the risk of weed seed spread by the header.

Both green and brown manuring can be used for treating weedy patches. The more practical option is to use herbicide, which is more effective where weed patches are dense compared to individual weeds scattered through the crop. Hay freezing or baling weed patches can be used to produce a fodder bank to increase the stock-carrying capacity of the property.

Patch treatment should only represent an initial response to the weed problem. It should be followed by development and implementation of a weed management plan, using a range of tactic groups, to reduce seedbank numbers of targeted weeds.

Whole-farm benefits

There are additional benefits from manuring and hay freezing crops:

- Manuring allows continuous cropping to occur with lower production and financial risk.
- Manuring will have a beneficial effect on organic matter and soil nitrogen status. The benefit will be much greater if the crop or pasture being manured has a high legume content. Farm data from the New South Wales Riverina have shown early-sown pea brown manure crops giving 25 to 30 per cent yield increases in the two subsequent crops.
- Manuring also allows trade stock to be fattened before manuring takes place, therefore generating income.
- Green or brown manuring or hay freezing can be used to manage other crop pests and diseases. Use of wild radish or other brassica weed species for manuring can also have beneficial soil fumigation effects for diseases.
- A competitive pulse manure crop followed by a canola crop gives an effective break to cereal root diseases and provides extended opportunities for grass weed control.
- Manuring a crop early can give sufficient time for the storage of soil moisture for the following crop.
- Hay freezing provides standing fodder for livestock.

Practicalities

Key practicality #1

Manuring must be carefully timed to prevent seedset and addition to the seedbank

Tactics aimed at reducing weed seedset must be carried out when the most advanced target weed is at the mid-flowering stage.

Green manuring needs to be carried out a little earlier than brown manuring as seed can continue to develop and mature after the plant has been cut or incorporated with a plough. A general guideline is to green manure at flowering of the most advanced weeds.

Herbicide application for brown manuring and hay freezing may be delayed until the milk stage of the most mature seeds. The herbicide works quickly and prevents further seed development if used at this stage.

Hay freezing for weed control is timed to match weed development and prevent seedset rather than to optimise forage dry matter and quality, and is conducted earlier than conventional haymaking.

Key practicality #2

Choice of crop species will influence the competitiveness of the crop

Anderson (2005), quoting research by Hoyle and Schultz (2003) investigating the proportion of total biomass that weeds represented within a manuring crop, stated that their results indicated some crop choices were far more effective at suppressing weeds than others (Table T3.4-3, below; also see *Agronomy 2 Improving crop competition*, section 3, page 61).

TABLE T3.4-3 Summary of weed biomass at flowering in a manure crop averaged across six Western Australian sites (Anderson 2005).

Manure crop	Annual ryegrass mean % of biomass	Range of biomass (%)
Harvested peas	14	7 to 19
Manured peas	11	1 to 18
Oats	3	0 to 7
Pea-oat mixture	3	1 to 7
Serradella	66	43 to 92

TABLE T3.4-4 Annual ryegrass density in wheat crop following green manuring of different crops, Coorow, Western Australia (Anderson 2005).

Treatment in previous season	Annual ryegrass plants per m^2
Harvested lupin crop	106
Green manured lupins	32
Green manured oats/serradella mixture	29
Green manured oats	19
Green manured mustard	19

Less weed biomass should restrict weed seed production but final levels of weed seed production in manure crops and pastures will be dependent on the success of the manuring treatments. In-crop annual ryegrass densities in wheat at Coorow, Western Australia, following various harvest treatments, are provided in Table T3.4-4 (above).

In general, manure crop species that had good early vigour and were able to establish quickly (oats or oats and pea mixes) were more effective at suppressing weed growth than those crop or pasture choices with slow early growth. The ability of the different manuring species to suppress weeds is summarised in Table T3.4-5 (below) (Anderson 2005).

Although the suppression of weed growth will be important with glyphosate or paraquat resistant weeds, an effective control practice, either herbicide or cultivation, should be performed before weed seedset. Total biomass produced before manuring is one of the important parts of manuring, so selecting what will create the largest biomass for the expected conditions is very important.

While cereals were good at suppressing annual ryegrass seed production (Table T3.4-5), in practical terms they are a poor choice. With these crops growers can be tempted to take the crop through to harvest as a cash return starts to look better and better as the season progresses. Another important reason not to use cereals is that they do not give a cereal disease break.

TABLE T3.4-5 Summary of suppression ability of different manure crop species (after Anderson 2005).

Excellent	Good	Fair	Poor
Barley Oats Triticale Wheat Field peas Mustard	Canola Lupins Vetch	Faba beans Medics	Clover Serradella Chickpeas Lathyrus Narbon bean

Key practicality #3

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

Manuring or hay freezing a grain crop forgoes the income from grain in that season. However, where other tactics have failed and hay or silage are not suitable options, manuring or hay freezing have significant merit.

Treatment of weedy patches rather than a whole paddock is often easier to justify, although growers often under-estimate the level of the problem being experienced. At the end of the season growers often wished they had treated the whole paddock. Where herbicide resistance in key weeds is problematic, the economics of completely stopping seedset in one or more years makes manure crop tactics more favourable.

Assess the economics of manuring on a rotational basis to capture ongoing benefits, as opposed to conducting single-year gross margins. The long-term benefits may outweigh the loss of income suffered by sacrificing the crop.

High-value stock, such as prime lambs and trade stock, used to grazing a competitive forage crop prior to imposing the treatment can make a big difference to the first-year economics. There will, however, be some penalty of nutrient removal by grazing animals. If grazing animals are not available, lupins, vetch or field peas may be a useful crop in which to conduct a green manure operation. These crops are reasonably inexpensive to establish ($70 to $100/ha), contribute a nitrogen boost and provide a useful disease break for subsequent cereal crops.

Key practicality #4

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

Consider grazing well in advance of your planned spray, in order to open up the sward. Use an appropriate water volume, spray pressure and nozzle to ensure the coverage and penetration of the herbicide is adequate to kill thick swards with large quantities of dry matter. Use registered herbicides and adhere to livestock grazing withholding periods when hay freezing.

Key practicality #5

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

Prepare the paddock. Use an autumn tickle at a later stage to encourage optimum seed emergence and reduction in weed seedbank when planting a manure crop (see *Tactic 1.4 Autumn tickle*, page 105). A dry tickle can be used on heavier textured soils that are less prone to erosion, particularly where stubble is present. On light textured soils prone to wind erosion a ‘wet tickle’ can be performed after sowing.

Aim for an even head emergence of the target weed for effective hay freezing and brown manuring. Graze heavily in spring and remove the stock in sufficient time for recovery prior to treatment. Where uneven head emergence is a problem, either because of mixed annual species or because of insufficient grazing pressure, heavier rates of glyphosate at full head emergence of the earliest flowering plants will effectively control seedset of the entire sward.

Key practicality #6

Monitor and manage regrowth

Monitor and control any regrowth or subsequent germinations. Control surviving weeds either with glyphosate or paraquat, or graze to eliminate subsequent weed seedset.

If glyphosate has been used for brown manuring, follow up with heavy grazing, cultivation or paraquat. This will produce a reduction in weed seedset while managing glyphosate and paraquat resistance.

Whole-farm considerations

There are multiple issues to consider when deciding when and how to use a manure crop or pasture:

- Cultivation leads to increased mineralisation of soil organic matter which needs to be considered when using green manuring. Brown manuring impacts positively on soil organic matter.
- Lighter textured soils may suffer excessive structural damage under green manuring. Brown manuring helps retain soil structure and surface cover.
- The number of tillage passes required by green manuring for a successful kill may be affected by soil moisture, with more cultivations required in a wet spring.
- The feed value and quantity of hay freezing fodder depend on the plant species and dry matter content of the area treated. Generally, feed value drops rapidly and the treated area needs to be grazed within a few months of spraying to gain most benefit.
- The protein content and digestibility of fodder following hay freezing deteriorate rapidly after rain, and the fodder suffers trampling losses over time. It does, however, provide and maintain better feed value than hayed-off standing pasture.

- A pasture hay-freezed at ryegrass flowering would be expected to maintain good quality for two months after spraying. After approximately three months the quality of the feed in the treated paddock will be similar to that in untreated paddocks (Arkell 1995).
- Plan to graze soon after treatment to avoid the risk of forage quality loss due to weather damage. Strip grazing with an electric or movable fence can reduce trampling loss.

Contributors

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TACTIC 3.5 GRAZING – ACTIVELY MANAGING WEEDS IN PASTURES

Pasture weed management requires maintaining a balance of pasture species (i.e. maximising the mix of desirable plants, legumes and specific grasses while keeping weed levels low).

Most weeds are susceptible to grazing. Grazing management of weeds is achieved through reduction in seedset, competitive ability of the weed and the encouraged domination of desirable species. The impact is intensified when the timing of grazing coincides with the vulnerable stages of the weed life cycle.

In crop based rotations a two- to three-year pasture phase may significantly reduce weed seedbanks to manageable levels before returning to a cropping phase. During this period, pasture phase grazing in association with other tactics may be used to help reduce weed numbers. Grazing can be coupled with hay and silage making, mowing and pasture spray-topping for increased weed control (see *Tactic 3.3 Silage and hay – crops and pastures*, page 190 and *Tactic 3.2 Pasture spray-topping,* page 184).

Benefits

Key benefit #1

Timed grazing pressure can be used to manipulate pasture composition

High grazing pressure in autumn will significantly reduce the proportion of annual grasses (Rossiter 1966) because small plants are physically removed by grazing animals. Short periods of intense grazing are recommended to minimise damage to non-weed species.

Different pastures will require different management techniques, and understanding the ecology of the pasture species will aid management decisions. Management of vulpia (*Vulpia* spp.) is enhanced with light grazing pressure in autumn (Taylor and Sindel 2000). Desirable annual species will be encouraged to re-establish under less intense autumn grazing pressure (see *Agronomy 4 Improving pasture competition*, section 3, page 79) and the number of bare areas where weeds may germinate will be reduced.

PHOTO: ANDREW STORRIE

Sheep are effective weed managers if per hectare stocking rates can be kept high enough.

Key benefit #2

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

Spray-grazing refers to the use of sublethal rates of selective herbicides (often phenoxy-based) to increase the palatability of broadleaf weeds for preferential grazing. It is usually undertaken in autumn or early winter and is especially beneficial for the control of erodium (*Erodium* spp.), capeweed (*Arctotheca calendula*), Paterson's curse (*Echium plantageneum*) and wild radish (*Raphanus raphanistrum*) (Bickford 1995). The use of phenoxy-based herbicides causes the flat weeds to curl up and thus become more accessible to livestock.

High stocking rates up to four times the normal rate for the area are required for this technique to work effectively. Weeds that are not killed by spraying alone will recover in two to three weeks and exhibit normal growth if they are not grazed heavily after spraying. If carried out correctly, competition from the pasture species will reduce the weed population (Peirce 1993).

Key benefit #3

Grazing can be used to reduce seedset in grass weeds

Sheep and cattle will preferentially graze the small heads of annual ryegrass (*Lolium rigidum*) (Matthews 1996). Intensive spring grazing can reduce annual ryegrass seed production (Beattie 1993; Doyle *et al* 1993) but also limit seed production of the more desirable species.

Grass species with sharp-awned seeds (e.g. *Bromus* spp., *Hordeum* spp., *Vulpia* spp.) are less palatable to stock and intensive grazing for these species should commence prior to full emergence of the seed-head. Research by Taylor and Sindel (2000) found that heavy grazing in spring reduced seedset of vulpia significantly (100 DSE/ha for five to seven days to reduce pasture dry matter by 80 per cent).

Key benefit #4

Exploiting differences in species acceptability to sheep can reduce weed numbers

Some legume species (e.g. biserrula) are less palatable to sheep at certain times of the season. Grazing at these times will increase the pressure on weeds and reduce weed numbers (Revell and Thomas 2004).

The impact on annual ryegrass when grazed with three pasture legume species is illustrated in Table T3.5-1 (page 204). Note the large reduction in annual ryegrass in cultivar Casbah biserrula compared to the more palatable medic pastures.

Key benefit #5

Tillering of annual grasses can be decreased by timely grazing

Defer grazing or reduce stocking pressure to decrease tillering of annual grasses. Fewer tillers mean fewer seed-heads and consequently less seedset. This is particularly useful as an aid in controlling barley grass (*Hordeum* spp.) (Burton *et al* 2002).

Whole-farm benefits

Well-managed grazing provides other benefits on the farm:

- Grazing increases legume composition of pastures and improves feed quality.
- More productive legumes can improve levels of nitrogen fixation for the benefit of subsequent crops.
- Increased stocking rates under set stocking can increase wool production per hectare and reduce both the mean fleece fibre diameter and the variation in fibre diameter along the staple (Doyle *et al* 1993).

TABLE T3.5-1 Effect of grazing and pasture cultivar on annual ryegrass tiller numbers (as at early October 2001) and estimated annual ryegrass seedset. In-crop annual ryegrass was measured in September 2002 in a wheat crop sown without herbicide application (Revell and Thomas 2004).

Treatment		Pasture cultivar		
		Casbah biserrula	Sava snail medic	Santiago burr medic
Ungrazed	Annual ryegrass tillers/m^2	85	93	145
	Length of seed-head (cm)	13	15	13
	Estimated seedset (no./m^2)	4240	5352	7504
Grazed	Annual ryegrass tillers/m^2	16	171	139
	Length of seed-head (cm)	5	9	10
	Estimated seedset (no./m^2)	311	6522	5396
	In-crop annual ryegrass Sept 2002 (no./m^2)	37	296	105

Practicalities

Key practicality #1

Grazing pressure needs to be high enough to prevent selective grazing

High grazing pressure (at least two to four times the average district stocking rate) is needed to ensure weed control. Stock numbers required to give optimum grazing pressure must be adjusted depending on pasture growth rates, and pasture and stock condition must be continually monitored and adjusted accordingly.

Insufficient grazing pressure in spring favours vulpia, barley grass and brome grass, which have unpalatable seeds (Matthews 1996). Strip grazing is a practical method of overcoming tock shortages.

Key practicality #2

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

To control annual grasses in a predominantly winter rainfall area, rotational grazing is required in autumn while annual legumes are establishing (Figure T3.5-1, page 205). Grazing pressure should then be reduced during winter to encourage grasses to grow upright, making them more accessible to grazing.

PHOTO: ANDREW STORRIE

Mowing of pasture can be used to reduce spring growth to enable stock to keep up with weed growth as seen here near Mingenew, WA.

High intensity grazing must be introduced before grasses flower to prevent seedset. If insufficient stock is available, silage making and/or spray-topping can be introduced if pasture growth rates exceed the ability of available stock to maintain sufficient grazing pressure.

Key practicality #3

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

Practising good hygiene between paddocks on a property will assist with minimising the transfer of weeds from infested paddocks (Taylor and Sindel 2000; also see *Tactic 5.1d Manage livestock feeding and movement*, page 233).

Some suggestions include the following:

- Move stock to frequently used holding areas following grazing on weedy paddocks.
- Hold new stock in yards or a quarantine paddock for at least five days to empty any seeds in the gut before allowing them on to the rest of the property. Research has found 10 days of quarantine will enable most seeds to be cleared from the gut of livestock (St John-Sweeting and Morris 1990; Stanton *et al* 2002; Stanton *et al* 2003).
- Set aside containment areas if hand-feeding stock with imported feed.
- Alter shearing schedules to ensure that fleece length is short when grasses are shedding seed (this also reduces vegetable fault in fleeces).

Key practicality #4

Livestock movement across paddocks can bury weed seeds

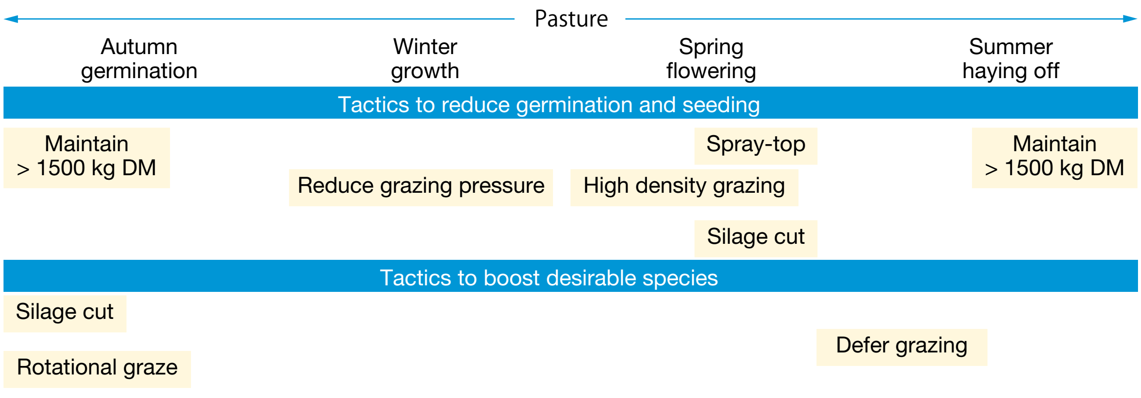
In some species seed burial encourages germination and allows control with herbicides. On the other hand, burial can protect some weed seeds against tactical burning. Knowledge of potential weed species will aid understanding of the likely impact of livestock.

Key practicality #5

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

Rossiter (1996) found that livestock experience difficulty when grazing weeds with a flat rosette growth habit, such as capeweed and erodium. Herbicide application can cause these weeds to curl, enabling better access for stock. However, grazing pressure must be high to ensure that stock eat these weeds.

FIGURE T3.5-1 Timeline for the implementation of tactics for management of annual grass weeds in pastures (Burton *et al* 2002).



Note: For Western Australian wheatbelt pastures and low rainfall areas across Australia, a dry matter maintenance target is >800 kg of plant material per hectare.

Whole-farm considerations

Determine the suitability of grazing as a weed management tactic by considering the following points:

- Livestock traffic can lead to soil compaction and erosion. Fine textured soils are more prone to compaction, especially if grazed after rain.
- Intensive grazing during the flowering and seedset stages of desirable species impedes their ability to set seed. The same paddock should not be intensively grazed in successive years (Doyle *et al* 1993).
- Intensive spring grazing on some paddocks may lead to others being under-used. If there is excess feed, mow it for fodder or treat it with herbicides for weed control.

Contributors

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T 3.1 In-crop weed management for seedset control

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TACTIC 4 PREVENT VIABLE WEED SEEDS WITHIN THE TARGET AREA BEING ADDED TO THE SOIL SEEDBANK

TACTIC 4.1 WEED SEED CONTROL AT HARVEST

Our most problematic weed species of annual cropping systems are prolific seed producers capable of establishing large, viable seedbanks in just one season. Despite this, the high proportion of seed retained on upright stems at crop maturity creates the potential to target these seeds at harvest. Weed seed control at harvest represents an excellent opportunity to control weed seeds, preventing their input to the seedbank.

Modern grain harvesters are efficient at sorting weed seed from crop grain, with the weed seeds returned to the field, primarily in the chaff fraction (Balsari *et al* 1994; Petzold 1955; Walsh and Powles 2007). For example, annual ryegrass (*Lolium rigidum*) and wild radish (*Raphanus raphanistrum*) can retain a large proportion of their seed attached to the plant at the same height as the crop seed-heads at crop maturity. Most of this seed can pass intact through the grain harvester returning to the crop field in the chaff fraction, thus perpetuating an ongoing weed problem (Walsh and Powles 2007). As most small weed seed exits with the chaff fraction, harvest weed seed control options target the harvest residue fraction. For example, up to 95 per cent of annual ryegrass seed that enters the harvester will exit in the chaff fraction.

A recent scoping study in the northern grain region (Widderick and Walker 2012) has shown that there is potential to employ harvest weed seed control techniques for some winter crops. In southern Queensland and northern New South Wales, field surveys at winter crop harvest showed sowthistle (*Sonchus oleraceus*) and possibly wild oats (*Avena* spp.) have the majority of their seeds above harvest height in chickpeas.

The weeds measured included fleabane (*Conyza* spp.) with 96 per cent seed above harvest height, sowthistle with 78 per cent, wild oats with 83 per cent, turnip weed (*Rapistrum rugosum*), cudweed (*Gamochaeta* spp.) and paradoxa grass (*Phalaris paradoxa*) all with 100 per cent, wireweed (*Polygonum* spp.) with 98 per cent and black bindweed (*Fallopia convolvulus*) with 93 per cent. In wheat crops, 66 per cent of sowthistle and 96 per cent of wild oats seeds were above harvest height but fleabane and turnip weed had much less seed above harvest height at 15 and 33 per cent respectively. However, it is unlikely that the very small seed of either fleabane or sowthistle would be able to be captured by the harvest operation.

The collection and management of the weed seed-bearing chaff fraction can result in significant reductions in annual weed population densities (Newman 2009). Lower in-crop weed densities are easier to manage and their potential development into herbicide resistant populations is dramatically reduced. Western Australian farmers have driven the development of several systems

PHOTO: PETER HOOPER

These wild oats will have shed seed well before harvest of the wheat crop reducing the effectiveness of any harvest seed collection techniques.

that are now available to effectively reduce inputs of annual ryegrass and wild radish into the seedbank (see *Tactic 4.1a Narrow header trail*, page 215; *Tactic 4.1b Chaff cart*, page 218; *Tactic 4.1c Bale direct system*, page 220; and *Tactic 4.1d Harrington Seed Destructor*®, page 221).

Benefits

Key benefit #1

Weed seed control at harvest prevents a large proportion of viable weed seed entering the seedbank

Weed seed collection at harvest is the last weed control opportunity of the growing season. The prevention of weed seed entering the seedbank has substantial long-term benefits.

Harvest weed control strategies can result in the removal of high proportions of total weed seed production: for example, annual ryegrass 80 per cent, wild radish 87 per cent, brome grass (*Bromus* spp.) 68 per cent and wild oats 80 per cent (Walsh *et al* 2011). However, the proportion collected will vary according to time between crop maturity and actual harvest as well as a number of agronomic and weather-related factors.

In 14 trials across southern and Western Australia, Walsh (2012) found that harvest weed seed collection tactics gave between 30 and 90 per cent reduction in annual ryegrass in the following season (Table T4.1-1, below).

TABLE T4.1-1 Average range of annual ryegrass control across 14 trials using different harvest seed destruction techniques (Walsh 2012).

Harvest seed kill method	Range of annual ryegrass control (%) Average of 14 trials
Windrow burning	30–90
Chaff cart	32–75
Harrington Seed Destructor	35–90

Key benefit #2

Small crop grain is collected and removed in harvest residues

As well as controlling weed seeds, harvest weed control practices also target small and shrivelled crop grain exiting in the chaff fraction, reducing the number of crop volunteers emerging as weeds in fallow and in the following crop.

Practicalities

Key practicality #1

Cutting height should be as low as practically possible

The efficacy of harvest weed control strategies is totally reliant on the amount of weed seeds that enter the front of the harvester. Therefore, a low cutting height (15 to 20 cm) should be used in an effort to collect as many seed-heads as possible into the front of the harvester. Obviously a lower cutting height may slow harvest, particularly for lower capacity harvest machinery.

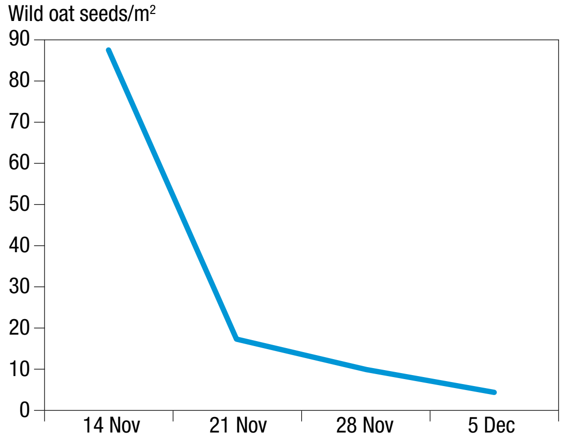
Key practicality #2

Timing of harvest affects the amount of seed collected during harvest

The longer harvest is delayed past maturity the greater the proportion of weed seeds that will shed, shatter or lodge prior to harvest, reducing the total proportion of seed able to be collected. Trials on wild oats in Hawker, South Australia, in 2009 showed that chaff carts were ineffective in controlling wild oats due to rapid shedding of seed post-crop maturation, with seedbank numbers in March going from 92 per m^2 to nearly 6000 per m^2 in one year (Van Rees *et al* 2011). When wild oats seeds above and below harvest height were measured at weekly intervals post-crop maturity it was found that numbers could drop significantly in a one-week interval (Figure T4.1-1, page 214).

Brassica weeds such as wild radish, charlock (*Sinapis arvensis*), turnip weed and Indian hedge mustard (*Sisymbrium orientale*) can establish throughout the year and early cohorts can produce viable seed that can be shed well before crop maturity and harvest (Cheam *et al* 2008). This pre-harvest seed shedding behaviour negates the use of harvest seed capture techniques (see *Section 6 Profiles of common weeds of cropping,* page 249).

FIGURE T4.1-1 Rapid decline in wild oat seed numbers more than 15 cm above ground level following crop maturity at Clare, South Australia, 2009, due to shedding (Van Rees *et al* 2011).



Key practicality #3

Farmers must have a strategy to dispose of collected harvest residues bearing weed seed

The collected weed seed-bearing harvest residues must be destroyed or removed from the paddock. Chaff material is usually burned in the paddock but can also be used as a feed source for in situ grazing or in a feedlot. Livestock feeding on chaff dumps can spread weed seeds if not well managed. A Western Australian study found that sheep foraging in chaff dumps reduced the volume of the dump by almost a half (from 11 to 6 m^3) while tripling the chaff-spread area in a three-week period (Devenish and Leaver 2000). Grazed chaff dumps that have been spread out and lowered in height burn more quickly than ungrazed heaps (see *Tactic 1.1 Burning residues,* page 92).

Livestock eating fodder contaminated with weed seed should be confined to the paddock in which they are grazing (see *Tactic 4.2 Grazing crop residues*, page 222). A percentage of weed seeds ingested by livestock will remain viable and take as long as 10 days to pass through the gut (Stanton *et al* 2002). The number of seeds that remain viable will depend on the weed species and the grazing animal so it is important to develop a feed-out strategy to contain the problem. When grazing harvest residues that contain weed seeds remember the following:

- Livestock can spread weed seeds. A significant proportion of the annual ryegrass seeds ingested by sheep and cattle remain viable when excreted: 6 per cent in sheep and 12 per cent in cattle (Stanton *et al* 2002).
- In areas where annual ryegrass toxicity is a problem, veterinary advice should be sought before grazing harvest residues with high annual ryegrass content.

Key practicality #4

Repeated use and dependence on seed collection at harvest for weed control may favour the development of shorter, quicker maturing (early shedding) weed types

A Western Australian study surveyed paddocks with an eight-year history of seed collection compared to neighbouring paddocks where seed collection had never been used. The study looked at the plant characteristics of annual ryegrass and found no phenotypic evolution had occurred (Ferris 2003). Despite lack of evidence from this study, a risk remains. Diversity is the key to managing weeds and the use of tactics from alternative tactic groups is essential.

Contributors

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TACTIC 4.1a NARROW HEADER TRAIL

The burning of crop residues is the oldest form of weed seed destruction to be used routinely in crop production systems. Stubble burning is typically conducted in autumn on crop fields to reduce stubble levels in preparation for seeding as well as for reducing the carryover of stubble-borne diseases. It is more common in the southern and western grain regions and much less practised in the northern region. The destruction of weed seeds has been a somewhat secondary but significant result of this practice.

During typical whole paddock stubble burning, very high temperatures (300ºC or greater) occur for only a few seconds. However, the effectiveness of weed seed destruction by burning is increased when seeds are exposed to these high temperatures over a period of several minutes. For example, to kill annual ryegrass seed requires temperatures of 400ºC for 10 seconds while 100 per cent kill of wild radish seed retained in pod segments requires 500ºC for this same short 10 second duration (Walsh and Newman 2007). Higher burning temperatures (500ºC+) and longer durations (greater than three minutes) are only possible with high stubble levels. Therefore, when burning is to be used as a weed control option, concentrating harvest residues into a narrow windrow improves the weed control potential of this practice.

Benefits

Key benefit #1

Narrow windrow burning effectively reduces viable weed seed numbers in the seedbank

Narrow windrow burning has been shown to control up to 99 per cent of annual ryegrass and wild radish seed present in the windrow (Walsh and Newman 2007) but is more likely to be in the range of 30 to 90 per cent (Walsh 2012). Additionally, the same levels of weed seed control have been recorded following burning of wheat, lupin and canola windrows.

Key benefit #2

Burning a narrow windrow reduces the percentage of the paddock that is burnt, thereby reducing the area prone to wind or water erosion

Normally the narrow windrow is 0.6 to 1.5 m wide depending on the width of the header cutter bar.

Harvest in action producing narrow chaff rows for burning the following autumn.

PHOTO: ANDREW STORRIE

Doug Smith, Pingrup, WA, demonstrating how easy it is to build a shute to produce narrow windrows.

Practicalities

Key practicality #1

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

Reduction in weed seed numbers due to burning is highly variable and dependent on the exposure of the seeds to high temperatures. This in turn is dependent on the quantity, quality and distribution of residue, the conditions at time of burning, the weed species present and the placement of the weed seeds.

Key practicality #2

Burn windrows when there are light (5 to 10 kph) winds

Burning windrows in light cross or head winds helps achieve a slow burn, with windrows burning to the soil surface. By autumn weed seeds are present on the soil surface so, to ensure complete weed seed kill, windrows must burn to the ground (Walsh and Powles 2007).

Key practicality #3

Time burning to suit residue conditions and legislative limitations

Although burning early in the season is likely to achieve best weed seed control, in many instances this is not practical due to weather conditions, the risk of fire spread and the increased risk of erosion of paddocks bared for longer periods. Early removal of stubble in a fallow period also reduces the efficiency of water conservation.

Although hotter burns will occur when ambient temperatures are higher earlier in the season (Pearce and Holmes 1976), there are practical and legislative limitations to burning during summer.

Walsh and Newman (2007) found that lower temperatures can also be effective in killing weed seeds if exposure periods are increased. Late autumn (or 'cool') burning of residues reduces the viability of seeds susceptible to heat treatment to some extent. In north-eastern Victoria, for example, Davidson (1992) achieved a 57 per cent reduction in annual ryegrass establishment with a late autumn burn.

Data from trials on the Darling Downs, Queensland (S.R. Walker, pers. comm. 2005), found that an autumn stubble burn reduced the seedbank of turnip weed by 30 per cent, wild oats by 34 per cent and paradoxa grass by 40 per cent.

The McArthur Grassland Fire Danger Meter (Figure T4.1a-1, right) is a useful tool to determine how your windrows will burn. It can be used on-line (at www.firebreak.com.au/mcarthur_meter.html) or as a hand-held calculator wheel (at www.csiro.au/en/Outcomes/Safeguarding-Australia/Grass-Fire-Danger-Meter.aspx#a2).

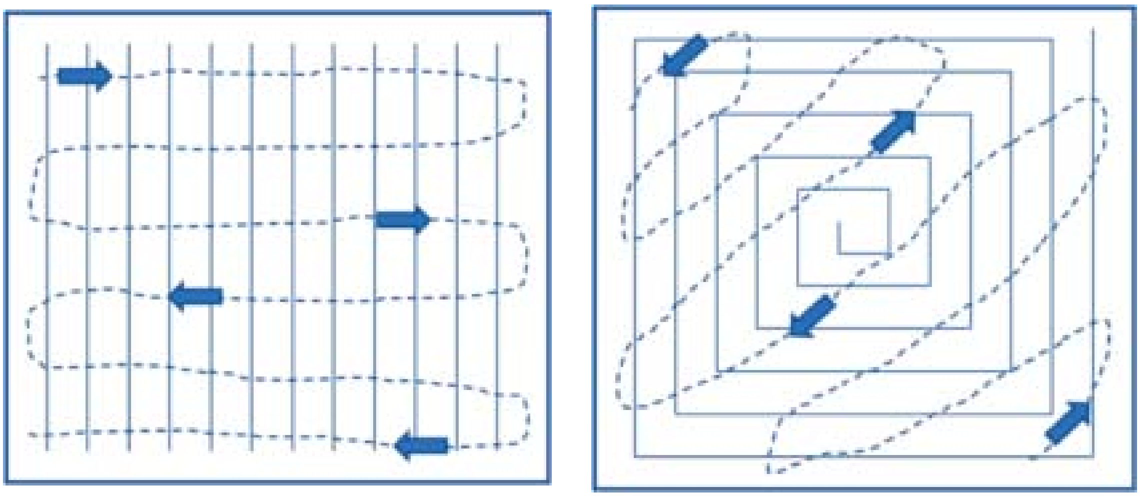
The McArthur Grassland Fire Danger Meter estimates fire behaviour from measurements of wind speed, temperature, humidity, level of fuel 'curing' and fuel quantity.

FIGURE T4.1a-1 The McArthur Grassland Fire Danger Meter that can be carried in the glove-box.

As a rule of thumb, a Grass Fire Weather Index of:

- less than 15 will give a reasonable windrow burn
- eight to 10 is good and probably ideal
- two and lower will not give a good burn as it is too cold and humid
- greater than 15 carries the risk of the fire getting out of control.

FIGURE 4.1a-2 Recommended lighting patterns are determined by the harvest pattern.



Some tips include:

- Don't 'over-thresh' the straw as it will become too fine and won't burn well come March.
- Ignite the windrows when the wind is at 90 degrees across or diagonal to the windrow (rather than parallel) as this prevents the fire developing a face which can carry between the rows.
- Light up across the windrows every 75 m in good conditions and plan to light much closer as conditions cool down. The fires will burn to meet each other (see Figure 4.1a-2, above).
- Best burning conditions are in the second half of March for southern Australia.
- Plan to commence burning just on dark when it is cooler but also plan to have the burning finished when the dew falls, as this limits stubble smouldering and flare-ups during the next day.
- Time constraint means that only 200 to 300 ha (per team) can be burnt each night.
- Use 'Meteogram' weather forecasts for your area. Meteograms predict weather variables such as wind, temperature and humidity up to seven days ahead.
- Don't guess the conditions; measure them and take a note of the result, because every year is different so a lower or higher fire index might be needed to achieve the right burn.

Key practicality #4

Windrow burning is not suitable for barley stubble or high yielding wheat crop stubble

It is very difficult to contain the burn to barley windrows due to the high proportion of leaf material at harvest, or wheat windrows from crops yielding more than 3 t/ha. Burning barley windrows often results in the whole paddock burning and complete loss of stubble cover.

Key practicality #5

Windrows need to be moved each year to prevent concentration of potassium

The use of autosteer on harvesters has led to the accumulation of potassium and increases in soil pH in windrow strips where burning of narrow windrows is commonly practised (Newman 2012).

TACTIC 4.1b CHAFF CART

Chaff carts are towed behind headers during harvest to collect the chaff fraction. Collected piles of chaff are then either burnt the following autumn or used as a source of stock feed. Because of the considerable volume of chaff material produced during harvest, chaff heaps are typically burned the following autumn. Table T4.1-2 (below) shows the value of using chaff carts versus no cart for the removal of weed seed from the paddocks.

TABLE T4.1-2 Annual ryegrass seed collection during harvest for header and chaff cart systems in five locations in Western Australia, 1999 (Walsh and Powles 2007).

Location	Seed entering header	Seed on ground pre-harvest	Total seed production	Seed on ground post-harvest	Proportion of seed removed	
					%	
	Seeds/m^2				Standing annual ryegrass	Total annual ryegrass
Mingenew (a) (no cart)	12,000	8800	18,200	17,800	4	2
Mingenew (b)	7800	9200	16,900	11,000	76	38
Mingenew (c)	13,000	10,000	23,100	11,900	86	50
Moora	4500	3800	8300	4900	73	39
Lake Varley	14,500	5900	20,500	9700	74	52

Benefits

Key benefit #1

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

Chaff cart systems have been found to collect 30 to 85 per cent of annual ryegrass seed and 85 to 95 per cent of wild radish seed entering the header (Walsh and Powles 2007; Walsh 2012). In South Australia Matthews *et al* (1996) reported an annual ryegrass seedbank reduction of 52 per cent, while Gill (1996) reported a 60 to 80 per cent reduction. A survey in Western Australia by Llewellyn *et al* (2004) found that growers expect to achieve an average 60 per cent (40 to 80 per cent range) reduction in the number of annual ryegrass seeds returning to the seedbank.

Chaff cart in action at Tarin Rock, WA.

Chaff dumps prior to burning.

PHOTOS: ANDREW STORRIE

PHOTOS: ANDREW STORRIE

Large capacity chaff carts are needed for high yielding crops.

Dumping system for large capacity chaff cart.

Practicalities

Key practicality #1

Burning chaff heaps

Chaff heaps are typically dumped in lines across a paddock during harvest. The following autumn when fire restrictions have been lifted a firebreak is cultivated around these lines of dumps which are then burnt during late afternoon to early evening. The introduction of the conveyor belt chaff delivery system allows some straw to be collected along with the chaff material. The inclusion of straw maintains air pockets inside the heaps, increasing the speed of burning. To further decrease the time of burning, chaff heaps can be spread out just prior to burning to allow more air into the compacted chaff.

Key practicality #2

Grazing chaff heaps might spread weed seeds

Although Stanton *et al* (2002) found that 6 to 10 per cent of ryegrass seed remained viable when fed to sheep and cattle respectively, there is little field evidence that sheep grazing chaff dumps cause the spread of ryegrass from the dumps. Cattle, on the other hand, spread dumps more than sheep do and have a higher likelihood of spreading seed. If there is concern about the spread of seed, such as glyphosate and paraquat resistance, do not graze dumps with cattle.

Key practicality #3

Chaff dumps can smoulder for days, upsetting neighbours and town residents

If dumps are damp or not sufficiently aerated they can smoulder for several days. This creates smoke hazards, particularly during inversion conditions. Avoid burning during inversions (stable high pressure systems) by monitoring seven-day forecasts from the Bureau of Meteorology.

Contributors

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TACTIC 4.1c BALE DIRECT SYSTEM

The bale direct system uses a baler attached to the harvester to collect all chaff and straw material. Approximately 95 per cent of annual ryegrass seed entering the harvester is collected and removed in the baled material (Walsh and Powles 2007). As well as controlling weeds the baled material has an economic value as a livestock feed source.

Benefits

Key benefit #1

Direct baling of chaff and straw residues exiting the harvester is a highly effective harvest weed control tool

The collection of all harvest residues directly from the rear of the harvester allows the harvester to manage the removal of weed seeds. The bales produced are usually sold off-farm as a feed source. This effectively allows the removal of weed seeds from the paddock without the need for burning or further residue management.

Practicalities

Key practicality #1

Set-up of bale direct system

This system requires a large hydraulic motor driven baler to be attached to the back of the harvester. Therefore this system has to be set up on a header with sufficient excess horsepower to drive the baler. See www.glenvar.com/ for the story and development of header-towed baling systems.

Key practicality #2

Sale of baled material

The availability of suitable markets for the baled material has limited the adoption of this system in Western Australia. Typically, where used, the bales are sold into an export market as a livestock feed source. However, these markets tend to fill easily, hence effectively limiting the adoption of this technology.

In the eastern states of Australia cattle feedlots can be useful markets for these bales.

PHOTO: MICHAEL WALSH

Immediately baling crop residue at harvest minimises weed seed return to the seedbank.

TACTIC 4.1d HARRINGTON SEED DESTRUCTOR®

The Harrington Seed Destructor® (HSD) is the invention of Ray Harrington, a progressive farmer from Darkan, Western Australia. Developed as a trail-behind unit, the HSD system comprises a chaff processing cage mill and chaff and straw delivery systems, and has its own power supply.

Benefits

Key benefit #1

The HSD controls high proportions of weed seeds present in the chaff fraction at harvest

The HSD system consistently destroys 90 to 95 per cent of annual ryegrass, wild radish, wild oats and brome grass seed present in the chaff fraction during harvest.

Key benefit #2

All harvest residues remain in the paddock.

The retention of all harvest residues in the field reduces the loss and/or banding of nutrients compared with windrow burning and chaff carts (Newman 2012).

Practicalities

Key practicality #1

Cost

At the time of writing the HSD had a capital cost of approximately $240,000 while its running costs, including depreciation, are approximately $14 per hectare (Walsh, pers. comm. 2012).

Key practicality #2

Selection for more prostrate or early shedding biotypes or species

Like all harvest seed management technologies, if used as a primary weed management tactic the HSD has the potential in the medium to long term to select for weed biotypes and species that are more prostrate, or lodge or shed earlier than current main biotypes and species.

Contributors

Michael Walsh and Andrew Storrie

PHOTO: MICHAEL WALSH

Harrington Seed Destructor Mark III during the 2012 harvest.

TACTIC 4.2 GRAZING CROP RESIDUES

Grazing weed contaminated crop residue can be a cost-effective way of controlling weed growth. Animal digestion of weed seeds prevents a large proportion from entering the seedbank.

It should be noted that the feed value of the crop residue will be variable, and grazing has the potential to spread undigested weed seeds.

Benefits

Key benefit #1

Grazing reduces the number of weed seeds added to the soil seedbank

Depending on the weed species, grazing can greatly reduce the number of viable seeds in the soil seedbank. Animals eat the seed-heads and vegetative growth of the weed, thus decreasing the number of seeds entering the seedbank.

Key benefit #2

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

Weed seed contaminated fodder includes not only hay, silage and feed grain but also harvest residues that may be weed infested. Harvest residues can be collected using chaff carts to remove residue and weed seeds from the header, leaving chaff dumps in the paddock which can be used as a low value livestock feed source.

Some farmers who use chaff dumps find they do not need to hand feed sheep over summer, compared with farmers who do not use chaff carts at harvest (Peltzer pers.comm.).

PHOTO: ANDREW STORRIE

Sheep can be an effective tool for grazing crop residues.

Whole-farm benefits

There are additional benefits to be obtained when using grazing of crop residue as a weed management tactic:

- Weed seeds can provide a significant proportion of the nutritional value when stock graze crop residue.
- Post-harvest grazing may reduce crop establishment problems through reduction in stubble burdens.
- Seed burial through trampling may enhance weed germination pre-sowing. Using a knockdown herbicide and delaying sowing can then capitalise on this process.
- Seed of desirable plants (pasture species) may be distributed in faeces.

Practicalities

Key practicality #1

Grazing livestock can distribute weed seeds across a paddock

Feeding trials have shown the viability of annual ryegrass (*Lolium rigidum*) seed excreted by sheep to be 4 per cent and when excreted by cattle 12 per cent (Stanton *et al* 2002). Annual ryegrass seed was detected in both sheep and cattle faeces within 24 hours of the stock being introduced to the weed seed contaminated diet, and they continued to excrete viable seeds for five days after being removed from the diet.

Experiments in Western Australia (Devenish and Lever 2000) found that sheep are unlikely to spread major quantities of ryegrass seed from chaff dumps, while observations of sheep camps found small numbers of ryegrass plants. It is recommended that cattle are not used to graze contaminated stubble and chaff dumps.

Contaminated fodder needs to be checked for its feed value and the presence of toxins such as annual ryegrass toxicity. It should be fed in an area that can be readily monitored (e.g. a feed-lot) to minimise the spread of seeds.

Key practicality #2

The impact of grazing on weed numbers entering the seedbank is dependent on the biological features of the weed

Grazing is successful in reducing weed seed numbers in weeds that are palatable and where the seeds can be easily eaten and digested. However, seed palatability varies from weed to weed. The presence of awns, thorns or biochemical traits makes weeds less attractive to grazing animals.

Seed location: Stock must be able to access seed to ingest it. Seed still in the head, or in chaff dumps or feed troughs, is easier to access than seed lying on the soil surface.

Seed size: Once shed from the seed-head, small seeds are more difficult for animals to graze. Small seeds are also more likely to survive ingestion and digestion.

Hard seeds: A high proportion of hard seeds will remain viable after digestion. The digestive process can also break seed dormancy, encouraging the germination of seeds shed in faecal matter.

Michael *et al* (2004) examined the viability of small-flowered mallow (*Malva parviflora*) seed following ingestion. The seed was placed into the rumen of fistulated sheep (sheep with direct access to the rumen through an external artificial plug). Up to 93 per cent of those seeds with an intact seed coat remained viable regardless of digestion time.

Key practicality #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

In the process of grazing, stock will knock seed to the ground and bury weed seeds with their hooves. Shallow burial during grazing may result in increased germination, not unlike that achieved with an autumn tickle (see *Tactic 1.4 Autumn tickle*, page 105), due to the placement of the seed in a better environment for germination.

Whole-farm considerations

Grazing may also cause:

- an increased risk of soil, water and wind erosion
- increased soil compaction
- potential toxicity issues for sheep, e.g. lupinosis.

Contributors

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T 4.1 Weed seed control at harvest

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T 4.1a Narrow header trail

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T 4.1b Chaff cart

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TACTIC 5 ON-FARM HYGIENE

'Risk aware' growers can implement strategies to reduce and avoid unnecessary introduction and spread of weeds. These strategies will reduce not only the likelihood of introducing new weed species but also the risk of importing herbicide resistant weeds.

Modelling the impact of importing herbicide resistant seed (Diggle 2004)

Good on-farm hygiene can assist in the management of herbicide resistant gene flow.

Modelling was used to predict the rate of development of glyphosate resistance in annual ryegrass in a 100 ha paddock in Western Australia. Two scenarios were tested:

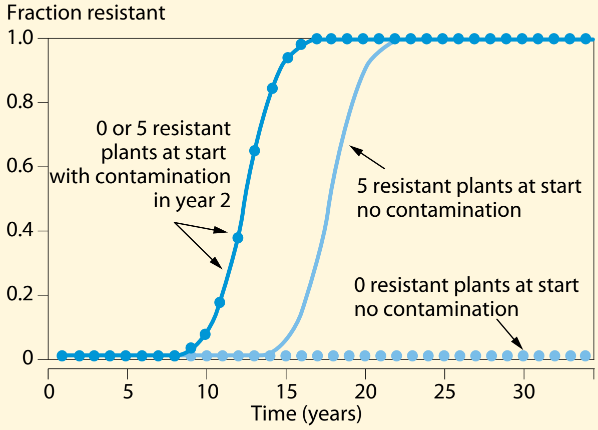
1. Crop seed contaminated with 10 annual ryegrass seeds/kg, of which one was glyphosate resistant
2. No contamination of crop seed.

The modelling demonstrated that if glyphosate was applied as a knockdown every year in the 100 ha paddock, the initial five glyphosate resistant plants in 500 million would increase to agronomically important levels in 17 years (Figure T5.1-1, right).

The introduction of similarly contaminated seed in the second year would cause resistance to develop five years earlier.

The greater the level of contamination with resistant seeds, the faster resistance will develop.

FIGURE T5.1-1 A pictorial description of modelling the impact of contamination with herbicide resistant seed (Diggle 2004).



Where no resistant individuals are present and none are introduced, no resistance develops.

Weed importation and spread can be impeded at several critical points, namely:

- sowing of the seed
- fencelines and non-cropped areas in cropping paddocks (e.g. water courses)
- machinery and vehicle usage
- stock feed and livestock movement
- in fields following floods and inundation.

A well-managed on-farm hygiene strategy will address all of these elements.

Benefits

Key benefit #1

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

The benefits of planning and enforcing good on-farm hygiene include the following:

- Weed seeds will not be added to the seedbank from other areas of the same paddock, other paddocks on the same farm, other farms or other regions.
- Management costs will be reduced in the long term.
- Weed problems will be quarantined or confined to known areas where they can be more effectively managed.
- The risk of introducing herbicide resistant weed populations from alternative sources into paddocks and onto the farm will be reduced.

TACTIC 5.1a SOW WEED-FREE SEED

Benefits

Key benefit #1

Weed seeds are not added to the seedbank unnecessarily

Weed seed is regularly spread around and between farms as a contaminant of sowing seed. Seed for sowing is commonly grower-saved and more often than not contaminated with weed seeds, frequently at very high levels (Moerkerk 2002; Powles and Cawthray 1999; Roya Niknam *et al* 2002; Michael *et al* 2010).

Moerkerk (2002) reports that of 243 samples of cereal sowing seed from Victoria and southern New South Wales, only 39 per cent met Victorian certified seed standards and only 21 per cent was free of foreign seed. Similarly, of 98 pulse samples, 41 per cent met Victorian certified seed standards and 24 per cent was free of foreign seeds. A broad range of weed types was found, with annual ryegrass being the most common in both cereal and pulse seed.

In a survey of retained grower seed in Western Australia, Michael *et al* (2010) found an average of 62 weed and volunteer crop species per 10 kg of cleaned seed. Uncleaned seed for sowing was found to have 25 times more foreign seeds than cleaned seed. This seed was found to have varying levels of herbicide resistance, so farmers were unwittingly sowing herbicide resistant weeds around their farms.

Practicalities

Key practicality #1

Check seed analysis before purchasing seed-lots to avoid importing weed seed

Growers should understand the certification standards and allowable weed seed contamination levels of commercial seed in their state. The Seed Analysis Certificate, which should be supplied with all seed purchases, provides details of the type and level of weed seed contamination.

Purchasing certified or commercial seed is not a guarantee of weed-free status. Always check the fine print and the Seed Analysis Certificate. When purchasing seed of a public variety from another grower, be alert to weed seed contamination and where possible:

- Know the weed status of any farm from which you buy seed.
- Plan seed purchases ahead of time and inspect the paddock where the seed is being grown.
- Obtain a sample of the seed and have it analysed for both weed seed contamination and germination.
- Determine the herbicide resistance status of weeds present on the source farm and paddock, and avoid purchasing seed from paddocks with known resistance.

Key practicality #2

Plan ahead when retaining seed on-farm for sowing

Demarcate seed paddocks and ensure weed numbers in those paddocks are very low. Hand-pull problem weeds in the seed paddocks. In the long term it will pay off to apply stringent management tactics to a seed block to avoid spreading weeds in seed.

With multiple farms it is often advisable to have seed paddocks on each farm and not transfer grower-saved seed from farm to farm. This way weeds will not be spread from one property to another.

Seed cleaners cannot guarantee a weed-free sample and should not be relied on to remove all foreign seed. Ensure the seed cleaning contractor is prepared to take the time to do a thorough job and that the seed cleaning plant is thoroughly cleaned prior to coming onto the property.

Some weed seeds are very similar in size and weight to the seed being cleaned and are unlikely to be removed during seed cleaning. This is particularly true of a mobile seed cleaning plant without a gravity table. Transporting seed to a larger seed cleaning plant with a gravity table may obtain better results, but the economics of doing so should be considered first.

To estimate the number of weed seeds being introduced at sowing:

1. Obtain a random 1 kg sample of the seed to be sown.
2. Separate the foreign seed from the crop seed.
3. Count each type of foreign seed, including weeds and volunteer crop seeds.
4. Multiply the number of weed seeds of each species by the proposed crop sowing rate (kg/ha). This will give you the number of weeds you will be sowing per hectare of crop.
5. To calculate the density of weeds/m^2, divide the weeds/ha by 10,000.

While the number may work out to be only small (perhaps one to two weeds/m^2 or less), it is important to remember that many weed species are prolific seed producers and a single plant growing in ideal conditions can contribute a large number of seeds to the seedbank.

Key practicality #3

Keep good records of seed purchases

Keeping records of seed purchases enables a degree of traceability if there are problems such as weed contamination or low germination. Do not expect the seed merchant to have a copy of the seed lines you have bought. Keep good records so the source of any problems can be traced.

TACTIC 5.1b MANAGE WEEDS IN NON-CROP AREAS

Benefits

Key benefit #1

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

Weed infestations often commence in non-crop areas (e.g. around buildings, along roadsides or along fencelines). Controlling these initial populations will prevent weeds from spreading to other parts of the property. This is particularly important for weeds with wind-blown seed such as fleabane and sowthistle.

North American research found that seed of Canadian fleabane (*Conyza canadensis*) regularly disperses at least 500 m from the parent plant although 99 per cent of the seed falls within 100 m (Dauer *et al* 2007). Less than 1 per cent of the seed will travel further than this and it often has lower viability (20 to 40 per cent) due to its smaller seed size (Borger 2012).

Practicalities

Key practicality #1

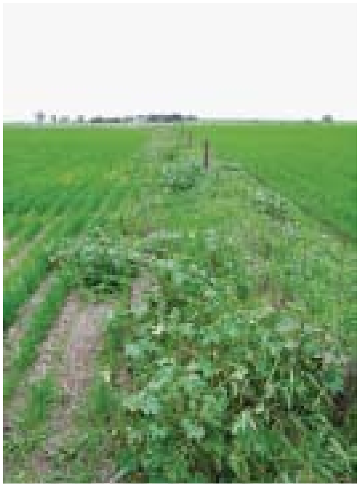
Weeds in non-crop areas can impact greatly on farm weed status, but are often easily controlled

Weeds in non-crop areas experience no crop competition and so are able to produce large quantities of seed. Observant growers will have noticed that new weeds often tend to creep into the crop area from non-crop areas unless they are kept in check.

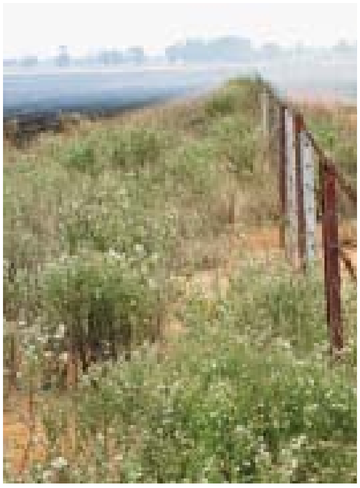
Weeds along fencelines, paddock edges and non-crop areas of crop paddocks can be controlled by knockdown and pre-emergent herbicides, hay or silage cutting, and/or cultivation, or preferably a combination of all these options. Unlike other activities, timing for fenceline weed control is reasonably flexible with a wide window of opportunity, although control should be carried out prior to seed maturity.

PHOTOS: ANDREW STORRIE

Fencelines should be kept clean, but don't rely on glyphosate alone for weed control.



Small flowered mallow infesting fenceline between two crop paddocks – an ideal situation for spread.



Flaxleaf fleabane along this fence will easily spread into neighbouring fields.

TACTIC 5.1c CLEAN FARM MACHINERY AND VEHICLES

Benefits

Key benefit #1

Good vehicle hygiene (i.e. regular cleaning) can reduce the risk of new infestations and weed spread

Moerkerk (2006) inspected 110 vehicles and plant machinery and found 250 contaminant species or taxonomic groups, including 24 Victorian noxious weeds. The majority of seeds were found in the cabin of passenger and four-wheel drive vehicles, with the engine bay being the next most frequent location.

Practicalities

Key practicality #1

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

Clean all farm machinery and vehicles before relocation. Pay special attention when moving from areas and/or paddocks with high weed burdens, new incursions or herbicide resistant weed populations.

If possible, harvest paddocks in order from least weedy to most weedy, and finish clean areas in a paddock before harvesting more weedy areas. Avoid harvesting individual patches of a problem weed. This will slow the spread of weeds but will still add seeds to the seedbank. Alternatively, it may be possible to minimise the spread by using seed collection carts, modifying header trails or collecting seed in the grain sample for later removal.

Take the time to clean bins, trucks and grain handling equipment (e.g. augers) between paddocks or seed-lots. This is a crucial step prior to harvesting and handling grain which will be retained for sowing subsequent crops.

Enforce machinery cleaning standards with all harvest, baling, windrowing and grain transporting contractors. Record areas where harvest contractors started on your property and especially where any in-field repairs were carried out on header equipment. These areas should be entered into next year's diary for detailed inspection for new weed incursions.

PHOTOS: ANDREW STORRIE

(Above) Vehicles are major sources of new weed infestations.

Slashers and mowers must be cleaned before moving to a new area.

TACTIC 5.1d MANAGE LIVESTOCK FEEDING AND MOVEMENT

Benefits

Key benefit #1

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

New livestock, or those returning to the property from agistment, can carry weed seeds from other areas. Weeds can be easily imported from different regions or states because livestock can travel significant distances by road within a 24 hour period.

Practicalities

Key practicality #1

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

Be aware of any contaminants that grain or hay may contain, and feed livestock in a way that ensures that contaminants are not spread. Hay that has been contaminated with weed seeds (and, increasingly, herbicide resistant weed seeds) is unfortunately a major source of imported weed seeds. Drought feeding further exacerbates the issue as producers often drop their guard during stressful periods, and weeds are more difficult to control in dry conditions.

The same feeding precautions should be observed where chaff heaps collected from the header at harvest are grazed and/or baled for fodder or for feeding grain. See *Tactic 4.1 Weed seed control at harvest* (page 212) and *Tactic 4.2 Grazing crop residues* (page 222) for information on the survival of weed seeds following digestion by sheep and cattle.

Silage is less risky because cutting is carried out when the weed seeds are less mature. More importantly the silage process kills most weed seeds, although some do survive the ensiling process (see *Tactic 3.3 Silage and hay – crops and pasture*s, page 190).

Stock should be 'emptied out' after feeding on fodder contaminated by weed seed prior to returning to pasture. New stock should also be emptied out before moving to pasture. If there is a designated feeding or sacrifice area 'emptying' will be easily achieved, and any weeds that grow in this area can be monitored, managed and contained.

Plan livestock movement to avoid introducing or spreading new weeds. Remember that fleeces, hides and/or mud or dirt in hooves can harbour and distribute weed seeds in addition to those relocated through faeces.

PHOTO: ANDREW STORRIE

New stock like these steers need to be quarantined in a small paddock before moving onto the farm.

TACTIC 5.1e MONITOR PADDOCKS FOLLOWING FLOOD FOR NEW WEED INCURSIONS

Floods and inundation of fields are a common source of new weed infestations through the transport of seeds and vegetative propagules such as stolons, rhizomes and tubers. This source of weed invasion is likely to increase with the predicted increase in climate variability (MacDonald *et al* 2006; Truscott *et al* 2006).

Benefits

Key benefit #1

Low level infestations of new weeds can be controlled at low cost and most likely eradicated

By monitoring post-flood the chance of eradication of new weed species is greatly enhanced.

Practicalities

Key practicality #1

Good observation for what weeds are new or different is needed to identify potential new threats

For effective monitoring to occur the observer needs to be on the lookout for what is different or new. This requires a familiarity with the plant species normally present. Anything thought to be new should be collected for correct identification. Contact your local department of agriculture or primary industries or your local adviser to help identify the specimens in question.

Contributors

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PHOTO: ANDREW STORRIE

This creekline is infested with glyphoasate resistant annual ryegrass, noogoora burr and a range of other weeds. During the next flood these seeds will spread across previously clean paddocks.

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NOTES