Section 3: Agronomy

Successful weed management relies on implementation of the best available agronomical practices to optimise crop environment and growth. Basic agronomy and finetuning of the cropping system are the first steps towards weed management. Using the best available agronomy will increase the benefit gained from the weed management tactics employed.

Some 'agronomy for weed management' decisions may seem obvious or 'second nature'. These include optimising competitive ability of the crop by sowing on time, placing the seed at the ideal depth, and using best practice disease and insect management. Other decisions, such as growing a 'new' crop to enable implementation of a weed control tactic (eg sowing field peas to enable non-selective crop-topping) require significant change and greater planning.

The economics of change, particularly dramatic change, should be analysed to examine all the costs and benefits of implementation.

Section 3 discusses a range of agronomic practices that can be used to enhance the impact of weed management tactics and their effect on both weeds and crop.

Agronomy 1 Crop choice and sequence

Many agronomic management implications arise from the sequence in which crops are sown. These implications include benefits that can enhance weed management. Planning crop rotation in advance minimises disease and insect problems and maximises crop fertility. With disease, insects and fertility managed optimally, crops become more competitive against weeds.

The implementation and/or effectiveness of some weed management tactics rely on specific crop type and variety, or the sequence of cropping. For example, Group 2 tactics that aim to kill weeds (often with a herbicide) can be greatly enhanced by growing a more competitive crop type or variety.

At the same time the ability to control a target weed in a specific crop may be so limited that growing that particular crop should be avoided in paddocks where the target weed is a problem. For example, winter pulses should not be grown in paddocks where black bindweed or wireweed are a problem.

Another example of the importance of crop and variety choice (when implementing a weed management tactic) relates to 'in-crop seed-set control' tactics – Tactic Group 3. These tactics are much less detrimental to crop yield and quality where the crop variety matures prior to the weed species.

To assist in making crop choices, key information about winter crop types is provided in Table A1.1. Knowledge of relative competitiveness, sowing time, maturity, available herbicide options and difficult to control ('No Go') weeds is important. Similar information about specific varieties should be sought on a local basis.

The ability to compete with weeds varies between crop types and between varieties within a crop type. In high weed pressure paddocks, growing a competitive crop will enhance the reduction in weed seed-set obtained through employing weed management tactics. It will also reduce the impact that surviving weeds have on crop yield.

Sowing bread wheat or barley is recommended to maximise crop competition (Storrie et al 1998). For example, in areas where summer crops can be grown successfully, a winter fallow – summer sorghum rotation prior to wheat is a very effective way of managing wild oats and paradoxa grass.

Table HR5 Known populations of herbicide resistant grass weeds in Australia (compiled by Stewart 2005)

Crop	Competitive ability	Relative sowing time	Relative maturity	Available herbicide options	'NO GO' weeds [a]	Key weeds to target	Most suitable tactics other than pre- and post-emergent herbicide application	Agronomy to enhance weed management [b]
Barley	High	Mid–late	Early	Several for grass; Many for broadleaf	Barley grass *Vulpia* Brome grass	Most broadleaf	Autumn tickle Double knockdown Delayed sowing Crop desiccation Winter clean pasture in previous year	Variety choice Improved fertiliser placement Increased sowing rate Good seed (clean and high germinating) Direct drill
Canola – imidazolinone tolerant (IT) varieties	Medium	Early	Early	Many for grass; Several for broadleaf	Group B resistant brassicas	Grass weeds – particularly brome grass Groups A and M resistant grass weeds 'imi' susceptible broadleaf weeds	Autumn tickle Burn residues (not sandy soils) Crop desiccation Windrowing Seed catching Windrow/burn residues Winter clean pastures in previous year	Variety choice Improved fertiliser placement Direct drill (using a full-cut sowing system following a germination event and the use of a knockdown)
Canola – standard varieties	Medium	Early	Early	Several for grass; Limited for broadleaf	Group A resistant grassesbrassicas (eg wild radish, wild mustards, wild turnip) Fumitory Black bindweed Vetch	Grass weeds	Autumn tickle Burn residues (not sandy soils) Crop desiccation Windrowing Seed catching Windrow/burn residues Winter clean grasses in previous year	Variety choice Improved fertiliser placement Direct drill
Canola – triazine tolerant (TT) varieties	Medium	Early	Early	Many for grass; Several for broadleaf	Triazine resistant brassicas	Grass weeds Triazine susceptible broadleaf weeds Fumitory	Autumn tickle Burn residues (not sandy soils) Crop desiccation Windrowing Seed catching Windrow/burn residues	Variety choice Improved fertiliser placement

Chickpeas	Poor	Mid–late	Late	Many for grass; Limited for broadleaf	Fumitory Black bindweed Wireweed (no-till and stubble retention) Vetch	None	Double knockdown Wide row – shielded spraying or inter-row cultivation and band spraying Crop-topping Desiccation Wick/blanket wiping	Improved fertiliser placement High sowing rate
Faba beans	Medium	Mid	Mid–early	Many for grass; Limited for broadleaf	Wild radish Musk weed Vetch	Grasses	Crop-topping Windrowing Windrow/burn residues	Improved fertiliser placement High sowing rate
Field peas	Medium	Late	Early	Many for grass; Several for broadleaf	Fumitory Bifora Vetch	Grasses	Delayed sowing Double knockdown Crop-topping Desiccation Green/brown manuring	Variety choice Improved fertiliser placement
Lentils	Poor	Late	Early	Many for grass; Limited for broadleaf	Brassicas Vetch	None	Wick/blanket wiping Crop-topping	Improved fertiliser placement
Lupins – narrow leafed and albus	Poor	Early	Late	Many for grass; Many for broadleaf	Sand plain (blue) lupins	Vulpia spp.	Residual herbicides Windrowing Crop-topping Desiccation	Improved fertiliser placement High sowing rate
Oats – graze and grain	High	Early–mid	Early–mid	Limited for grass; Many for broadleaf	Wild oats (for grain) Brome grass oats (for grain) Barley grass oats (for grain) *Vulpia* spp.	Broadleaf weeds	Hay or silage Silage Short, sharp grazing Hay freezing	High nitrogen rate Improved fertiliser placement High sowing rate

Crop	Competitive ability	Relative sowing time	Relative maturity	Available herbicide options	'NO GO' weeds [a]	Key weeds to target	Most suitable tactics other than pre- and post-emergent herbicide application	Agronomy to enhance weed management [b]
Oats – hay	High	Late	Late	Limited for grass; Many for broadleaf	Brome grass Barley grass *Vulpia* spp. Ryegrass *Emex* spp.	Strict guidelines for export	Delayed sowing Double knock Post-cut knockdown Hay Hay freezing	High sowing rate High nitrogen rate Improved fertiliser placement
Oats – grain only	Medium–high	Mid–late	Early–mid	Limited for grass; Many for broadleaf	Wild oats Brome grass Barley grass *Vulpia* spp.	Broadleaf weeds	Delayed sowing Double knock Winter clean	Long fallow High sowing rate Improved fertiliser placement
Triticale – grain only	Medium–high	Late	Late	Several for grass; Many for broadleaf	Cereal rye Brome grass *Vulpia* spp.	Broadleaf weeds	Delayed sowing Double knock	Long fallow Improved fertiliser placement Narrow row spacing
Triticale – graze and grain	High	Early–mid	Late	Several for grass; Many for broadleaf	Cereal rye Brome grass *Vulpia* spp.	Broadleaf weeds	Double knock Short-sharp grazing	Improved fertiliser placement High sowing rate High nitrogen rate
Wheat – early sown	High	Early	Mid	Many	Multiple resistant ryegrass; barley	Broadleaf weeds, wild oats, annual ryegrass	Seed carts Burn residues	Improved fertiliser placement Narrow row spacing High sowing rates
Wheat – main season	Medium–high	Mid	Mid	Many	Multiple resistant ryegrass; barley	Broadleaf weeds, wild oats, annual ryegrass	Selective spray-topping Seed carts Burn residues	Variety choice Improved fertiliser placement High sowing rates
Wheat – quick maturing – short season varieties	Medium	Mid–late	Early	Many	Multiple resistant ryegrass; barley	Broadleaf weeds, wild oats, annual ryegrass	Delayed sowing Autumn tickle Double knock Windrowing Burn residues	Improved fertiliser placement High sowing rate Narrow row spacing

Wheat – graze and grain	High	Early	Late	Many	Multiple resistant ryegrass	Broadleaf weeds, wild oats, annual ryegrass	Short-sharp grazing Burn residues	Improved fertiliser placement High sowing rate High nitrogen rate
Wheat – durum	Medium	Mid–late	Early	Many (tolerance limit with some herbicides)	Multiple resistant ryegrass; Group A resistant wild oats	Broadleaf weeds	Delayed sowing Burn residues	Improved fertiliser placement Narrow row spacing High sowing rate
Lucerne	High (density dependent)	N/A	N/A	Limited for seedling; Several for mature	Must use trifluralin for establishment – wireweed	Grasses	Spray-topping Winter cleaning Green/brown manuring Silage or hay Grazing management	High phosphorous rate Good nodulation Variety choice
Sub clover	Low–medium	Early–mid	N/A	Several	Bedstraw	Grasses	Spray-topping Green/brown manuring Silage or hay Grazing management Spray-grazing Blanket/wick wiping	Rotation High phosphorous rate Good nodulation Variety choice
French (pink) serradella (eg Cadiz)	Low–medium	Early–mid	N/A	Several for grass; Limited for broadleaf	Bedstraw Broadleaf weeds	Grasses	Hay-freezing Green/brown manuring Spray-topping Silage or hay Grazing management Blanket/wick wiping	Rotation High sowing rates Good nodulation Variety choice
High density annual legumes (arrowleaf, berseem, Persian, sulla)	High if sown early; Low if sowing delayed	Early	N/A	Limited		Grasses	Spray-topping Green/brown manuring Silage or hay Grazing management Spray-grazing Blanket/wick wiping	Rotation High phosphorous rate Good nodulation Species and variety choice

Crop	Competitive ability	Relative sowing time	Relative maturity	Available herbicide options	'NO GO' weeds [a]	Key weeds to target	Most suitable tactics other than pre- and post-emergent herbicide application	Agronomy to enhance weed management [b]
Sorghum	Density dependent	Spring–summer	Variable	Limited for grass; Several for broadleaf	Johnson grass *Sorghum almum*	Winter grasses	Inter-row shielded spray or cultivation	Variety choice Narrow row spacing High sowing rate Summer fallow No-till
Sunflowers	Low	Spring–summer	Variable	Several for grass; Limited for broadleaf	Burrs (*Xanthium* spp.) *Datura* spp. *Physalis* spp. Bladder ketmia *Ipomoea* spp. Parthenium weed and many summer broadleaf weeds	Winter grasses	Inter-row shielded spray or cultivation	Rotation
Mungbeans	Low	Spring–summer	Early	Several for grass; Limited for broadleaf	Burrs (*Xanthium* spp.) *Ipomoea* spp.	Winter and summer grasses		Rotation Narrow row spacing High phosphorous rate Good nodulation

[a] Presence of listed weeds severely limits use of crop type in a sustainable cropping system.

[b] Highly suited tactics that can be used in addition to the traditional pre-sowing non-selective knockdown, pre-emergent residual herbicides and early post-emergent herbicides.

Agronomy 1.1 Crop sequencing to minimise soil- and stubble-borne disease and nematodes

A healthy crop that is not constrained by disease is far more competitive with weeds and less affected by them as a result.

An integrated approach to disease management is the best way to limit yield losses. Sound rotation of crops and varietal selection can minimise the negative impact of soil- and stubble-borne diseases and nematodes on crop yield and seedling vigour.

Any constraint (such as weeds) which limits growth of the rotation crop is likely to have a negative impact on the effectiveness of that crop as a disease break.

Benefits

Key benefit #1

Crops with dense canopies act as more effective break crops.

Recent research (Kirkegaard et al 2004) has shown that break crops such as canola and mustard (which have dense canopies) are more effective for crown rot than chickpeas, which grow slowly (Figure A1.1). The canopy development of mustard is the fastest (Figure A1.2), while chickpeas do not reach full canopy closure until much later in the season (Simpfendorfer et al in press). The denser canopy enhances microbial decomposition of cereal residues which harbour the crown rot fungi.

Practicalities

Key practicality #1

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

In northern New South Wales and southern Queensland key issues to consider in wheat production are crown rot and root lesion nematode. In southern cropping systems key issues include cereal cyst nematode and the fungal diseases 'take-all' and *Rhizoctonia*.

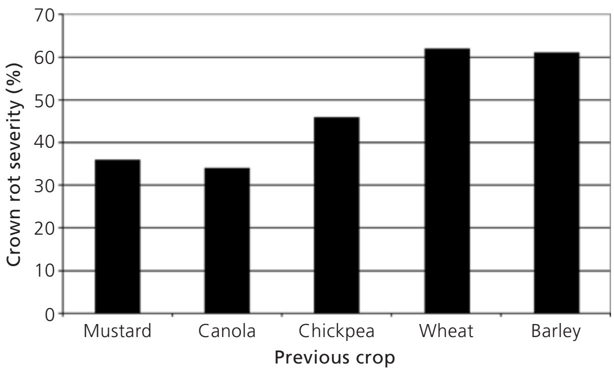

Figure A1.1 The effect of previous break crops on the level of crown rot in spring wheat at Tamworth, New South Wales (Kirkegaard et al 2004).

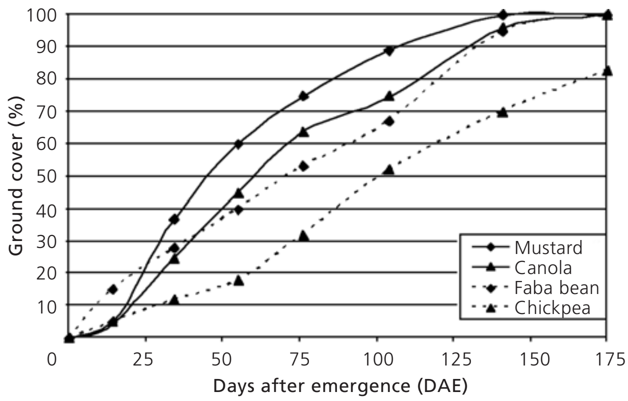

Figure A1.2 Development of ground cover through the 2004 season for various break crops (Simpfendorfer et al in press).

When selecting varieties there is usually a trade-off between tolerance to specific diseases on the one hand and desirable crop traits on the other. Thus, when selecting a variety it is important to conduct a risk–benefit analysis for all diseases and significant yield, quality and agronomic traits for the individual paddock and crop varieties in question.

Key practicality #2

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

Grass weeds are alternate hosts for fungal pathogens which cause crown rot and take-all in winter cereal crops. Broadleaf weeds can also act as alternate hosts for sclerotinia, which can affect a wide range of pulse and oilseed crops. *Practylenchus neglectus* nematode will multiply readily in wild radish and exceptionally well in wild oats. Similarly, barley grass acts as a suitable host for *P. thornei*.

Use of crop sequencing as a disease break is only effective if alternate weed hosts are controlled during the fallow and in-crop.

Key practicality #3

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

The use of either knockdown herbicides or tillage to remove plant growth for a period prior to sowing can significantly reduce the level of *Rhizoctonia inoculum* in the soil. Tillage to 10 cm depth immediately prior to sowing also physically disrupts fungal hyphae and suppresses the disease in the short term.

In a no-till system, using modified sowing points that provide soil disturbance below the seed can also limit the occurrence of *Rhizoctonia*. Be aware of *Rhizoctonia*, and understand when and where it is likely to occur in your region so that appropriate management steps can be implemented.

Key practicality #4

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

The most obvious symptom of crown rot infection in wheat and barley crops is the premature ripening of heads on infected tillers to produce what is termed a 'whitehead'. Whiteheads either contain no grain or severely shrivelled, lightweight grain which greatly reduces grain yield and quality. The formation of whiteheads is related to moisture stress post flowering, when the crown rot fungus is believed to block the 'plumbing' system of the plant, preventing the movement of water from the soil into the heads.

Poor control of weeds over the summer fallow and in-crop means that valuable stored soil moisture is spent growing weeds rather than the crop. This can increase moisture stress late in the season and exacerbate the production of whiteheads in winter cereal crops infected with crown rot.

Contributors

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Agronomy 2 Improving crop competition

The impact of weeds on crop yield can be reduced and the effectiveness of weed control tactics increased by improving crop competition. The rate and extent of crop canopy development are key factors influencing a crop's competitive ability with weeds. A crop that rapidly establishes a vigorous canopy, intercepting maximum sunlight and shading the ground and inter-row area, will provide optimum levels of competition.

Canopy development can be influenced by:

- crop and variety
- row spacing, sowing rate and sowing depth
- crop nutrition
- foliar and root diseases, and nematodes
- levels of beneficial soil microbes such as vesicular arbuscular mycorrhiza (VAM)
- environmental conditions including soil properties and rainfall.

Each will in turn affect plant density, radiation adsorption, dry matter production and yield. Early canopy closure can be encouraged through good management addressing the above factors.

Agronomy 2.1 Crop type

The most competitive crop type will depend on the regional and individual paddock conditions, including soil type and characteristics (eg plant available water, drainage, pH), rainfall and cropping history. Crop species or varieties that are susceptible to early insect or disease damage also become more susceptible to subsequent weed invasion and competition.

Choose a crop that suits the situation and, if possible, choose the most competitive variety. Generally, the best suited variety for the situation will also be the most competitive.

Benefits

Key benefit #1

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

Crops can be roughly ranked in competitive ability (Table A2.1). Oats are the most competitive crop against annual ryegrass. Chickpeas have been shown to have limited ability to compete against weeds and would be equal to narrow-leafed lupins (Whish et al 2002).

In a 1998 trial at Newdegate, Western Australia, the ryegrass dry matter in barley and oats was half that in wheat and triticale at 450 plants/m^2 (competitive ability ranked oats > barley > wheat > triticale). This reduced ryegrass seed production by over 2000 seeds/m^2.

Table A2.1 The relative competitive ability of a number of annual winter crops and the crop yield reduction (percentage) from 300 plants/m^2 of annual ryegrass at Wagga Wagga, New South Wales (Lemerle et al 1995).

Crop	Rank	Yield reduction from annual ryegrass (%)
Oats	1 – most competitive	2–14
Rye	2	14–20
Triticale	3	5–24
Oilseed rape	4	9–30
Spring wheat	5	22–40
Spring barley	6	10–55
Field pea	7	100
Narrow-leafed lupin	8 – least competitive	100

Within each crop there is a wide range of competitive abilities. Lemerle et al (1996) tested a large range of wheat varieties from Australia and overseas. Selected data from their results are shown in Table A2.2.

Table A2.2 The impact of the competitive ability of a range of wheat varieties on dry matter production of annual ryegrass at Wagga Wagga, New South Wales (Lemerle et al 1996).

Source of wheat genotype	Annual ryegrass dry matter production (g/m^2)
Old varieties (released before 1950)	103
Victorian varieties	138
Cargil varieties	148
NSW DPI varieties	151
Durum varieties	259

The wide range in the ability of field pea varieties to either tolerate competition from weeds or to suppress weed growth and seed-set is illustrated in Table A2.3. When planning weed management in paddocks with large weed numbers it is important to consider competitive ability and not just yield when choosing a crop and variety.

Table A2.3 The relative ability of field pea varieties to suppress weed growth and seed-set, and to tolerate competition from weeds (annual ryegrass and wheat) (MacDonald 2002).

Tolerance to competition	Ability to suppress weeds		
	Low	Medium	High
Low	Bonzer Bluey Mukta	Glenroy Soups Progreta	
Medium	Bohatyr	Alma Dundale Parafield	
High		Jupiter	Morgan

There is significant variation in the ability of different cereal species and cultivars to compete with weeds. In 1935 Pavlychenko and Harrington found that barley was more competitive with weeds than other cereals due to early root development. On the Darling Downs Marley and Robinson (1990) found that barley was more competitive than wheat with turnip weed *(Rapistrum rugosum)* and black bindweed *(Fallopia convolvulus)*.

Modern semi-dwarf wheats are less competitive than older types (Lemerle et al 1996; Table A2.2). Current commercial wheats also exhibit considerable differences in their abilities to compete with weeds. For example, at a wheat plant density of 150 plants/m^2 Lemerle et al (1995) recorded yield losses of 20–40% in strongly and weakly competitive cultivars.

Data also shows considerable variability between cultivars for weed competition between years and sites (Cousens and Mokhtari 1998; Lemerle et al 2001), making reliable recommendations about the competitive status of individual varieties difficult.

Cultivars of wheat were assessed for competitiveness with annual ryegrass across south-eastern Australia (Lemerle et al 2001). Nearly all the variation in crop yield could be attributed to cultivar x environment effects. Only 4% of variability could be attributed to cultivar x weed x environment effects. Some cultivars exhibited a competitive advantage in some environments, highlighting the need to grow locally suitable cultivars.

Manipulation of crop agronomy and species choice are likely to be more reliable than crop variety choice (within a species) for improving competition for weed control.

Agronomy 2.2 Sowing rate

The optimum plant density for each crop will differ (seek local advice) and will depend on growing conditions, time of sowing and economic viability. In unfavourable conditions (eg delayed sowing, poor soil conditions) the growth of individual plants becomes limited, so higher plant densities may improve competitive ability and yield.

At any sowing time increasing sowing rate can result in earlier crop canopy closure and greater dry matter production, improving weed suppression and the effectiveness of other weed management tactics.

Benefits

Key benefit #1

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

Weed biomass is highly correlated to weed seed production (Radford et al 1980; Watkinson and White 1985; Table A2.4). Increasing crop density can reduce weed biomass, translating into reduced weed seed-set and seedbank replenishment. In addition, crop yields in the presence of weeds usually increase with crop density (Godel 1935; Lemerle et al 2004; Marley and Robinson 1990; Martin et al 1987).

High sowing rates increase crop competitive ability by:

- promoting early canopy closure and increased dry matter production
- better use of resources (water, nutrients and light) in competition with the weeds.

In turn, improved crop competition increases the effectiveness of herbicides and other weed management tactics used, and suppresses weed seed-set by survivors.

Table A2.4 Summary of some of the research conducted in Australia to assess the effect of increasing crop sowing rate in the presence of weeds

Key message	Study	Weed impact	Crop impact	Comments
At least 200 plants/m^2 are required to suppress annual ryegrass.	Wheat sowing rate x with or without annual ryegrass (50–450 plants/m^2). Nine sites across southern Australia (rainfall 200–400 mm). (Lemerle et al 2004)	Increased crop density (100 to 200 plants/m^2) halved weed dry matter from 100 g/m^2 to approximately 50 g/m^2.	Under weed-free conditions yield peaked when wheat was sown at 200 plants/m^2, and declined only slightly (4–5%) at wheat plant densities up to 425 plants/m^2. In the presence of weeds yield increased with wheat density up to 425 plants/m^2 over all sites. Presence of weeds reduced yield (compared to weed-free) by 23% at 100 plants/m^2 and only 17% at 200 plants/m^2.	Crop densities of at least 200 plants/m^2 were required to suppress annual ryegrass. Probability of reduced crop grain size and increased screenings was negligible up to 200 plants/m^2.
More competitive wheat crops have the potential for improving weed control and reducing herbicide rates.	Wheat sowing rate x herbicide dose rate. Wild oats or paradoxa grass. Southern Queensland. (Walker et al 2002)	Lowest paradoxa grass seed production was at 80 crop plants/m^2 and 100% recommended herbicide rate. Lowest wild oat seed production was at 130 crop plants/m^2 and 75% recommended herbicide rate (or 150 plants/m^2 and 50% herbicide rate).	Highest crop yield with paradoxa grass was at 80 crop plants/m2. Highest crop yield with wild oats was at 130 crop plants/m^2.	At high crop density 100% recommended herbicide rate reduced yield (especially in wild oats). This then impacted adversely on suppression of weed seed production.
Annual ryegrass decreases with increases in wheat sowing rate without affecting wheat grain yield or quality.	Wheat sowing rate x variety x row spacing. Victorian mallee. (Birchip Cropping Group 1998)	Annual ryegrass heads/m^2 declined with increasing wheat sowing rate from 60 to 120 kg/ha.	Wheat yields increased with sowing rate and narrower row spacings.	Grain screenings declined with increasing sowing rate and narrow row spacings.

Increasing crop density led to a decrease in weed seed production.	Wheat and barley x sowing rate. Wild oats, paradoxa grass or turnip weed. Southern Queensland. (Walker et al 1998)	Increasing crop density from 50 to 100 plants/m^2 reduced the average wild oat seed production from 550 to 230 seeds/m^2 in wheat and from 21 to 7 seeds/m^2 in barley.	In dry season no impact. In wetter season wheat tiller density and grain yield increased with the higher crop densities. Barley yield was reduced by 4% with the increase from 100 to 150 plants/m^2 as a result of decreased grain size.	In wheat, sowing rates of 100–150 plants/m^2 with low herbicide rate improved the weed seed-set control.
Doubling the wheat sowing rate decreased the dry matter of annual ryegrass by 25%.	Competitive differences between wheat cultivars. Southern New South Wales. (Lemerle et al 1996)	Doubling wheat sowing rate to 110 kg/ha reduced ryegrass dry matter by 25%.	Uniform density of ryegrass reduced wheat yields by 80% with above average growing season rainfall, and by 50% with below average rainfall.	Ranking of the competitiveness of varieties was the same at both crop plant densities.
Increasing plant population decreased yield losses caused by weeds.	Wheat/barley density effects on *R. rugosum* and *F. convolvulus*. Southern Queensland. (Marley and Robinson 1990)	Weed biomass in barley was 38% less than that in wheat. Going from 60 to 120 crop plants/m^2 reduced weed biomass by 50%.	Over 10 experiments broadleaf weeds reduced barley yields by 8% and wheat yields by 17%. Losses due to weeds decreased with increasing crop population.	Barley produced greater early biomass.
Increased wheat density led to decreased wild oat tiller numbers.	Wheat density relationships with wild oat density. Northern New South Wales. (Martin et al 1987)	Increasing wheat density decreased wild oat seed yield via reduced tiller numbers.	Increasing wheat population above the weed-free optimum is not a viable alternative to herbicide or rotation. 50 wheat plants with 50 wild oat plants/m^2 reduced wheat yield by 21%.	Optimum wheat population in northern NSW is 100 plants/m^2. Weed-free wheat yield declined with increasing crop density.

Key message	Study	Weed impact	Crop impact	Comments
Increasing crop density led to a decrease in weed biomass.	Wheat spatial arrangement x sowing rate. Annual ryegrass (50 or 200 plants/m^2). Central-eastern New South Wales. (Medd et al 1985)	Crop spatial arrangement did not affect competition against weeds at any density. Increased density (75 to 200 plants/m^2) reduced weed biomass.	Yield was highest at high crop plant densities (200 plants/m^2). Grain size was reduced by 10–15% at high crop density.	Wheat yields and ryegrass density were not affected by spatial arrangement of the crop.
Increasing crop sowing rate led to a decrease in weed biomass and weed seed production.	Wheat sowing rate x wild oat density. Southern Queensland. (Radford et al 1980)	Weed biomass and seed production reduced with increased crop sowing rate, especially at low weed population densities.	Optimum wheat yield was at higher density in wild oat infested plots (compared to weed-free plots).	Increased wheat density up to 150 plants/m^2 resulted in optimum yield when wild oats were present.

Key benefit #2

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

Most small grain comes from secondary tillers. At higher plant populations there is a greater reliance on primary tillers.

Most data indicates that wheat plant densities ranging from 120 to 200 plants/m2 result in similar or higher yield, and actually lead to lower screenings in most seasons, when compared to low sowing rates (Anderson and Barclay 1991; Birchip Cropping Group 1998; Lemerle et al 2004; Minkey et al 2005; Sharma and Anderson 2004). However, in some situations high sowing rates can lead to yield decline and/or increased grain screenings.

Anderson and Barclay (1991) found that in weed-free conditions in the central wheatbelt of Western Australia increasing the wheat plant density from 50 to 200 plants/m^2 substantially increased crop yield, with no evidence of yield decline at higher densities. In central-western New South Wales in a low rainfall environment there was mixed response of grain yield to plant density variation from 50–250 plants/m^2, depending largely upon seasonal rainfall. Data from the 2001–04 seasons showed that the probabilities of changes in yield with increasing plant numbers were: a decrease, 9%; no change, 36%; an increase, 55% (Motley et al 2005).

In Western Australia a study of sowing rate trials by Anderson et al (2004) estimated the minimum wheat population required to optimise yield potential based on both pre-sowing rainfall and growing season rainfall (Table A2.5). Sowing rates presented are seen as the minimum rates needed to avoid yield loss resulting from insufficient plant numbers. Increases of up to 50% on the plant densities / sowing rates cited can be used beneficially to increase crop competition against weeds.

Six trials conducted in Western Australia evaluated the impact of increasing wheat plant populations on the level of screenings. Only two sites showed an increase in screenings, while the other four sites showed significantly reduced screenings with an increased sowing rate (Sharma and Anderson 2004).

Practicalities

Key practicality #1

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

Using high sowing rates (within the optimum range for the region and target grain yield) will not only ensure maximum grain yield, but also tend to minimise small grain screenings in years with average rainfall during grain filling. Sowing rates in excess of the optimum can increase screenings in some cases (and in a few cultivars) but the economic importance of this is likely to be relatively small.

In situations where terminal stress is likely, choose a cultivar that has good average grain size and stability of grain size.

Agronomy 2.3 Row spacing

Row spacing affects the ease of stubble handling at sowing and of controlling disease events in some crops. It also influences crop fertiliser use options. When all other factors are equal, narrow crop rows usually deliver much better crop competition than do wider rows. However, wider row spacings may in some instances lead to improved ability to obtain even crop establishment through more accurate seed and fertiliser measurement and placement. This can result in improved early vigour and ultimately increased crop competition.

Table A2.5 Estimates of minimum wheat plant population (plants/m^2) based on pre-sowing rainfall (PSR, mm) and rainfall in the growing period (GSR, mm) in Western Australia (Anderson et al 2004).

PSR (mm)	GSR (mm)	Yield expectation (t/ha)	Minimum population needed (plants/m^2)	Approximate sowing rate (kg/ha)
0	150	1.50	60	22
	200	2.25	90	39
	250	3.00	120	56
100	200	2.55	102	47
	250	3.30	132	65
	300	4.05	162	86
200	250	3.60	144	76
	300	4.35	174	92
	350	5.10	204	116

When making decisions regarding row spacing, consider:

- paddock conditions (eg the weed burden and stubble load)
- the capacity of the equipment or machinery available
- crop type and variety
- opportunities or limitations for pest control (eg inter-row weed control)
- opportunities for improved fertiliser placement (eg deep banding).

Whichever row spacing is used, always ensure an optimum sowing rate is maintained.

Depth of seed placement, covering depth, seed–soil contact, crop density, fertiliser placement and under-furrow soil strength are further considerations. These will affect the competitive ability of crop seedlings with weeds, and the germination and growth of weeds.

Another important parameter in the sowing operation is the ratio of disturbed to undisturbed soil surface. Sowing equipment components should minimise soil surface disturbance. Each point on a tyne-based sowing machine will disturb a strip of soil equal to twice the operating depth of the point plus the width of the point. As operating speed increases, soil throw makes this ratio even higher. Weed seeds left on the soil surface are less likely to germinate and more likely to suffer predation.

A low disturbance sowing opener, StubbleStar®, is currently being developed by the CRC for Australian Weed Management. The StubbleStar® aims to reduce both row spacing and the disturbed soil ratio. The design of the StubbleStar® allows easier soil penetration and reduced smearing and hair-pinning. The StubbleStar® concept was validated by hand-sown experiments in 2002, which indicated that for cultural weed control, seeders need to be able to place seed at high rates on narrow rows and close to precision placed fertiliser, with tillage localised under each crop seed or group of seeds (Gregor et al 2004).

Benefits

Key benefit #1

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

When the weed burden is high the impact of weed competition on crop yield is high, and the benefit obtained from narrow rows on weed management tactics is significant.

A number of recent studies in Western Australia reported improved suppression of annual ryegrass in wheat sown in narrow (18 cm) rows compared to wide (36 cm) rows, particularly at high sowing rates (Minkey et al 2000; Newman and Weeks 2000; Reithmuller 2005). A clear trend between ryegrass suppression, sowing rate and row spacing in a 1998 Western Australian trial is shown in Figure A2.1. Ryegrass numbers reduce with increased sowing rates and narrower row spacings.

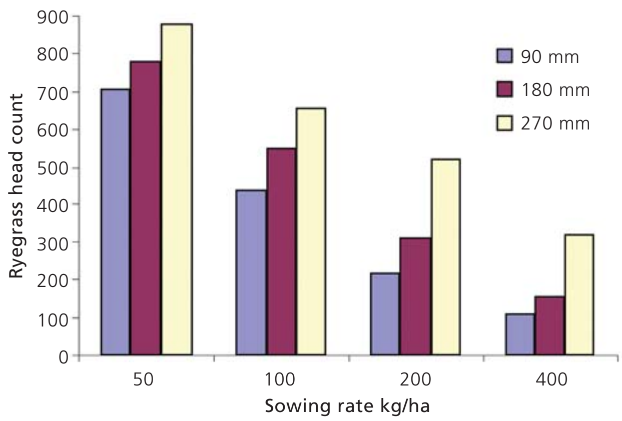

Figure A2.1 The impact of sowing rate (kg/ha) and row spacing (mm) on annual ryegrass head counts (Minkey et al 1999).

In pulses row spacing has less impact on weed suppression. In northern New South Wales Whish et al (2002) found that there was no difference in weed competition in desi chickpeas at 32- and 64-cm row spacings. Similar results were found in lupins (18–36 cm) in Western Australia (Jarvis 1992) and field peas (23–46 cm) at Wagga Wagga, New South Wales (Lemerle et al 2002).

Practicalities

Key practicality #1

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

Minkey et al (2005) found that annual ryegrass seed production was reduced with narrow row spacings, particularly at higher sowing rates.

Marley and Robinson (1990) found variable yield results in wheat and barley where row spacings varied between 17.5 and 35 cm. Turnip weed *(Rapistrum rugosum)* biomass increased 38% with the wider spacing, leading to more weed seeds and harvest and grain quality problems.

A study in southern Queensland compared wheat and barley sown in 25 cm and 50 cm rows with crop ability to compete with sowthistle. The barley outcompeted the sowthistle regardless of row spacing, while the wheat sown in wide rows (50 cm) resulted in higher sowthistle biomass (Widderick 2002).

Whole-farm considerations

- In order to operate practically in retained stubble at narrow row spacings, an advanced technology seeder such as the StubbleStar® may be a necessary capital expense.

Agronomy 2.4 Sowing depth

Benefits

Key benefit #1

Sowing depth can be used to enhance crop competitive ability.

Maximum competitive ability will come from a crop sown at optimum and uniform depth to get rapid and uniform establishment.

Much of the yield loss from weed competition occurs in the first few weeks of crop growth. A crop with a few days' or one week's head start on weeds will be significantly advantaged. Sowing healthy seed (with a high germination rate) into ideal soil moisture at the optimal depth for establishment gives the crop a competitive advantage against weeds.

Optimum sowing depth for each particular soil type and crop type will vary. Achieving an optimum and uniform sowing depth will result in synchronous emergence, benefiting crop yield and improving crop competition.

Practicalities

Key practicality #1

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

Moisture seeking or sowing at depth (below 5 cm) into subsurface soil moisture is a common practice in many regions where sowing rainfall is unreliable. This can be done with all pulse species and cereals, and results in improved establishment due to more favourable soil moisture for both the seed and subsequent seedlings under dry conditions. Moisture seeking ensures timely establishment of the crop ahead of the germinating weeds, giving it a competitive advantage.

An extension of moisture seeking is furrow sowing, which is the practice of sowing at depth but only returning a light cover of soil over the seed, effectively leaving it at the bottom of a seed furrow. With crops that have poor coleoptile strength, this extends the option to moisture seek long after a rainfall event while maintaining crop seedling vigour. This is only applicable when there are no significant rainfall events near sowing time.

Key practicality #2

Take care to sow seed at optimum depth.

Crops that are sown too shallowly can sometimes be more prone to herbicide damage. Herbicides can become more mobile and active on sandy or coarse-textured soils. On these soils it is recommended to apply herbicides such as simazine before sowing, sow deeper, and incorporate the herbicide by sowing so as to minimise damage.

Sowing too shallowly can also result in uneven germination, with some seed being placed in dry soil and not germinating until a follow-up rain is received.

Sowing too deeply can lead a crop to expend much of its stores of energy by having to push up through the soil. When such crops do emerge they are often slow growing, weak competitors, and are more susceptible to disease, insect attack and/or herbicide damage until they recover.

Equipment costs for independent depth control on each row will need to be considered when making row spacing decisions, and the optimal trade-off between row spacing and depth control may vary with the type of crops grown and the paddock topography.

Agronomy 2.5 Sowing time

Benefits

Key benefit #1

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

Time of sowing has a large effect on early crop vigour, canopy development, dry matter production and final yield, and all these factors have a direct impact on the competitive ability of a crop. Delaying sowing reduces these factors, giving the weeds an advantage.

Delaying sowing beyond the optimum window recommended in a given district will reduce early vigour, extend the time taken to reach canopy closure and reduce overall dry matter production. It is therefore important to sow within the recommended time period, not only to maximise yield but also to make the crop competitive.

Practicalities

Key practicality #1

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

If using delayed sowing with a non-selective knockdown herbicide as a weed management tactic, be aware of associated risk of yield reduction. Preferably use crop types and varieties that can be successfully sown later, such as field peas, chickpeas, barley or short season wheat.

Key practicality #2

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

As delays in sowing lead to a rapid decline in yield in several key crop types, significant delays are rarely used as a planned strategy. However, a widely adopted tactic is to plan to sow weedy paddocks last. The sowing operation as a whole is not delayed, and the benefit of delayed sowing (allowing a knockdown herbicide application time to work) is applied to paddocks where it is needed most.

Agronomy 2.6 Soil properties

Benefits

Key benefit #1

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

Crops growing in unsuitable soils are far more susceptible to disease and insect attack and can become more prone to damage from pre-emergent herbicides. Poor early vigour can also result from crops grown in unsuitable soils. When not actively growing, crop seedlings are unable to detoxify herbicide, which further reduces crop vigour and biomass. The slow crop growth is also advantageous to the weed. Nodulation of pulses can be reduced, thus decreasing plant biomass and competitiveness.

For example, on very acidic soils (pH less than 4.5) grow narrow-leaf lupins, triticale or acid tolerant wheat as these are more suited than other crops to such soils. On heavy soils that suffer periodic waterlogging during early winter, the best suited break crop is faba bean.

Sowing equipment should be tailored to suit soil properties to obtain the highest plant count in the shortest time. In heavy clay soils press wheel pressure may need to be increased as the soil dries.

Improving soil constraints to plant growth (eg acidity, salinity, sodicity, boron toxicity) can dramatically improve crop growth. On an acidic soil in southern New South Wales the use of lime to ameliorate the soil acidity resulted in suppressed weed growth and improved crop yields (Li and Conyers 2004).

Agronomy 2.7 Fertiliser use and placement

Benefits

Key benefit #1

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

Macronutrients (including N, P, K, S, Ca, Mg) are most important for plant growth. Ensure that these nutrients are in good supply before considering the micronutrients (Cu, Zn, Mn, Fe, Mo, B, Cl). In some locations there may be known deficiencies of some micronutrients that need to be addressed for either good plant growth or subsequent animal growth. For example, cobalt (Co) and selenium (Se) are deficient in southern WA and molybdenum (Mo) is deficient in the ironstone soils of Tasmania (Peverill et al 1999).

Practicalities

Key practicality #1

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

Aim to place fertiliser nutrients, in both space and time, where they are most available to the crop plants to optimise competitive ability. Without exposing germinating seed to toxicity risks, a three-hopper sowing machine allows placement of an N–P–(K) starter fertiliser with the seed, while extra nitrogen (N) is banded below, to avoid toxicity. The banding depth will also affect both soil disturbance (see Agronomy 2.3 *Row spacing*) and depth control (see Agronomy 2.4 *Sowing depth*).

For example, research in New South Wales (Koetz et al 2002) found that N banded close to the crop reduced the impact of weeds on crop yield to about one-third compared to broadcasting N at sowing (Table A2.6).

The tactical application of N (in method and timing) reduced the production of excessive weed biomass and limited weed seed production and subsequent replenishment of the weed seedbank. In situations of high soil N and high wheat shoot number, delayed application of N will be beneficial to wheat yield if weeds are a problem (Koetz et al 2002).

Table A2.6 Impact of N fertiliser (urea) placement on wheat yield in the presence and absence of annual ryegrass (expressed in quantitative yield (t/ha) and percentage loss due to weeds (Koetz et al 2002).

Fertiliser placement		Yield (t/ha)		Yield loss (%)
Broadcast prior to sowing	*weed free*		6.8	
	+ ryegrass	4.9		28
Top dressed at end of tillering (Zadoks decimal code 31)	*weed free*		6.8	
	+ ryegrass	5.4		19
Banded midway between wheat rows at sowing	*weed free*		6.5	
	+ ryegrass	5.6		14
Banded under wheat rows at sowing	*weed free*		6.8	
	+ ryegrass	6.1		10

Unlike nitrogen, phosphorus (P) is immobile in the soil. The grain yield advantage of banding P with the seed compared to broadcasting (in terms of yield in weed-free situations) has been demonstrated many times (Egan and Bunder 1993; Jarvis and Bolland 1990; Scott et al 2003). Banding P under the seed rows means that crop roots can readily access it, even under dry conditions. In addition, the available P is not mixed with a large volume of soil which will immobilise it after broadcasting.

Agronomy 2.8 Disease and pest management

One of the key strategies for managing diseases and insect pests is enterprise sequencing (see Agronomy 1.1 *Crop sequence*). It is well known that annual and (some) perennial grasses are hosts for some root diseases, and a significant grass-free period is required to reduce these pathogens before cereals should be grown. A range of other pathogens are also carried between seasons on crop residues.

Benefits

Key benefit #1

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

A healthy crop will best compete with weeds. Preventing and controlling crop diseases (eg take-all, crown rot, *Rhizoctonia*, stripe rust) and insect damage (eg *Heliothis*, aphids, red-legged earth mites) will give crops a fighting chance against weeds.

Practicalities

Key practicality #1

Monitor crop health and control pests and diseases.

Sowing equipment capable of disturbing the soil below the seed zone will reduce attack by fungal diseases such as *Rhizoctonia*.

Because disease, mite and insect damage can reduce the general health and competitiveness of crops, it is important to take adequate precautions against these threats. Thorough monitoring and strategic control programs can manage them all economically.

Key practicality #2

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

The loss of a large number of crop plants within a defined area makes an ideal haven for weeds. These areas need to be managed to prevent weed seed 'blow-outs'. Sacrificing the low crop yield of a high weed-density area will greatly reduce the numbers of weed seeds entering the soil.

(see Tactic 2.4 *Spot spraying, chipping, hand roguing, wiper technologies*, Tactic 3.3 *Silage and hay – crops and pastures)* and Tactic 3.4 *Renovation crops and pastures – green manuring, brown manuring, mulching and hay freezing)*.

Contributors

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Agronomy 3 Herbicide tolerant crops

In Australia herbicide tolerant (HT) crops are a relatively new technology. The technology can be introduced into crops either by genetic modification or by traditional or conventional breeding methods. For example, conventionally bred HT canola was first used in commercial production in 1994, and conventionally bred HT wheat was introduced into Australia in 2001. Genetically modified (GM) HT cotton has been commercially grown in Australia since 2000, having undergone Australian field trials (see Biotechnology Australia Factsheet No 29: www.biotechnology.gov.au).

HT crops have a tolerance to a herbicide that normally would cause severe damage, such as Group B imidazolinone herbicide in CLEARFIELD® canola. Using HT crops can simplify weed control for growers in the short term.

There has been some public concern regarding the threat of 'super weeds', ie weeds resulting from out-crossing with HT crop varieties. Recent identification of hybridisation between canola and charlock *(Sinapis arvensis)* in the United Kingdom (Brown 2005) caused some alarm amongst environmentalists.

Many factors influence the ability of a plant to out-cross. These include the relative timing of flowering of the two species, pollen dispersal (by wind and/or animal) and viability, pollen compatibility, environmental factors and the proximity of plants with similar reproductive genetics.

Work by Timmons et al (1995) showed that canola pollen travelled 1.5 km in sufficient enough quantities to pollinate other canola plants. A review by Rieger et al (1999) showed that low levels of hybrids between canola as the pollen donor and charlock *(Sinapis arvensis)* and wild radish *(Raphanis raphanistrum)* were possible; however, the offspring were often sterile. Rieger et al (2001) showed in field experiments in South Australia that the frequency of hybridisation into canola from wild radish was one in 400 million, with resulting hybrids found to be fertile.

While such gene transfer can be expected, the ramifications are unlikely to be substantial. In situations where it is the canola that acts as the pollen recipient, resulting seeds will be harvested and processed. When canola receives the pollen from other related species, the seeds produced are usually matromorphic, having not received the genetic material from the pollen.

For this reason, any concern about hybridisation should be directed at situations where the canola is the pollen donor to the weed. It is important that growers of HT crops closely follow the information provided with management packages developed for these crops.

Glossary

- pollination – the transfer of pollen from an anther to a stigma, effecting fertilisation
- self pollination – the transfer of pollen from the anther to the stigma of flowers on the same plant
- cross pollination – the transfer of pollen from the anther of one individual plant to the stigma of another plant of the same species. Some species must have this pollen transfer between plants in order to produce fertile seeds
- out-crossing (also known as hybridisation) – the transfer of pollen from the anther of one individual to the stigma of another individual of a different species.

Weeds are constantly evolving resistance, and herbicide resistant weeds can become problematic with or without input from gene technology.

Benefits

Key benefit #1

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

Inclusion of an HT crop in a cropping program, along with a range of weed management tactics, can ensure good control of otherwise hard-to-control weeds and avoid blow-outs in the seedbank. For example, triazine tolerant canola has been used as an effective break crop in paddocks infested with wild radish, whereas conventional canola, faba beans, chickpeas and lentils are not viable choices in these paddocks, thereby limiting the number of available break crops.

Practicalities

When using HT crops in an IWM program the following key practicalities must be addressed.

Note: Specific HT crop technology stewardship programs are an excellent source of more detailed information. Examples include: CLEARFIELD® Stewardship Program and Triazine Tolerant (TT) Canola Program.

Key practicality #1

Always use HT crops within an IWM framework.

An HT crop should represent only one part of an IWM plan. A range of weed management tactics from a mix of tactic groups, including non-herbicide measures and rotation of herbicide mode of action (MOA), should be used in conjunction with the HT crop and its associated herbicide.

Follow best management practices as defined by the relevant stewardship program and product label, as well as the current CropLife Australia Limited (formerly Avcare – The National Association for Crop Production and Animal Health) herbicide resistance management guidelines (www.croplifeaustralia.org.au).

Basic guidelines include the following:

- farm practices and herbicide and crop rotations should be developed to allow for use of alternative MOA herbicides
- weeds suspected of being herbicide resistant should be tested prior to growing an HT crop to ensure effectiveness of the herbicides applied
- IWM should be planned and practised on a paddock-by-paddock basis. Always consider paddock history as well as options for future use
- when planning future crop sequences and management of herbicide resistant weeds (that may include HT crop volunteers) consider rotating herbicide MOA for all herbicides used and use tactics from a range of tactic groups
- reduce selection pressure by using herbicide combinations and non-herbicide tactics. For example, in the IWM plan for a Group B HT crop, use the Group B herbicide in conjunction with a herbicide from another MOA group that has significant activity against the target weed(s). A Group D herbicide used at sowing to target annual ryegrass will reduce the selection pressure placed on the ryegrass population when the Group B herbicide is applied to the HT crop. This is critical in situations where there is likely to be a high density of annual ryegrass.

Key practicality #2

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

There are limitations on the number of herbicides of a particular MOA group that can be applied within specified time intervals. For example, with Group B tolerant crops:

- only one Group B herbicide may be applied per season. If a pre-emergent Group B herbicide is used then another Group B product must not be applied post-emergent to that crop or during the ensuing fallow
- limit Group B herbicides in each paddock to a maximum of two applications in any 4-year period
- avoid the use of Group B herbicides in consecutive years (valid as of December 2005).

Herbicide resistance management guidelines for Australia for MOA groups can be downloaded from the CropLife Australia Limited website (www.croplifeaustralia.org.au).

Key practicality #3

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

Control of HT crop volunteers in the following crop is a requirement for responsible use of HT crop technologies. Crop volunteers become weeds that can compete with subsequent crops, become hosts for plant diseases and increase the risk of spread of herbicide tolerance via cross-pollination with neighbouring crops and seed movement.

To reduce the risk of HT crop volunteers persisting:

- do not sow a conventional crop of the same species after sowing an HT crop because controlling HT volunteers will be difficult or impossible. Seed harvested from the conventional crop is likely to be contaminated with HT volunteers
- adhere to industry technology stewardship guidelines in relation to the use of herbicide in the following fallow and growing season.

Farm hygiene is important to limit the spread of HT crop seed. As with general weed management, a machinery clean-down protocol should be in place when growing HT crops.

Take extra care with sowing, harvesting and storage, and when transporting equipment:

- harvest on time to minimise seed loss, and adjusting the header to reduce seed numbers in the chaff and straw
- seal any cracks in the header that allow seed to spill (with special attention to the table, front elevator and grain tank areas)
- thoroughly clean the header to minimise spread of seed between paddocks or while the header is in transit
- seal cracks and covering loads to avoid spills during grain storage, handling and transport
- immediately clean any spilt seed, recording spill types and locations, and checking for subsequent germination(s) and controlling as needed.

Key practicality #4

Adhere to all herbicide label directions.

Not all HT crops are tolerant at all growth stages. In addition, there are also application rate limitations to tolerance levels.

Key practicality #5

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

To avoid mistakes:

- use paddock signage for easy identification of paddocks sown to HT crops in both the crop year and the following season
- integrate the control of HT crop volunteers into normal weed management planning processes
- prevent any HT crop plants that germinate from setting seed in the fallow period
- control all crop volunteers in following crops with effective weed management tactics.

Key practicality #6

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

Out-crossing (hybridisation) can occur with several related species and with other varieties of canola but the frequency of cross-pollination is low. This is because pollen viability is short-lived and decreases with distance from the pollen source, and there is significant competition between self-fed and foreign pollen in fertile plants. Low levels of cross-pollination between adjoining canola fields is expected.

The risk of hybridisation will increase according to population size of both canola crop and weed. In situations where canola is widely grown, and closely related weeds (*Brassica* spp.) are densely located within the vicinity (<1 km), the risk of hybridisation between crop and weed is high. Two important weeds, wild radish *(Raphanus raphanistrum)* and buchan weed *(Hirschfeldia incana)*, are known to cross-pollinate at a low frequency with canola (Ellstrand et al 1999).

Given that the primary reason for growing GM canola crops is to assist control measures for herbicide resistant wild radish, the likelihood of hybrids arising is high. In July 2005 a hybrid between GM canola and charlock was discovered in Britain (Brown 2005). Although the two plants were found to be sterile, the incident highlights the potential for hybridisation despite the low risk.

The result of out-crossing in canola differs between types of herbicide tolerance. For example, triazine tolerance is not transferred with the pollen in TT canola varieties, while the tolerance gene for imidazolinone tolerance is transferred by pollen in CLEARFIELD® varieties. In both cases out-crossing with wild relatives such as wild radish is possible. However, in the case of triazine tolerance the pollen would have to come from the radish and fertilise the ovary on the TT canola plant for the progeny to express herbicide tolerance.

To reduce the risk of HT canola out-crossing:

- do not precede or follow HT canola with another canola crop
- control volunteer canola plants at all times
- control all brassica weeds both in-crop and in adjacent sites (eg along fencelines), particularly before flowering
- ensure equipment and machinery is cleaned down between each canola crop sown, harvested or transported
- avoid growing HT canola in paddocks adjacent to crops of other canola varieties
- cover loads during harvest and transport.

Key practicality #7

Use agronomic practices to minimise out-crossing in wheat.

Wheat tends to be poorly persistent as a weed. Its presence is usually restricted to the fallow period and the crop following the wheat. While it does occur as a weed on road verges and in some other non-crop situations, its presence is mainly due to poor hygiene and it usually does not persist.

While wheat can out-cross with wild *Triticum* species at a rate of up to 6%, there are no known wild or established weedy populations of *Triticum* or closely related species (eg goat grass *Aegilops* spp.) in Australia.

To minimise the spread of HT wheat and the contamination of non-herbicide tolerant wheat:

- control all crop volunteers in the fallow and following crop
- if the following crop grown is wheat **do not save seed** from this crop
- ensure good weed control around fencelines while the HT crop is being grown and in the following fallow and season
- cover loads during transport.

Contributors

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Significant use has been made of the CLEARFIELD® and TT Canola Production stewardship program materials in compiling this section.

Further reading

Dow AgroSciences (www.dowagro.com)

- *Includes information such as:*
  - how to protect crops from genetic out-crossing
  - managing out-crossed volunteer canola
  - the science of herbicide tolerant volunteer canola.

Canola Council of Canada (www.canola-council.org/)

- *Includes information such as:*
  - factsheet on ecology and management of volunteer canola
  - herbicide tolerant volunteer canola
  - pollen flow and out-crossing
  - multiple resistant canola.

Crop Science Online (http://crop.scijournals.org/)

- *Includes information such as:*
  - isolation distances for minimising out-crossing in spring wheat (Hucl and Matus-Cadiz).

DuPont Biotechnology (www2.dupont.com/Biotechnology/en_US/)

- *Includes information such as:*
  - herbicide resistant crops and weed management: scientific summary and the DuPont perspective
  - gene flow via pollination – oilseed brassica species
  - the likelihood of gene flow from cultivated brassica to wild relatives.

Agronomy 4 Improving pasture competition

Pastures represent an important component of many rotations, and normally take 1–5 years to break up extended periods of cropping. Incorporating pastures can help restore soil fertility (organic matter and soil nitrogen) that may have declined due to frequent cropping, and in turn improve the competitive ability of crops.

Pastures provide a valuable opportunity to manage weed problems using tactics not able to be used in cropping situations, such as grazing, mechanical manipulation and non-selective herbicides. See also Tactic 3.5 *Grazing – actively managing weeds in pastures*.

For further reading on weed control in pastures, refer to Burton and Dowling (2004).

Benefits

Key benefit #1

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

Where desirable species dominate pasture (greater than 80%), weeds have less opportunity to establish. It follows then that weeds may be best controlled by pasture plants themselves which compete for light, moisture, space and nutrients.

Strong competition against weeds is encouraged by:

- high plant densities of desirable plants
- use of fertilisers to provide the best possible soil conditions for vigorous growth of legumes and desirable grasses
- tactical grazing that incorporates 'grazing-free' periods – this enables desirable species to increase in size, favours root development and competitive ability, and allows for seed-set and subsequent seedling recruitment (see Tactic 3.5 *Grazing – actively managing weeds in pastures*).

Key benefit #2

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

The best scenario for weed competition is high densities of desirable annual pasture plants germinating at the same time as weeds. The value of high densities of biserrula germinating at the break of season to suppress weed growth is illustrated in Table A4.1.

For perennial pastures maintain herbage above 1500 kg DM/ha with greater than 80% ground cover to reduce the germination of annual grass weeds. Apply fertiliser (and lime where required) to increase the vigour of desirable species.

Table A4.1 Influence of pasture production on weed growth (Miling, Western Australia 2005). These annual legumes regenerated after a wheat crop and were ungrazed.

Species / variety	Seedling regeneration (plants/m^2) 15/4/05	Seedling regeneration (plants/m^2) 16/5/05	Spring herbage production (t/ha)	% weeds in spring
Sub clover cv Dalkeith	177	188	3.6	10.9
Burr medic cv Santiago	253	689	3.8	16.9
Biserrula cv Casbah	602	756	6.7	2.9

(Source: Revell unpublished)

Whole-farm benefits

- improved feed quality and quantity
- higher stocking rates with better pastures
- forage preservation (hay or silage) due to higher production
- less supplementary feeding.

Practicalities

Key practicality #1

Select species and varieties to suit your conditions.

Select the most appropriate species and varieties according to soil type, climatic conditions and farming system (eg permanent pasture or rotation with grain crops). Desirable species need to be managed to ensure the development of an adequate seedbank (Bellotti and Moore 1993) because large seedbanks are required to drive high density pasture regeneration.

Key practicality #2

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

Pasture re-establishment (resowing desirable species) will improve pastures that are severely degraded. Optimise this operation by implementing weed control prior to sowing (eg spray-topping, use of knockdown herbicides, cultivation).

In a pasture–crop rotation, if the pasture density declines to a level where weeds invade (eg due to drought, poor establishment or overgrazing), it may be necessary to shorten the pasture phase, spray-top or use a knockdown herbicide, and move into the cropping phase early.

Key practicality #3

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

Species mixtures can improve the resilience of pastures by providing a range of seed characteristics (and/or pest and disease tolerances. Mixtures should include perennial and annual grasses and legumes.

Whole-farm considerations

- ensure that appropriate grazing management (deferred and rotational grazing) is used
- devise strategies and paddock plans for pasture re-establishment
- ensure that pasture legumes are inoculated with their correct rhizobium.

Contributors

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Agronomy 5 Fallow phase

Fallows are defined as the period between two crops, or between a crop and a defined pasture phase, where the objective is to store and conserve soil moisture and nitrogen for the next crop. The term 'fallow' has different meanings in different parts of Australia.

There are four broad categories:

1. In a winter rainfall (southern) continual cropping sequence of two or more crops the period between the harvest of one crop and sowing of the next crop represents the shortest fallow period. This is typically about 4 months. Since the short fallow commences after harvest, it has no impact at all on the previous winter-growing weed seed production. In wet summers, summer-growing weeds can be controlled but this has no direct in-crop weed management benefits in a winter cropping sequence, other than reduced nutrient tie-up and improved moisture accumulation.

2. In a winter rainfall (southern) pasture–crop sequence the period between killing the pasture (usually August–September but can be earlier) and sowing the first crop would be thought of as a long fallow and would have a duration of about 8 months. Because such fallows should commence well before weed seed maturity, they are a potent method of weed seedbank management.

3. In northern areas of New South Wales and southern Queensland, where dryland summer crops can be grown, fallow periods exist between winter cereal harvest and the sowing of a summer crop (eg sorghum), or roughly December through to the following October, a period of around 10 months.

   Similarly, a fallow can exist between sorghum harvest (about March) through to cereal sowing in the following year (about May–June), a period of around 14 months.

   In low rainfall environments some farmers opt to 'skip a year' and call this a long fallow. Harvest would take place in November of year 1 and sowing would not occur again until April–May of year 3, a period of about 18 months.

   These long fallows embrace both a winter and summer growing season. The winter growing season presents a potent management option for winter-growing weeds. Similarly, the summer season offers weed management options for summer-growing annual weeds.

4. In northern cropping systems it is also common to have consecutive winter-growing crops, depending on available subsoil moisture. As in category 1 above, the fallow period between these crops is about 6 months and has no impact on winter-growing weed species. Since it embraces a summer period, a short northern fallow will have an impact on summer-growing annual weeds.

Benefits

Key benefit #1

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

Fallows can be initiated and maintained using herbicides, cultivation or a combination of both. It is important that stubble cover be maintained for as long as possible to protect the soil surface during the fallow period. On mixed farms properly managed grazing can be useful in suppressing weeds, particularly the root development of weeds.

Winter rainfall and summer rainfall cropping systems are contrasted in Table A5.1. Note the length of the fallows in the summer rainfall system and the fact that winter fallows are a regular occurrence.

Note: Glyphosate is the main tool for managing no-till/minium-till fallows in both systems. Resistance in annual ryegrass has become an increasingly common problem in summer rainfall cropping systems, largely due to no-till winter fallow periods.

Key benefit #2

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

A range of non-selective control techniques can be used to practically prevent weed seed production. Options include grazing, cultivation and herbicides, or combinations of these. No in-crop or in-pasture weed treatment offers this level of weed control and reduced risk of evolving resistant weeds.

Key benefit #3

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

Paraquat belongs to MOA Group L and glyphosate to Group M. In Australia there is annual ryegrass resistance to Group M herbicides but not to Group L; and barley grass, northern barley grass, *Vulpia* spp. and capeweed resistance to Group L but not to Group M (see www.croplifeaustralia.org.au). Careful herbicide selection and rotation can decrease the risk of resistant weeds.

Key benefit #4

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

Great care is needed to reduce the possibility of herbicide carryover and the evolution of weeds resistant to these other MOA groups.

Table A5.1 Contrast between simple winter and summer rainfall cropping systems

<table>
<tr><th>Season</th><th colspan="2">Winter rainfall area</th><th colspan="2">Summer rainfall area</th></tr>
<tr><td>Autumn</td><td>fallow</td><td>plant wheat</td><td>fallow</td><td>plant wheat</td></tr>
<tr><td>Winter</td><td colspan="2">wheat crop</td><td colspan="2">wheat crop</td></tr>
<tr><td>Spring</td><td colspan="2">wheat crop</td><td colspan="2">wheat crop</td></tr>
<tr><td>Summer</td><td>wheat crop</td><td>fallow</td><td>wheat crop</td><td>fallow</td></tr>
<tr><td>Autumn</td><td>fallow</td><td>plant canola</td><td colspan="2">fallow</td></tr>
<tr><td>Winter</td><td colspan="2">canola crop</td><td colspan="2">fallow</td></tr>
<tr><td>Spring</td><td colspan="2">canola crop</td><td>fallow</td><td>plant sorghum</td></tr>
<tr><td>Summer</td><td>canola crop</td><td>fallow</td><td colspan="2">sorghum crop</td></tr>
<tr><td>Autumn</td><td>fallow</td><td>plant wheat</td><td>sorghum crop</td><td>fallow</td></tr>
<tr><td>Winter</td><td colspan="2">wheat crop</td><td colspan="2">fallow</td></tr>
<tr><td>Spring</td><td colspan="2">wheat crop</td><td colspan="2">fallow</td></tr>
<tr><td>Summer</td><td>wheat crop</td><td>fallow</td><td colspan="2">fallow</td></tr>
<tr><td>Autumn</td><td>fallow</td><td>plant canola</td><td>fallow</td><td>plant wheat</td></tr>
</table>

Key benefit #5

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

In-crop or in-pasture it is possible that surviving weeds can remain undetected by remaining hidden among desirable plants, allowing herbicide resistant weeds to develop unnoticed. By contrast, weeds that survive control tactics are more obvious in fallows.

Whole-farm benefits

- *Soil moisture will be conserved.* This is often cited as the number one advantage of fallowing. In lower and/or less reliable rainfall areas moisture conservation in-fallow is regarded as essential for reliable crop production. In northern cropping systems sowing summer or winter crops on low subsoil moisture levels is regarded as high risk. In contrast, in the eastern Riverina district of New South Wales (for example) stored fallow moisture may only provide significant benefit in one year out of four, simply because growing season rainfall is sufficient and reliable.
- *Available nutrient levels will be optimised.* A significant impact of weeds is to tie up available nutrients in their tissues. In past seasons a number of observations of 'timely' control versus 'late' control of fallow weeds in southern New South Wales revealed a benefit of 40–50 kg of available N/ha (Medway 1995), representing a significant saving in nitrogen fertiliser.
- *Fallow paddocks can provide fire protection for farms and livestock.* Stubble-free fallows provide a safe refuge for stock during bushfires.

Practicalities

Key practicality #1

Control weeds of fallows when they are small.

Small weeds are less likely to be stressed and are easier to control with both herbicide and cultivation in fallows. Small weeds also use less moisture and available nutrients.

Key practicality #2

Avoid over-reliance on cultivation.

Cultivation increases the risk of erosion through loss of soil structure. If cultivation is used it should be for a range of reasons such as incorporating lime plus a double-knock for a fallow spray. Over-reliance on cultivation will also lead to a different range of weed problems, such as the spreading of perennial weeds including field bindweed and silverleaf nightshade.

In some systems fertiliser can be added or soil-applied herbicides incorporated while cultivating a fallow just prior to sowing.

Key practicality #3

Rotate herbicide MOA groups.

Avoid over-reliance on one herbicide MOA group. This rule applies to non-selective knockdowns as well as selective herbicides. Using paraquat will require more forward planning to achieve equivalent results than choosing glyphosate.

Key practicality #4

Residual herbicides may be used for managing fallow weeds.

Using residual herbicides creates an advantage by reducing the frequency of knockdown herbicide application. However, this will impose extra selection pressure on weeds, increasing the risk of resistance developing in the target weed species. Under dry conditions residual herbicides may last long enough to affect the following crop or pasture phase, so be aware of plant-back periods.

Key practicality #5

Avoid cultivating wet soil.

Cultivation of wet soil causes compaction and smearing. Transplanting can also reduce the effectiveness of weed control.

Whole-farm considerations

- *Moisture accumulation.* During fallow moisture accumulation can lead to deep drainage into groundwater and increase salinisation of the landscape. Planning for opportunity cropping must account for weed and disease management issues.

Contributors

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Agronomy 6 Controlled traffic or tramlining for optimal herbicide application

'Controlled traffic' refers to a cropping system designed to limit soil damage by confining all wheel traffic to permanent lanes for all field operations. 'Tramlining' refers to the use of semi-permanent traffic lanes for in-crop spray/spreading operations.

Some form of traffic lane will increase the health of the crop due to improved soil characteristics, thus improving the competitive ability of the crop. The most accurate guidance systems provide new physical and chemical weed management options, while tramlining improves the effectiveness of herbicides.

Benefits

Key benefit #1

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

Accurate tramlines or controlled traffic lanes clearly reduce the problems of overlap/underlap, and are generally credited with reducing overall input costs by about 10% (Rainbow 2005).

Use of tramlines or traffic lanes also enables improvements in the timing of applications because trafficability in high soil moisture conditions is increased.

Key benefit #2

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

In wide-row controlled traffic systems narrower bandwidth inter-row and band spraying can be used, which is economically and environmentally valuable. High-precision guidance systems also improve the potential for effective in-crop physical control without damaging the crop.

Physical control in the cropping phase has traditionally been dependent on the skills of the operator, with inter-row cultivation (see Tactic 2.3 *Weed control in wide-row cropping*) sometimes followed by manual chipping (see Tactic 2.4 *Spot spraying, chipping, hand rouging, wiper technologies*). By using precision guidance a more effective job is possible with an accuracy to within 2–3 cm of the plant row.

A number of growers have seen the potential for in-crop physical control as a method of reducing the risk of herbicide resistance development. In-crop physical control can also reduce the crop damage that often accompanies inter-row shield spraying.

Key benefit #3

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

Controlled traffic farming avoids wheel compaction except on wheel tracks, resulting in better surface and subsurface soil conditions, and improving plant available water in the soil profile. Many planting delays caused by wet ground are eliminated.

Precision is easier in most controlled traffic crop operations because firm permanent traffic lanes develop. Ease of precision is particularly noticeable during planting and inter-row operations when working softer, more uniform soil. Tractor power requirements are significantly reduced and zero tillage is facilitated.

Practicalities

Key practicality #1

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

Tramlines can be installed using marker arms or manual layout, but are increasingly being carried out using global positioning system (GPS) guidance.

Contributors

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