SECTION 3
AGRONOMY

Agronomy to enhance the implementation and benefits of weed management tactics

INTEGRATED WEED MANAGEMENT IN AUSTRALIAN CROPPING SYSTEMS

SECTION 3: AGRONOMY TO ENHANCE THE IMPLEMENTATION AND BENEFITS OF WEED MANAGEMENT TACTICS

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 can also assist soil 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, Tactic Group 2 (section 4, page 113) 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 (*Fallopia convolvulus*) or wireweed (*Polygonum* spp.) are a problem, and sunflowers should not be grown in paddocks with heavy broadleaf weed burdens.

Another example of the importance of crop and variety choice when implementing a weed management tactic relates to in-crop seedset control tactics (Tactic Group 3, section 4, page 170). 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 crop types is provided in Table A1.1 (pages 55–57). 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 seedset 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 (*Avena* spp.) and paradoxa grass (*Phalaris paradoxa*).

Crop sequencing to minimise soil-borne 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 parasitic 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.

TABLE A1.1 Crop choice options to aid weed management.

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* spp. 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 germination rate) Direct drill
Canola – imidazolinone tolerant (IT) varieties	Medium	Early	Early	Many for grass; several for broadleaf	Group B resistant brassicas (e.g. wild radish, wild mustards, wild turnip)	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 pasture in previous year	Variety choice Improved fertiliser placement Direct drill
Canola – standard varieties	Medium	Early	Early	Several for grass; limited for broadleaf	Group A resistant grasses, brassicas (e.g. 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 – glyphosate tolerant (RR) varieties	Medium	Early	Early	Many for grass; several for broadleaf	Glyphosate resistant weeds Brassica weeds	Grass weeds Some broadleaf weeds	Autumn tickle Burn residues (not sandy soils) Crop desiccation Windrowing Seed catching Windrow/burn residues	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 Winter clean grasses in previous year	Variety choice Improved fertiliser placement Direct drill
Chickpeas	Poor	Mid–late	Late	Many for grass; limited for broadleaf	Fumitory Black bindweed Wireweed (no-till and stubble retention) Vetch	Grass weeds such as feathertop Rhodes grass	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

TABLE A1.1 Crop choice options to aid weed management – continued.

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]
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	Late	Many for grass; limited for broadleaf	Brassicas Vetch	None	None None	Improved fertiliser placement
Lupins – Narrow-leafed and *L. albus*	Poor	Early	Late	Many for grass; many for broadleaf	Sand plain (blue) lupin	*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 Brome grass Barley grass *Vulpia* spp.	Broadleaf weeds	Hay or silage Silage Short, high intensity grazing Hay freezing	High nitrogen rate Improved fertiliser placement High sowing rate
Oats – hay	High	Late	Late	Limited for grass; many for broadleaf	Brome grass Barley grass *Vulpia* spp. Annual 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	Broadleaf weeds	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 time, high intensity grazing	Improved fertiliser placement High sowing rate High nitrogen rate
Wheat – early sown	High	Early	Mid	Many	Multiple resistant annual ryegrass Barley grass	Broadleaf weeds, wild oats, annual ryegrass	Seed carts, Harrington S.D. Burn residues	Improved fertiliser placement Narrow row spacing High sowing rate
Wheat – main season	Medium–high	Mid	Mid	Many	Multiple resistant annual ryegrass; Barley grass	Broadleaf weeds, wild oats, annual ryegrass	Selective spray-topping Seed carts, Harrington S.D. Burn residues	Variety choice Improved fertiliser placement High sowing rate
Wheat – quick maturing – short season varieties	Medium	Mid–late	Early	Many	Multiple resistant annual ryegrass; Barley grass	Broadleaf weeds, wild oats, annual ryegrass	Delayed sowing Autumn tickle Double knock Windrowing, seed carts, Harrington S.D. Burn residues	Improved fertiliser placement High sowing rate Narrow row spacing

TABLE A1.1 Crop choice options to aid weed management – continued.

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]
Wheat – graze and grain	High	Early	Late	Many	Multiple resistant annual ryegrass	Broadleaf weeds, wild oats, annual ryegrass	Short duration, high intensity 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 annual 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 seedlings; several for mature stands	Must use trifluralin for establishment – wireweed	Grasses	Spray-topping Winter cleaning Green/brown manuring Silage or hay Grazing management	High phosphorus rate Good nodulation Variety choice
Subclover	Low–medium	Early–mid	N/A	Several	Bedstraw	Grasses	Spray-topping Green/brown manuring Silage or hay Grazing management Spray-grazing Wick/blanket-wiping	Rotation High phosphorus rate Good nodulation Variety choice
French (pink) serradella (e.g. 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 Wick/blanket wiping	Rotation High sowing rate 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 Wick/blanket wiping	Rotation High phosphorus rate Good nodulation Species and variety choice
Sorghum	Density dependent	Spring–summer	Variable	Limited for grass; several for broadleaf	Johnson grass (*Sorghum halepense*) *Sorghum almum* Feathertop Rhodes grass grass	Winter grasses Summer broadleaf weeds	Inter-row shielded spray or cultivation	Inter-row shielded spray or cultivation
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 Summer grasses	Inter-row shielded spray or cultivation	Inter-row shielded spray or cultivation
Mungbeans	Low	Spring–summer	Early	Several for grass; limited for broadleaf	Burrs (*Xanthium* spp.) *Ipomoea* spp.	Winter and summer grasses	Inter-row shielded spray or cultivation	Rotation Narrow row spacing High phosphorus rate Good nodulation Summer/winter fallow

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.

Common sowthistle growing in fallow (no competition) vs growing in crop (wheat and barley). There was no in-crop herbicide applied to control the weed. The lack of sowthistle in-crop is entirely due to crop competition. The 2001 Condamine (Queensland) season had a relatively dry start so the crop established before the weeds.

Benefits

Key benefit #1

Crops with dense canopies act as more effective break crops

Research (Simpfendorfer *et al* 2006) has shown that break crops such as canola and mustard, which have dense canopies, are more effective for crown rot management than chickpeas, which grow slowly (Figure A1.1, below). The canopy development of mustard is the fastest (Figure A1.2, page 59), while chickpeas do not reach full canopy closure until much later in the season. The denser canopy enhances microbial decomposition of cereal residues which harbours the crown rot fungus.

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).

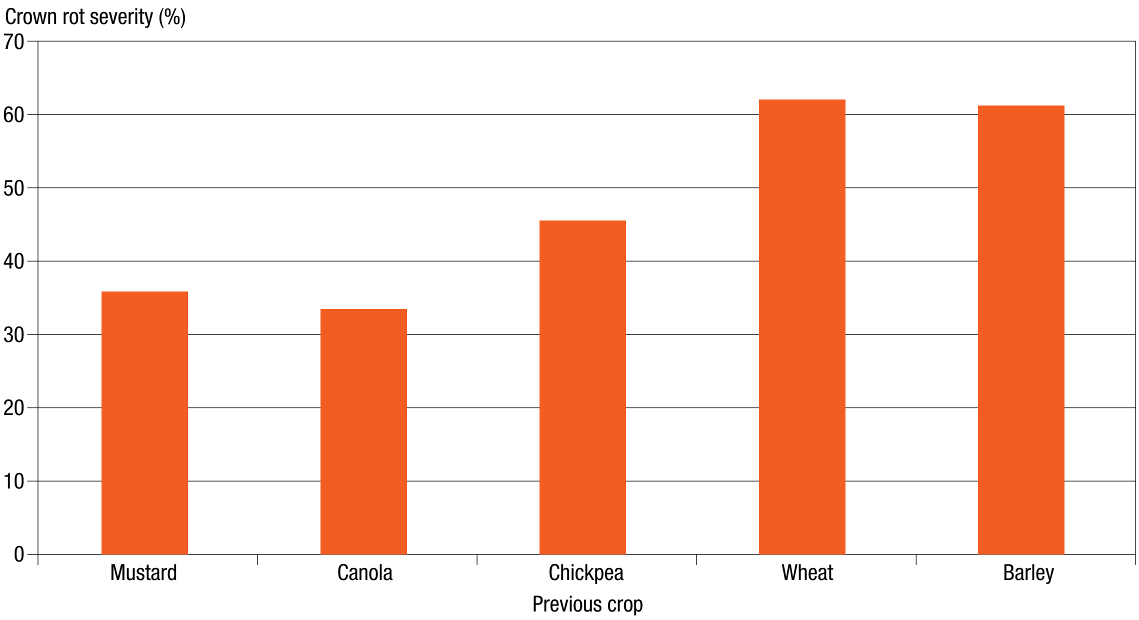


PHOTO: ANDREW STORRIE

A pasture phase gives the opportunity to control difficult weeds such as *Vulpia* with low herbicide resistance risk herbicides, such as simazine.

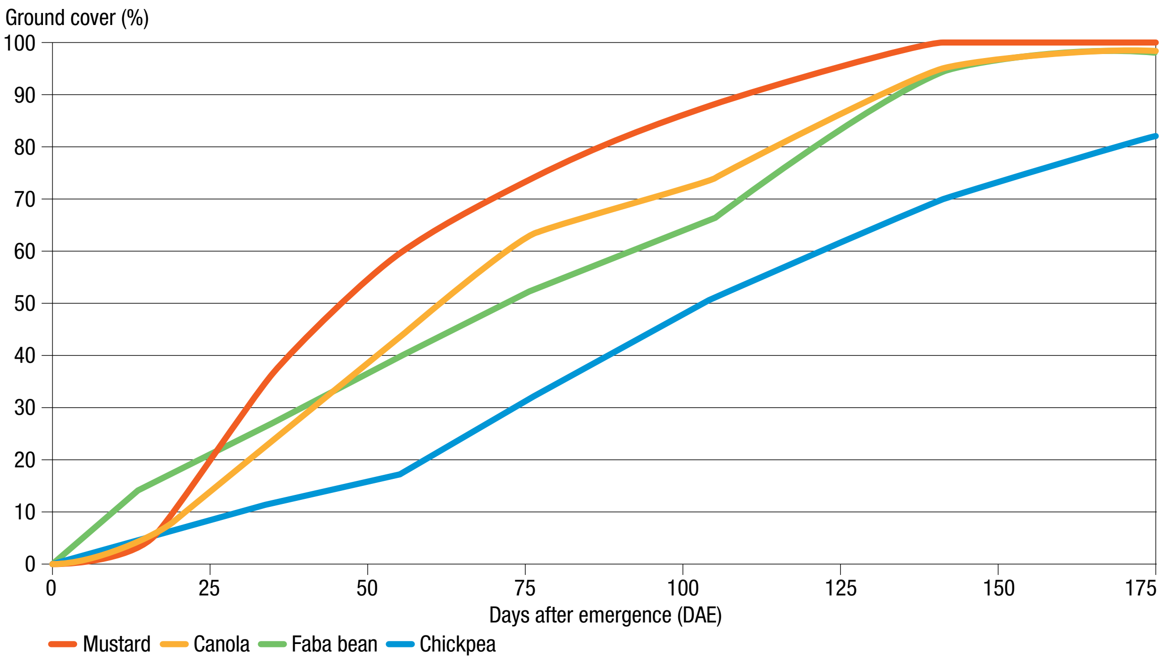
Practicalities

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 nematodes. In southern cropping systems key issues include cereal cyst nematode and the fungal diseases 'take-all' and *Rhizoctonia*.

FIGURE A1.2 Development of ground cover through the 2004 season for various break crops (Simpfendorfer *et al* 2006).



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. 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 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. The root lesion nematode *Pratylenchus neglectus* will multiply readily in wild radish (*Raphanus raphanistrum*) and exceptionally well in wild oats. Similarly, barley grass (*Hordeum* spp.) acts as a suitable host for *Pratylenchus 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 strategies 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 contain either no grain or severely shrivelled, lightweight grain which greatly reduces grain yield and quality. The formation of whiteheads is related to moisture stress after 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

Steve Simpfendorfer, Di Holding, Vanessa Stewart and Andrew Storrie

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, crop orientation, sowing rate and sowing depth
- seed size, germination and vigour
- 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.

Crop type

The most competitive crop type will depend on the regional and individual paddock conditions, including soil type and characteristics (e.g. 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 seedset

Crops can be roughly ranked in competitive ability (Table A2.1, below). Oats are the most competitive crop against annual ryegrass (*Lolium rigidum*). 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 annual ryegrass dry matter in barley and oats was half that in wheat and triticale at 450 plants/m^2 (competitive ability ranked oats as greater than barley which in turn was greater than wheat, with triticale last). This reduced annual ryegrass seed production by over 2000 seeds/m^2 (Peltzer 1999).

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 (1 being most competitive and 7 least competitive)	Yield reduction from annual ryegrass (%)
Oats	1	2–14
Cereal 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	7	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 is shown in Table A2.2 (below).

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)
Varieties released before 1950	103
Victorian Department of Agriculture	138
Cargill	148
NSW Department of Primary Industries	151
Durum	259

The wide range in the ability of field pea varieties to either tolerate competition from weeds or to suppress weed growth and seedset is illustrated in Table A2.3 (below). When planning weed management in paddocks with large weed numbers it is important to consider competitive ability as well as yield when choosing a crop and variety.

TABLE A2.3 The relative ability of field pea varieties to suppress weed growth and seedset 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 Muktar	Glenroy Soups Progreta	
Medium	Bohatyr	Alma Dundale Parafield	
High		Jupiter	Morgan

Hybrid varieties of canola provide better competition than triazine tolerant varieties against weeds (Lemerle *et al* 2010). Vigorous biomass production by hybrid varieties suppressed weed biomass and reduced the impact of weeds on grain yield when annual ryegrass was present at 200 plants/m^2 (Figure A2.1, page 63).

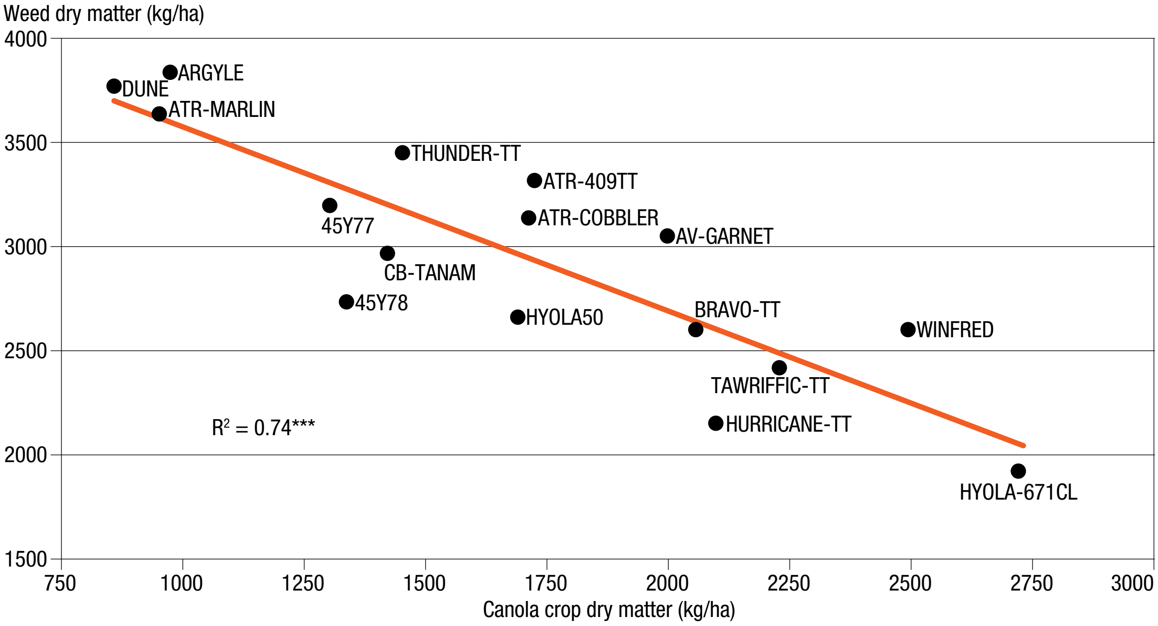
There is significant variation in the ability of different cereal species and cultivars to compete with weeds. In 1935 Pavlychenko and Harrington found that barley was more competitive with weeds than other cereals due to early root development. On the Darling Downs, Queensland, Marley and Robinson (1990) 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, above). 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 ranging from 20 to 40 per cent 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 by environment effects. Only 4 per cent of variability could be attributed to the combined effects of cultivar, weed and environment. Some cultivars exhibited a competitive advantage in some environments, highlighting the need to grow locally suitable cultivars.

FIGURE A2.1 **The impact of the competitive ability of a range of canola varieties on dry matter production of annual ryegrass at Wagga Wagga, New South Wales (Lemerle *et al* 2010).**



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

Sowing rate

The optimum plant density for each crop will differ with growing conditions, time of sowing and economic viability, so seek local advice. In unfavourable conditions (e.g. delayed sowing or poor soil conditions) 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). Increasing crop density can reduce weed biomass, translating into reduced weed seedset and seedbank replenishment (see Table A2.4, page 64) . 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). Research in Queensland by Wu *et al* (2010) has shown high crop densities (8 plants/m^2) of competitive sorghum cultivars reduced weed density, biomass and seed production of a model weed by 22, 27 and 38 per cent respectively, compared to the same cultivars at lower densities (5 plants/m^2).

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 seedset 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 oats 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/m^2 Highest crop yield with wild oats was at 130 crop plants/m^2	At high crop density 100% recommended herbicide rate reduced crop 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 oats 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 seedset 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 wild radish and black bindweed 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 oats tiller numbers	Wheat density relationships with wild oats density Northern New South Wales (Martin *et al* 1987)	Increasing wheat density decreased wild oats 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 oats plants/m^2 reduced wheat yield by 21% Yield was highest at high crop plant densities (200 plants/m^2)	Optimum wheat population in northern NSW is 100 plants/m^2 Weed-free wheat yield declined with increasing crop density
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	Grain size was reduced by 10–15% at high crop density Optimum wheat yield was at higher density in wild oats infested plots (compared to weed-free plots)	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 oats density Southern Queensland (Radford *et al* 1980)	Weed biomass and seed production reduced with increased crop sowing rate, especially at low weed population densities		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 benefitting 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/m^2 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 to 250 plants/m^2, depending largely upon seasonal rainfall. Data from the 2001 to 2004 seasons showed that the probabilities for changes in yield with increasing plant numbers were 9 per cent for a decrease, 36 per cent for no change and 55 per cent for an increase (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, below). Sowing rates presented are seen as the minimum rates needed to avoid yield loss resulting from insufficient plant numbers. Increases of up to 50 per cent on the plant densities and 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).

TABLE A2.5 Estimates of minimum wheat plant population (plants/m^2) based on pre-sowing rainfall (PSR, mm) and growing season rainfall (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
	250	5.10	204	116

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 improve the probability of obtaining 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.

PHOTO: GREG CONDON

Chickpeas growing in wide rows (750 mm) at Nyngan, NSW.

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 uniform crop establishment through more accurate seed and fertiliser measurement and placement. This can result in improved early vigour and, ultimately, increased crop competition. Summer crop (e.g. sorghum and sunflower) row spacing studies in Queensland have shown that as row spacing widened (greater than 1 m) crop yield penalty from uncontrolled weeds actually declined even though weed biomass and weed seed production increased (Osten *et al* 2006).

When making decisions regarding row spacing, consider:

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

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).

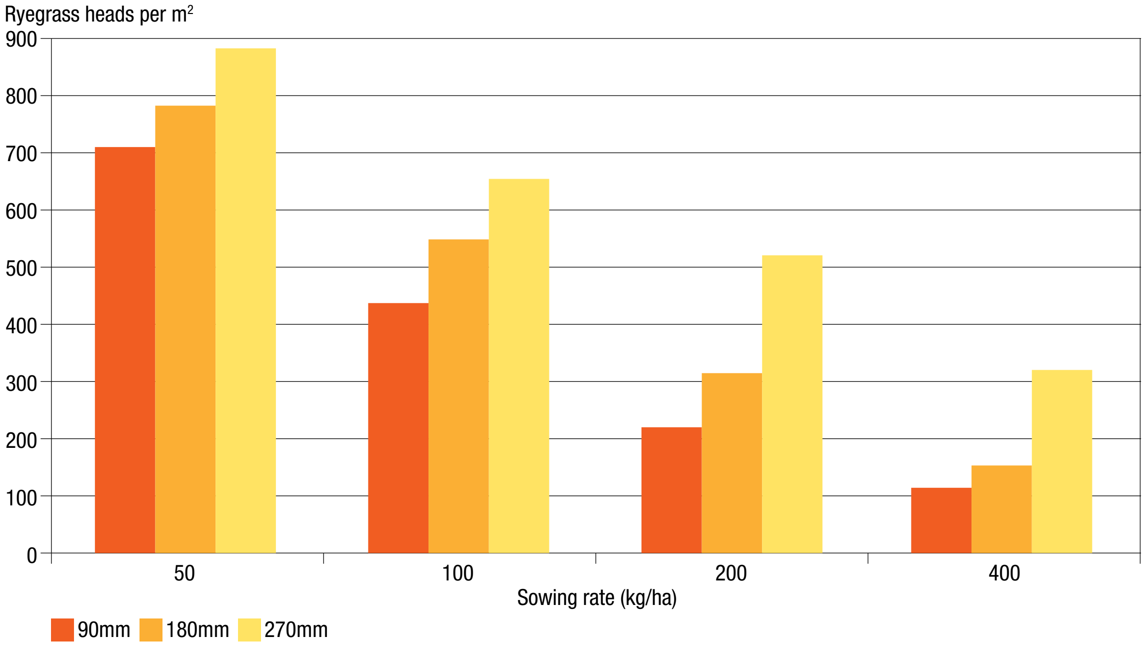
Benefits

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.

FIGURE A2.2 The impact of wheat sowing rate (kg/ha) and row spacing (mm) on annual ryegrass head counts (Minkey *et al* 1999).



A number of recent studies in Western Australia reported improved suppression of annual ryegrass in wheat sown in narrow (18 cm) rows compared with 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 A2.2 (above). Ryegrass numbers reduce with increased sowing rates and narrower row spacing.

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 cm and 64 cm row spacings. Similar results were found in lupins (18 and 36 cm) in Western Australia (Jarvis 1992) and field peas (23 and 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

Row spacing has less effect on wheat yields where grain yields are less than 3.5 t/ha (Martin *et al* 2010) although yield can be limited in seasons of above average rainfall. Although in the lower wheat yielding (2 t/ha) zones of the northern region, the Central Queensland Sustainable Farming Systems project (2002 to 2007) did find 50 cm row spacing to have negative impact on yield, particularly in average to good seasons (Osten pers. comm. 2013). Broadleaf crop yields are less sensitive to row spacing. However, in central Queensland research (Osten *et al* 2006) has shown sunflower yields reduce as row spacing widens. In presence of weeds, yield reduced by 35 and 44 per cent when moving from 0.75 m rows out to 1 and 1.5 m rows respectively.

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 biomass increased 38 per cent with the wider spacing, leading to more weed seeds at harvest and grain quality problems.

A study in southern Queensland compared wheat and barley sown in 25 and 50 cm rows with crop ability to compete with sowthistle (*Sonchus oleraceus*). The barley out-competed 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 may be a necessary capital expense.

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 it 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 shallow 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, and to sow deeper and incorporate the herbicide by sowing in order to minimise damage.

Sowing too shallow 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.

The yield reduction in a 'medium maturity' wheat from delayed sowing is shown in Figure A2.3 (below), while Figure A2.4 (below) shows that delaying the sowing time of chickpeas causes a smaller reduction in yield. This effect will be more pronounced in regions with shorter growing seasons.

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.

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 seedset

Time of sowing has a major 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.

Delayed 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.

FIGURE A2.3 Predicted effect of sowing date on yield of a 'medium maturity' wheat cultivar at Tamworth, New South Wales (Cox *et al* 2012).

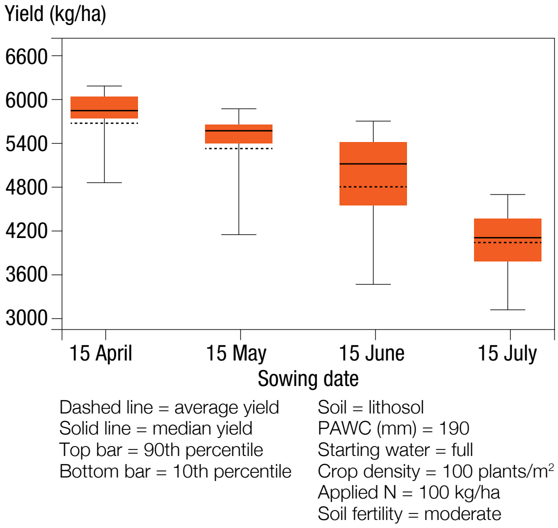
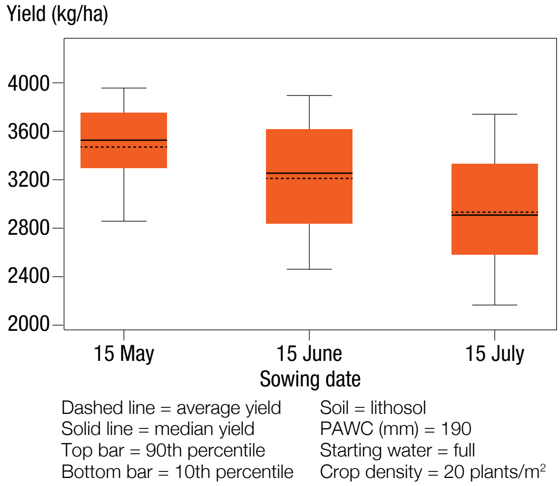


FIGURE A2.4 Predicted effect of sowing date on yield of chickpeas at Tamworth, New South Wales (Cox *et al* 2012).



The yield reduction in a ‘medium maturity’ wheat from delayed sowing is shown in Figure A2.3, while Figure A2.4 shows that delaying the sowing time of chickpeas causes a smaller reduction in yield. This effect will be more pronounced in regions with shorter growing seasons.

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.

Crop row orientation

The competitive ability of cereal crops can be increased by orientating crop rows at a right angle to the direction of sunlight, that is, sow crops in an east-west direction. East-west crops more effectively shade weeds in the inter-row space than north-south sown crops. The shaded weeds have reduced biomass production and reduced seedset.

Altering the orientation of a broadleaf crop has less impact on weed growth. This is because broadleaf plants will alter the angle of their leaves over the course of the day to ‘track’ the sun as it moves across the sky. Therefore, as the leaves of the broadleaf crop move to catch the most sunlight, they cast less shade over the inter-row space. Broadleaf crops are also slow to reach maximum canopy and therefore maximum light interception until late in the season allowing weeds to germinate and grow.

Changing crop row orientation should be used as a part of an integrated weed management program and not seen as a ‘stand-alone’ tactic.

Benefits

Key benefit #1

Choosing an east-west orientation for cereal crops suppresses weed growth and may increase crop yield

In paddocks with a high weed burden, crop orientation can have a significant impact on crop and weed growth. Trials at Merredin and Beverley, Western Australia (2002 to 2005) indicated that weed biomass was reduced by 51 per cent in wheat crops and 37 per cent in barley crops, when crops were sown in an east-west rather than north-south orientation. Grain yield increased by 25 per cent in wheat and 17 per cent in barley crops (Borger *et al* 2010).

When the weed burden is low, the impact of crop orientation on grain yield and weed biomass may not be apparent. In 2010 and 2011, trials at Merredin, Katanning and Wongan Hills, Western Australia (Table A2.6, page 71), annual ryegrass in east-west sown wheat and barley crops produced an average of 3000 seeds/m^2, compared to 5700 seeds/m^2 produced by annual ryegrass plants in north-south crops (C. Borger unpublished, 2013).

PHOTOS: CATHERINE BORGER

An east-west orientated wheat crop (left) will shade weeds in the inter-row space to a greater degree than a north-south orientated crop (right).

TABLE A2.6 Annual ryegrass seed production in east-west and north-south orientated crops, at six trials in Western Australia. Seed production was reduced in east-west crops in five out of six trial sites (Borger unpublished 2013).

Year	Location	East-west orientation (ARG seeds/m^2)	North-south orientation (ARG seeds/m^2)	LSD	P value
2010	Merredin	557	826	331	0.008
	Wongan Hills	24	300	36	0.038
	Katanning	529	465	131	0.967
2011	Merredin	27	125	35	0.048
	Wongan Hills	2610	6155	3469	0.047
	Katanning	14,113	26,276	1342	0.033

Practicalities

Key practicality #1

It is important to consider the weed species in the field

Broadleaf weeds can alter the angle of their leaves to 'track' the sun throughout the day. Therefore, while a cereal crop can shade broadleaf weeds, the weeds will still move their leaves to get the maximum benefit from any sunlight reaching them through the crop canopy. As a result, crops sown in an east-west orientation are less successful in suppressing the growth of broadleaf weeds compared with grass weeds. Further, any weed species that grow taller than the crop will also not be shaded.

Key practicality #2

It is important to consider the layout and latitude (location) of the paddock to be sown

It may not be possible to sow crops in an east-west direction in all paddocks, depending on the layout of individual fields.

The latitude of the farm will also influence the efficiency of weed suppression due to crop orientation. Sun angle in winter (i.e. how high the sun is above the horizon) is greatest at the equator (where the sun is close to being directly overhead at midday). Sun angle decreases as you move towards the poles. A low sun angle will cause an east-west crop to cast shade on the inter-row space for a greater proportion of the day. Therefore, crop orientation will have a greater impact on farms in southern Australia, compared to northern Australia.

Key practicality #3

Using an east-west crop orientation may be more practical with autosteer

If crops are sown in an east-west orientation, it is necessary to drive almost directly into the sun at sunrise and sunset during seeding, harvest and crop spraying. This will be unpleasant for the tractor driver and increases the risk of accidents; however, this is less of a problem when using autosteer.

Whole-farm considerations

Increased shading by an east-west crop reduces the soil surface temperature in the inter-row space and reduces evaporation, leading to increased surface soil moisture. This cool, moist environment in the inter-row space may increase the development of crop disease in some locations, although this was not observed in these trials (Borger *et al* 2010).

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, decreasing plant biomass and competitiveness.

For example, on very acidic soils (pH less than 4.5) grow narrow-leafed lupins, triticale or acid tolerant wheat as these are more suited to such soils than other crops. On heavy textured 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, presswheel pressure may need to be increased as the soil dries.

Improving soil constraints to plant growth (e.g. acidity, salinity, sodicity, boron toxicity) can dramatically improve crop growth. On an acidic soil in southern NSW the use of lime to ameliorate soil acidity resulted in suppressed weed growth and improved crop yields (Li and Conyers 2004). The period over which benefits will be returned depends on the amount of lime applied. Gazey and Andrew (2010) reported increased cereal yields at Kellerberrin in the Avon River Basin in Western Australia up to 17 years after lime was applied at 2.5 t/ha or more. The optimum rate of 5 t/ha of lime for the tenesol soil could be applied in a single operation, or through several applications over a number of years.

Fertiliser use and placement

Benefits

Key benefit #1

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

Macronutrients including nitrogen (N), phosphorus (P), potassium (K), sulphur (S), calcium (Ca) and magnesium (Mg) are most important for plant growth. Ensure that these nutrients are in good supply before considering micronutrients such as copper (Cu), zinc (Zn), manganese (Mn), iron (Fe), molybdenum (Mo), boron (B) and chlorine (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 Western Australia and 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 N is banded below, to avoid toxicity. The banding depth will also affect both soil disturbance (see *Row spacing*, page 66) and depth control (see *Sowing depth*, page 68).

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 with broadcasting N at sowing (Table A2.7, page 73). 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 content 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 A2.7 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

Disease and insect pest management

One of the key strategies for managing diseases and insect pests is enterprise sequencing (see *Crop sequencing to minimise soil- and stubble-borne disease and nematodes*, page 54). 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 is also carried between seasons on crop residues. These include all rust diseases as the rusts require a living host on which to survive. Removal of their 'green bridge' over summer by killing weeds in fallow dramatically reduces inoculum levels.

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 (e.g. take-all, crown rot, *Rhizoctonia*, stripe rust) and insect damage (e.g. *Helicoverpa*, 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*.

As 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 and wiper technologies*, section 4, page 156; *Tactic 3.3 Silage and hay – crops and pastures*, section 4, page 190; and *Tactic 3.4 Manuring, mulching and hay freezing*, section 4, page 195).

Contributors

Di Holding, Andrew Storrie, Deirdre Lemerle and David Gregor.

AGRONOMY 3: HERBICIDE TOLERANT (HT) CROPS

Herbicide tolerance and other genetic traits such as disease resistance are introduced into crops in two ways: either by conventional breeding methods or by genetic modification, which is the introduction of genes from another organism.

Crops with traits of herbicide tolerance bred using conventional methods have been used in Australia for some years. For example, triazine tolerant (TT) canola was first used in commercial production in 1994 and imidazolinone tolerant (IT) wheat was introduced in 2001. Genetically modified (GM) herbicide tolerant (HT) cotton has been commercially grown in Australia since 2000, while Roundup Ready® canola was first commercialised in some states in 2008.

HT crops are tolerant to a herbicide that would normally cause severe damage. One example is the Group B imidazolinone herbicide used in Clearfield® canola cultivars where these crops have been conventionally selected and bred for tolerance to this herbicide. Roundup Ready® (RR) is the name given to cultivars that have been bred using GM technology which include a gene endowing the cultivar with tolerance of the herbicide glyphosate. Cultivars without these traits would be killed or severely damaged.

HT crops can offer weed control tactics from different herbicide mode-of-action (MOA) groups than would normally be used in these crops. Growing HT crops can simplify weed control practices and in some instances lead to lower herbicide use.

With the ease and high levels of weed kill often experienced with glyphosate use in RR crops, the frequency of use of other control tactics has declined. Diversity in weed management tactics has decreased and selection pressure for the development of resistance to glyphosate has increased. In an attempt to offset this, many of the stewardship packages associated with HT technologies require the use of alternative technologies in situations where weed density or the risk of resistance to a particular herbicide are high.

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.

Benefits

Key benefit #1

Herbicide tolerant crops provide additional crop choice, enabling use of alternative 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 other weed management tactics, can ensure good control of otherwise hard-to-control weeds and avoid blow-outs in the seedbank. For example, TT canola has been used as an effective break crop in paddocks infested with wild radish (*Raphanus raphanistrum*), whereas conventional canola has fewer viable control options for this weed.

Key benefit #2

Herbicide tolerant crops can be grown where herbicide residues may be present in the soil from a previous crop

A crop that is tolerant to a herbicide can potentially be grown if the herbicide in question is a residual that was used in the previous crop, while a crop that is not tolerant to that herbicide would be severely damaged. For example Clearfield® canola can often be grown following a cereal crop treated with a Group B herbicide even if herbicide residues are suspected. This can happen when insufficient rain falls between spraying and subsequent planting time.

Key benefit #3

Herbicide tolerant crops can reduce the total amount of herbicide used and weed control costs

Prior to RR cotton there was far greater use of one or more pre-emergent herbicides, inter-row tillage and in-crop selective herbicides while large teams of cotton chippers were a relatively common site, chipping out weed escapes in the crop.

A similar situation exists in RR canola where the easy weed control afforded by the ability to use glyphosate in the crop has replaced a number of other weed management tactics. In RR crops there is a tendency for less use of pre-emergent herbicide, fewer other in-crop herbicides and, as there are often fewer weeds, less emphasis on 'at harvest' weed seed capture and subsequent management.

Practicalities

When using HT crops in an integrated weed management 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:

- PRAMOG® (Paddock Risk Assessment Management Option Guide) used with Roundup Ready® Canola www.monsanto.com/global/au/products/pages/pramog.aspx)
- Clearfield® Stewardship Program (www.agro.basf.com.au/crop-solutions/broadacre/clearfield)
- Triazine Tolerant (TT) Canola Program
- Liberty Link® Stewardship.

Key practicality #1

Always use HT crops as part of an integrated weed management program

An HT crop should represent just one part of an integrated weed management program. A range of weed management tactics from a mix of tactic groups, including non-herbicide measures and herbicides from alternative groups, 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.

Basic guidelines include:

- Farm history and forward planning for herbicide and crop rotations should be compiled and developed to account for the level of existing paddock risk and allow or plan for use of alternative or multiple MOA herbicides.
- If weeds are suspected of being herbicide resistant, reconsider what options are planned and test prior to growing an HT crop to ensure effectiveness of the herbicides applied.
- Integrated weed management should be planned and practiced 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 MOAs 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 integrated weed management 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 residual herbicide such as trifluralin (Group D), Sakura® (Group K) or Boxer Gold® (Groups J and K) used at sowing to target annual ryegrass (*Lolium rigidum*) will reduce the selection pressure placed on the ryegrass population to the Group B herbicide. This is essential 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 from a particular MOA group that can be applied within specified time intervals. Herbicide resistance management guidelines for Australia for MOA groups can be downloaded from the CropLife Australia Ltd website (www.croplifeaustralia.org.au).

Key practicality #3

Use technologies and weed management strategies that are appropriate to the weed spectrum and pressure

- RR technology as at 2013 requires application at or prior to the sixth true leaf of the crop. Weeds emerging after this time will either escape treatment or need to be controlled with other herbicides or control measures. In situations of high weed pressure, as has occurred with wild radish and annual ryegrass, the results have seen significant weed seed blow-outs in RR crops. In situations where there is a high weed burden, reliance on glyphosate alone also places a high selection pressure for resistance to glyphosate. Using a pre-emergent herbicide at planting that provides season-long suppression or control of weeds is recommended.
- Liberty Link® cotton cultivars have recently been commercialised in Australia. The herbicide used in Liberty Link cultivars is Basta® (glufosinate), a Group N herbicide. As with RR cotton cultivars, a risk assessment and field audit must be completed for each paddock that includes a weed control program, rotation plan and intended herbicides before cultivars can be grown. An example of a weed management strategy for a light infestation of broadleaf weeds could be:
  - to use glyphosate as the pre-sowing knockdown
  - to use glufosinate in-crop
  - to use inter-row tillage to clean up survivors
  - to use 'lay-by' selective herbicides (band sprayed post-crop-emergence) as needed.
- In a situation of heavier infestation of broadleaf weeds, all the above would be used but with the weed control base broadened by the addition of a pre-emergent herbicide at sowing.

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 and some herbicides have specific requirements for application.

Key practicality #5

Good paddock management records must be kept, referred to and be accessible whenever required

Mistakes are costly if a herbicide is applied to the wrong crop, and easily accessible records will provide valuable information in relation to which weeds and paddocks are more at risk of developing herbicide resistance. Such knowledge can be valuable when determining the intensity of post-spray scouting practices.

To avoid mistakes:

- use paddock signage for easy identification of paddocks sown to HT crops in both the crop year grown and in 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) to other crops

a. Canola

Out-crossing (hybridisation) can occur with several related species and with other cultivars of canola. In western Canada genes from HT canola have been found to be widespread in conventional canola spread across the landscape from canola volunteers (van Acker *et al* 2003). This has occurred despite frequency of cross-pollination being low as pollen viability is short-lived and decreases with distance from the pollen source. There is also significant competition between selfed and foreign pollen in fertile plants.

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 are in high density in the near vicinity, the risk of hybridisation between crop and weed is higher. Two important weeds, wild radish and Buchan weed (*Hirschfeldia incana*), are known to cross-pollinate at a low frequency with canola (Ellstrand *et al* 1999).

Where Group B and/or Group I herbicide resistant wild radish is a significant weed, RR canola cultivars may provide a useful alternate method of control. However, due to the proximity with a close weedy relative, the chance of hybrids arising is increased. In July 2005 a hybrid between GM canola and charlock (*Sinapis arvensis*) was discovered in the United Kingdom (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 cultivars, while the tolerance genes for imidazolinone and glyphosate tolerance are transferred in the pollen. In all 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 wild 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 (e.g. along fence lines) particularly before flowering.
- Ensure equipment and machinery is cleaned between each canola crop sown, harvested or transported.
- Avoid growing HT canola in paddocks adjacent to conventional canola cultivars.
- Seal bins and cover loads during harvest and transport.

b. Wheat

Wheat as a weed 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 10 per cent (Van Acker *et al* 2003) there are no known wild or established weedy populations of *Triticum* or closely related species such as goat grass (*Aegilops* spp.) in Australia.

To minimise the spread of HT wheat and the contamination of conventional wheat:
- Control all crop volunteers in the fallow and following crop.
- Do not follow the HT wheat with another wheat crop.
- Ensure good weed control around fence lines while the HT crop is being grown and in the following fallow and season.
- Do not grow HT wheat next to crops of conventional wheat.
- Cover loads during transport.

The creation of 'super weeds'?

- There has been some public concern regarding the threat of 'super weeds' (i.e. weeds resulting from out-crossing with HT crop cultivars). Identification of hybridisation between canola and charlock in the United Kingdom (Brown 2005) caused some alarm among 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), 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 quantities to pollinate other canola plants. A review by Rieger *et al* (1999) showed that while low levels of hybridisation between canola as the pollen donor and charlock and wild radish was possible, 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 (i.e. not receiving the genetic material from the pollen).

Contributors

John Cameron and Andrew Storrie

Further information

Office of the Gene Technology Regulator (OGTR), www.ogtr.gov.au

CropLife Australia, www.croplifeaustralia.org.au

Canola Council of Canada, www.canola-council.org

Seed and technology companies

Monsanto Australia, www.monsanto.com.au

Cargill Australia, www.cargill.com.au

Nuseed Australia, www.nuseed.com.au

Pacific Seeds, www.pacificseeds.com

Pioneer, www.australia.pioneer.com

Bayer Cropscience Australia, www.bayercropscience.com.au

AGRONOMY 4: IMPROVING PASTURE COMPETITION

Pastures represent an important component of many rotations and can range from one to five years' duration to break up extended periods of cropping. Incorporating pastures can help restore soil fertility (i.e. 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 (see *Tactic 3.5 Grazing – actively managing weeds in pastures*, section 4, page 202), mechanical manipulation and non-selective herbicides.

Benefits

Key benefit #1

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

Where desirable species dominate pasture by greater than 80 per cent, 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 which enable desirable species to increase in size, favour root development and competitive ability, and allow for seedset and subsequent seedling recruitment.

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 prior to or 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 (below).

For perennial pastures maintain herbage above 1500 kg DM/ha with greater than 80 per cent ground cover to reduce the germination of annual grass weeds. Apply fertiliser (and lime where soil pH is less than 5.5) 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 (Revell unpublished).

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
Subclover cv Dalkeith	177	188	3.6	11
Burr medic cv Santiago	253	689	3.8	17
Biserrula cv Casbah	602	756	6.7	3

Whole-farm benefits

Whole-farm benefits include:
- 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 (e.g. 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 by re-sowing desirable species will improve pastures that are severely degraded. Optimise this operation by implementing weed control prior to sowing (e.g. spray-topping, use of knockdown herbicides, cultivation).

In a pasture–crop rotation, if the pasture density declines to a level where weeds invade (e.g. 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 (e.g. drought, cropping)

Species mixtures can improve the resilience of pastures by providing a range of seed characteristics and/or pest and disease tolerance. Typical mixtures include annual grasses and legumes. Inclusion of perennial grasses and legumes should be considered in high rainfall (long growing season) environments.

Whole-farm considerations

- Ensure that appropriate grazing management (deferred and rotational grazing) is used.
- Devise strategies and paddock plans for pasture re-establishment (preferably one to two years in advance).
- Ensure that pasture legumes are inoculated with their correct rhizobium.

Contributors

Alex Douglas and Clinton Revell

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 water and nitrogen for the next crop and reduce the weed seedbank. The term 'fallow' has different meanings in different parts of Australia.

There are several broad categories:

1. When growing a winter-winter crop rotation, the period between the harvest of one crop and sowing of the next crop represents the shortest fallow period. This is typically about four 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, improved moisture accumulation and better sowing conditions through the killing of vine-forming weeds such as melons (*Citrullus* spp. and *Cucumis* spp.) and wireweed (*Polygonum* spp.).
2. In a winter rainfall (southern) pasture–crop sequence the period between killing the pasture (this is usually August to September but it can be earlier) and sowing the first crop would be thought of as a long fallow and would have a duration of about eight months. Because such fallows should commence well before weed seed maturity, they are an ideal opportunity for weed seedbank management.
3. In northern areas of New South Wales and southern Queensland where rain-fed summer crops can be grown, fallow periods exist between winter cereal harvest and the sowing of a summer crop (e.g. 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 to June), a period of around 14 months.
4. 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 to 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 valuable management opportunity for winter-growing weeds. Similarly, the summer season offers weed management options for summer-growing annual weeds. However, this type of fallow opens the system to high erosion risk, particularly if stubble covers are low.
5. In northern cropping zones, opportunity cropping is when a crop can be sown at any time there is sufficient stored soil water for this to occur. This can lead to some very short fallow periods in seasons when there is an abundance of rainfall.

All of these fallows present opportunities to manage late spring and summer emerging weeds. Summer crops sown in January to February are harvested in June or July. If no spring cropping opportunities occur, this country is either fallowed for six to seven months through to the following December to February for back-to-back summer crops, or fallowed for nine to 10 months to April or May for a winter crop. In these fallow situations, the first scenario targets late winter, spring and summer weeds for management, while the latter scenario targets the same but also includes autumn emerging 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 used to suppress weeds.

Note: Glyphosate is the main tool for managing no-till or minimum-till fallows in both systems. Resistance in annual ryegrass (*Lolium rigidum*) has become an increasingly common problem in all cropping systems. In northern cropping systems the species that have evolved resistance to glyphosate in fallows include awnless barnyard grass (*Echinochloa colona*), liverseed grass (*Urochloa panicioides*), windmill grass (*Chloris truncata*), sowthistle (*Sochus oleraceus*) and flaxleaf fleabane (*Conyza bonariensis*). Feathertop Rhodes grass (*Chloris virgata*) has become a major problem in no-till or minimum-till farming systems since 2006 as it is difficult to control with glyphosate. See *Section 6 Profiles of common weeds of cropping* (page 249) for more information on individual species.

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 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

A double knock of glyphosate followed three to 10 days later with paraquat (depending on the situation) gives high levels of weed control and controls a range of hard-to-kill or glyphosate resistant survivors

Use of a double knock in fallow greatly reduces the risk of the development of resistance to glyphosate and can be used to drive down seedbanks of glyphosate resistant weeds. See *Tactic 2.2b Double knockdown or 'double knock'* (section 4, page 128) for more information.

Key benefit #4

Under carefully planned conditions it is possible to use other herbicide MOA groups (Groups C, B, I or K) in fallow

Great care is needed to reduce the possibility of herbicide carryover and the evolution of weeds resistant to these other MOA groups. Research since 2007 in northern grain region fallows has shown that the addition of a residual herbicide to a single fallow herbicide application, or to the second knock herbicide application, is a reliable method to get close to 100 per cent control of annual weeds. A major problem that occurs, particularly with summer fallow, is that rain following some key application of knockdown herbicide stimulates another cohort of weeds to germinate and emerge. Also weeds might have already germinated but not emerged before the knockdown herbicide was applied. The addition of a herbicide with soil residual activity helps control weeds not yet emerged.

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 water conservation in-fallow is regarded as essential for reliable crop production.
- **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 to 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 (*Convolvulus arvensis*) and silver-leaf nightshade (*Solanum elaeagnifolium*).

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, as application to small weeds gives the most reliable control.

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, which has huge logistical advantages for the grower. 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 of weeds under these conditions is common.

Whole-farm considerations

During the fallow, moisture accumulation can lead to deep drainage into groundwater and increased salinisation of the landscape. Using opportunity cropping when the soil profile is full reduces the risk of deep drainage; however, weed and disease management issues must be taken into account.

Contributors

Steve Sutherland and Andrew Storrie

AGRONOMY 6: CONTROLLED TRAFFIC FARMING OR TRAMLINING FOR OPTIMAL HERBICIDE APPLICATION

Controlled traffic farming (CTF) refers to a cropping system designed to limit soil compaction damage by confining all wheel traffic to permanent lanes for all field operations, including seeding, harvesting and spraying activities.

Soil compaction between the tramlines is greatly reduced, resulting in increased health of the crop. This form of precision agriculture results in several potential benefits for weed management, namely:

- more efficient use of pesticide application due to reduced overlaps
- greater ability to access the field if soil is wet for timely spray application
- the ability to treat weeds in the inter-row more easily
- additional options for management of weed seeds at harvest.

Benefits

Key benefit #1

Accurately spaced tramlines provide guidance and a firmer pathway for more timely and accurate application of herbicide, which in turn improves weed control and reduces input costs

Accurate tramlines or controlled traffic lanes clearly reduce the problems of overlap or underlap, and are generally credited with reducing overall input costs by about 10 per cent (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 potential for new physical and chemical weed management options

In wide-row CTF systems, options to use inter-row shielded and band spraying are increased; however, registrations for products that can be applied in this manner are limited. High precision guidance systems also improve the potential for effective inter-row cultivation, with precision placement relative to the crop row minimising the level of damage to 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*, section 4, page 146) sometimes followed by manual chipping (see *Tactic 2.4 Spot spraying,*

PHOTO: WARWICK HOLDING

Wheat sown using controlled traffic on wide row spacing at the Darling Downs, Queensland. Controlled traffic cropping allows more options for weed control and management.

PHOTO: WARWICK HOLDING

Controlled traffic allows accurate inter-row sowing.

chipping, hand roguing and wiper technologies, section 4, page 156). By using precision guidance a more effective control is possible to within 2 to 3 cm of the plant row; however, some root pruning and crop damage is unavoidable.

Weed seeds caught at harvest can be placed on the permanent wheel track and controlled by higher rates of herbicides (but not exceeding label rates) applied just on the wheel track. While continuous compaction by machinery will not control all weeds in wheel track areas, it will kill some and does create a poor environment for weed establishment (see *Tactic 4.1 Weed seed control at harvest*, section 4, page 212).

Key benefit #3

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

Reduced compaction results in better infiltration of rainfall and better soil structure. This increases the level of plant available water in the soil profile.

Compacted traffic zones are often more trafficable in wet conditions. A proportion of planting delays caused by wet soil is eliminated, with a timely sowing date contributing to improved crop growth and competition with weeds.

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 and fuel requirements are significantly reduced and zero tillage is facilitated.

Practicalities

Key practicality #1

Tramlines can be installed relatively cheaply, with immediate economic benefits gained from more accurate field operations with less overlap

Tramlines can be installed using marker arms or manual lay-out, but they are increasingly being carried out using 2 cm real time kinematic (RTK) global positioning system (GPS) guidance.

Key practicality #2

Tramlines may be moved to minimise erosion and prevent concentration of nutrients, but future machinery may be capable of spreading residue evenly for even nutrient distribution

The even spreading of stubble when harvesting with wider header fronts is an issue with CTF. One suggestion is to have ‘temporary’ tramlines between normal tramlines that are only used in high residue years when there is a dry harvest, to even up nutrient distribution. Conducting this practice only during dry harvests reduces the effects of compaction by the header wheels.

Researchers are also investigating new harvesting machinery that will move the swath rather than moving the header, to avoid the concentration of nutrients between the wheel tacks.

Contributors

Jeff Tullberg and Nicholas Bromet.

REFERENCES

Anderson, W.K. and Barclay, J. (1991). Evidence for differences between three wheat cultivars in yield response to plant population. *Australian Journal of Agricultural Research* 42: 701–713.

Anderson, W.K., Sharma, D.L., Shackley, B.J. and D'Antuono, M.F. (2004). Rainfall, sowing time, soil type, and cultivar influence optimum plant population for wheat in Western Australia. *Australian Journal of Agricultural Research* 55: 921–930.

Bellotti, W.D. and Moore, A.D. (1993). Management for pasture establishment. *Pasture Management Technology for the 21st Century*. CSIRO, Melbourne, Australia, pp. 26–37.

Birchip Cropping Group. (1998). Competitive crops. www.bcg.org.au/members/va/media/BCG/Competitive_crops.pdf

Borger, C. P. D., Hashem, A., and Pathan, S. (2010). Manipulating crop row orientation to suppress weeds and increase crop yield. *Weed Science* 58: 174–178.

Brown, P. (2005). GM crops created superweed, say scientists. *Guardian Unlimited*. www.guardian.co.uk/

Burton, J. and Dowling, P. (2004). *Pasture management for weed control – a grazier's guide to controlling annual weeds in southern improved pastures*. NSW Agriculture and the Cooperative Research Centre for Australian Weed Management, Adelaide.

Cousens, R.D. and Mokhtari, S. (1998). Seasonal and site variability in the tolerance of wheat cultivars to interference from *Lolium rigidum*. *Weed Research* 38: 301–307.

Cox, H.L, Hammer, G.L., Mclean, G.B., Cowbrick, T.H. and King, C.A. (2012). 'WhopperCropper' (software). Queensland Department of Agriculture, Fisheries and Forestry.

Egan, J. and Bunder, R. (1993). Fertilizer strategies for lupins. South Australian Field Crop Evaluation Program, annual report, 1993, pp. 104–105. Primary Industries and Resources South Australia, Adelaide.

Ellstrand, N.C., Prentice, H.C. and Hancock, J.F. (1999). Gene flow and introgression from domesticated plants into their wild relatives. *Annual Review of Ecology and Systematics* 30: 539–563.

Gazey, C., and Andrew, J. (2010). Long-term effect of lime application on soil pH, crop yields and annual ryegrass competition. *Agribusiness Crop Updates 2010*, pp. 229–233. Department of Agriculture and Food WA and Grains Research and Development Corporation, Perth, Australia.

Godel, G.L. (1935). Relation between rate of seeding and yield of cereal crops in competition with weeds. *Science Agriculture* 16: 165–168.

Gregor, D., Lemerle, D., Chan, K.Y. and Tullberg, J. (2004). Preliminary development and testing of a novel opener for weed inhibition in conservation cropping. *GRDC Research Update Southern Region (Irrigation)*. Grains Research and Development Corporation.

Jarvis, R.J. (1992). *Lupin row spacing*. Western Australian Department of Agriculture Technote no. 2/92.

Jarvis, R.J. and Bolland, M.D.A. (1990). Placing superphosphate at different depths in the soil changes its effectiveness for wheat and lupin production. *Fertiliser Research* 22: 97–107.

Kirkegaard, J.A., Simpfendorfer, S., Holland, J., Bambach, R., Moore, K.J. and Rebetzke, G.J. (2004). Effect of previous crops on crown rot and yield of durum and bread wheat in northern NSW. *Australian Journal of Agricultural Research* 55: 321–334.

Koetz, E., Lemerle, D., Good, T. and Sutherland, S. (2002). Strategic nitrogen application for weed suppression in wheat. *Proceedings of the 13th Australian Weeds Conference*, *Perth*, pp. 67–70.

Lemerle, D., Cousens, R.D., Gill, G.S., Peltzer, S.J., Moerkerk, M., Murphy, C.E., Collins, D. and Cullis, B.R. (2004). Reliability of higher seeding rates of wheat for increased competitiveness with weeds in low rainfall environments. *Journal of Agricultural Science* 142: 395–409.

Lemerle, D., Sutherland, S., Koetz, E. and Smith, A. (2002). Suppressing weeds in conservation farming. *Proceedings of the 13th Australian Weeds Conference, Perth*, pp. 705–708.

Lemerle, D., Verbeek, B. and Coombes, N.E. (1995). Losses in grain yield of winter crops from *Lolium rigidum* competition depends on species, cultivar and season. *Weed Research* 35: 503–509.

Lemerle, D., Verbeek, B., Cousins, R.D. and Coombes, N.E. (1996). The potential for selecting wheat varieties strongly competitive against weeds. *Weed Research* 36: 503–513.

Lemerle, D., Verbeek, B. and Orchard, B. (2001). Ranking the ability of wheat varieties to compete with *Lolium rigidum*. *Weed Research* 41: 197–209.

Lemerle, D., Lockley, P., Luckett, D., and Wu, H. (2010). Canola competition for weed suppression. *17th Australasian Weeds Conference*, New Zealand Plant Protection Society Christchurch, New Zealand. pp. 60-62

Li, G. and Conyers, M.K. (2004). The effect of weeds on wheat grain yield in limed and unlimed soils. *International Crop Science Conference*, Toowoomba, Queensland.

MacDonald, G. (2002). Genotypic differences in competitive ability within peas. Cooperative Research Centre (CRC) for Australian Weed Management Research Project 2.2.2.3: Optimising the competitiveness of winter pulse crops through genetic improvement and agronomy. CRC for Australian Weed Management.

Marley, J.M. and Robinson, G.R. (1990). Strategies for Broadleaf Control in Barley. Final report to Barley Research Committee for Queensland.

Martin, R.J., Cullis, B.R. and McNamara, D.W. (1987). Prediction of wheat yield loss due to competition by wild oats (*Avena* spp.). *Australian Journal of Agricultural Research* 38: 487–499.

Martin, P., Scott, B., Edwards, J., Haskins, B., and Smith, J. (2010). Row spacing in cereal and broadleaf crops. *Mallee Sustainable Farming 2009 Research Compendium*, pp. 147 - 152.

Medd, R.W., Auld, B.A., Kemp, D.R. and Murison, R.D. (1985). The influence of wheat density and spatial arrangement on annual ryegrass *Lolium rigidum* Gaudin competition. *Australian Journal of Agricultural Research* 36: 361–371.

Medway, J. (1995). Objective monitoring – measuring your progress. *Riverina Outlook Conference 1995*.

Minkey, D.M., Bowran, D., Hashem, A. and Reithmuller, G. (1999). Effect of row spacing and seeding rate of wheat on the competitive ability of annual ryegrass in a zero tillage seeding practice. *Proceedings of the Crop Protection Updates 1999*, Western Australian Department of Agriculture, Perth.

Minkey, D., Hashem, A., Reithmuller, G. and Harries, M. (2000). Effect of seeding density, row spacing and trifluralin on the competitive ability of annual ryegrass in a minimum tillage system. *Proceedings of the Crop Updates 2000*. Western Australian Department of Agriculture, Perth.

Minkey, D., Reithmuller, G. and Hashem, A. (2005). Effect of row spacing and seeding rate of wheat on the emergence and competitive ability of annual ryegrass in a no-tillage seeding system. *Proceedings of the GRDC Agribusiness Crop Updates*, Perth.

Motley, K., Roberts, K. and Rice, A. (2005). The effect of sowing rate on the performance of wheat in the Forbes and Parkes districts. *CWFS Research Compendium 2004–2005*, pp. 72–76.

Newman, P. and Weeks, C. (2000). High wheat seeding rates coupled with narrow row spacing increases yield and suppresses grass. *Proceedings of the Crop Updates 2000*, Western Australian Department of Agriculture, Perth.

Osten, V., Wu, H., Walker, S., Wright, G., and Shields, A. (2006). Weeds and summer crop row spacing studies in Queensland. *15th Australian Weeds Conference*, Adelaide, South Australia. pp. 347-350

Pavlychenko, T.K. and Harrington, J.B. (1935). Root development of weeds and crops in competition under dryland farming. *Crop Science* 16: 151–160.

Peltzer, S. (1999). Controlling weed seed production with crop seeding rate. *Proceedings of the Crop Updates*. Department of Agriculture, WA, Perth.

Peverill, K.I., Sparrow, L.A. and Reuter, D.J. (1999). *Soil Analysis: An Interpretation Manual*. CSIRO Publishing, Australia.

Radford, B.J., Wilson, B.J., Cartledge, O. and Watkins, F.B. (1980). Effect of wheat seeding rate on wild oat competition. *Australian Journal of Experimental Agriculture and Animal Husbandry* 20: 77–81.

Rainbow, R. (2005). Managing soil compaction in a no-till system. GRDC research update for growers. www.grdc.com.au/growers/res_upd/south/s05s/ rainbow.htm

Reithmuller, G. (2005). Ryegrass seed set increases with increasing wheat row spacing and stubble retention. *Proceedings of the GRDC Agribusiness Crop Updates*, Perth.

Rieger, M.A., Potter, T.D., Preston, C. and Powles, S.B. (2001). Hybridisation between Brassica napus (L) and Rhaphanus raphanistrum L. under agronomic field conditions. *Theoretical and Applied Genetics* 103: 555–560.

Rieger, M.A., Preston, C. and Powles, S.B. (1999). Risks of gene flow from transgenic herbicide-resistant canola (*Brassica napus*) to weedy relatives in southern Australian cropping systems. *Australian Journal of Agricultural Research* 50: 115–128.

Scott, B.J., Carpenter, D.J., Braysher, B.D., Cullis, B.R. and Evans, C.M. (2003). Phosphorus fertiliser placement for lupins in southern New South Wales. *Australian Journal of Experimental Agriculture* 43: 79–86.

Sharma, D.L. and Anderson, W.K. (2004). Small grain screenings in wheat: interactions of cultivars with season, site, and management practices. *Australian Journal of Agricultural Research* 55: 797–809.

Storrie, A., Cook, T., Medd, R. and Edwards, J. (1998). Selective spray-topping for long term control of wild oats. New South Wales Department of Agriculture Agnote.

Timmons, J.D., O'Brien, E.T., Charters, Y.M., Dubbels, S.J. and Wilkinson, M.J. (1995). Assessing the risk of wind pollination from fields of genetically modified *Brassica napus* ssp. *oleifera*. *Euphytica* 85: 417–423.

Walker, S.J., Medd, R.W., Robinson, G.R. and Cullis, B.R. (2002). Improved management of *Avena ludoviciana* and *Phalaris paradoxa* with more densely sown wheat and less herbicide. *Weed Research* 42: 257–270.

Walker, S.R., Robinson, G.R. and Medd, R.W. (1998). Management of wild oats and paradoxa grass with reduced dependence on herbicides. *Proceedings of the 9th Australian Agronomy Conference*, Wagga Wagga, pp. 572–574.

Watkinson, A.R. and White, J. (1985). Some life-history consequences of modular construction in plants. *Philosophical Transactions of the Royal Society*, London B 313: 31–51.

WhopperCropper®. www.apsru.gov.au/apsru/Products/Whopper/

Whish, J.P.M., Sindel, B.M., Jessop, R.S. and Felton, W.L. (2002). The effect of row spacing and weed density on yield loss of chickpea. *Australian Journal of Agricultural Research* 53: 1335–1340.

Widderick, M.J. (2002). Ecology and management of the weed common sowthistle (*Sonchus oleraceus* L.). PhD thesis, University of New England, Armidale.

Further reading

Row spacing

Scott, B.J., Martin, P, Riethmuller, G.P. (2013). Graham Centre Monograph No. 3: Row spacing of winter crops in broad scale agriculture in southern Australia. Eds T Nugent and C Nicholls. NSW Department of Primary Industries, Orange. Available at: www.grahamcentre.net.

Controlled traffic

GRDC Precision Agriculture links page, http://www.grdc.com.au

Blackwell, P., Davies, S., Riethmuller, G., Bakker, D., Hall, D., Lemon, J., Hagan, J., Isbister, B. and Yokwe, S. (2013). 22 Questions you may ask about controlled traffic in WA. Technical note. Department of Agriculture and Food, Western Australia, North Stirlings–Pallinup Natural Resources and Northern Agricultural Catchments Council.

Webb, B., Blackwell, P., Riethmuller, G. and Lemon, J. (2004). Tramline farming systems. Technical Manual, Department of Agriculture Western Australia, Grains Research and Development Corporation Project DAW 718.