SUMMER FALLOW WEED MANAGEMENT

A REFERENCE MANUAL FOR GRAIN GROWERS AND ADVISERS IN THE SOUTHERN AND WESTERN GRAINS REGIONS OF AUSTRALIA

AUTHORS:
John Cameron (ICAN),
Andrew Storrie (Agronomo)

GRDC Grains Research & Development Corporation
Your GRDC working with you

Title: SUMMER FALLOW WEED MANAGEMENT
A reference manual for grain growers and advisers in the southern and western grains regions of australia

Project Code: ICN00012

Authors: John Cameron (ICAN), Andrew Storrie (Agronomo)

Cover photo: Fallow spraying at Dumbleyung WA

Photographer: Andrew Storrie

In submitting this report, the researchers have agreed to the GRDC publishing this material in its edited form.

ISBN 978-1-921779-62-6
Published April 2014

Acknowledgement: The assistance from James Hunt (Research Scientist, CSIRO Plant Industries) and Colin McMaster (Research & Development Agronomist, New South Wales Department of Primary Industries) in reviewing this document is acknowledged and much appreciated. A number of data sets used in this document on water and nitrogen effects of summer fallow weed management have been developed as a part of the GRDC supported Water Use Efficiency initiative. The GRDC WUE Initiative Ground Cover Supplement (2012) provides a summary of that work.

Enquiries: John Cameron, Independent Consultants Australia Network Pty Limited, PH: (61) (02) 9482 4930 john@icanrural.com.au

This document should be cited as: Cameron, J. and Storrie, A. (eds). (2014). Summer fallow weed management in the southern and western grains regions of Australia – a reference for grain growers and advisers. GRDC publication, Australia

GRDC Contract details:
Ms Maureen Cribb
Publishing Manager
GRDC
PO Box 5367
KINGSTON ACT 2604
PH: 02 6166 4500
Email: maureen.cribb@grdc.com.au
Web: www.grdc.com.au

Copies of this report are available from Ground Cover Direct Free phone: 1800 11 00 44, Email: ground-cover-direct@canprint.com.au
www.grdc.com.au/bookshop

Design and production:
Peter Hoffmann (Lightning Designs)

GRDC Grains Research & Development Corporation
Your GRDC working with you

ICAN Independent Consultants Australia Network

CONTENTS

1 Introduction

Key issues:

In a winter cropping system, the return on investment from managing weeds in summer fallow (ie. the period between crops) is high. Economic benefits flow from both extra amounts of high value water and nitrogen, crop establishment benefits and reduced issues with weed vectored disease and insect pests.

Stopping weed growth in the fallow can lead to yield increases in the following crop via several pathways. These include:

- Increased plant available water
- A wider and more reliable sowing window
- Higher levels of plant available N
- Reduced levels of weed vectored diseases and nematodes
- Reduced levels of rust inoculum via interruption of the green bridge
- Reduced levels of diseases vectored by aphids that build in numbers on summer weeds, and
- Reduced weed physical impacts on crop establishment.

How farming country is managed in the months or years before sowing can be more important in lifting water use efficiency (WUE) than in-crop management. Of particularly high impact are strategies that increase soil capture and storage of fallow rainfall to improve crop reliability and yield.

Practices such as controlled traffic farming and long term no-till seek to change the very nature of soil structure to improve infiltration rates and improve plant access to stored water by removal of compaction zones.

Shorter term management decisions can have an equal or even greater impact on how much plant available water (PAW) is stored at sowing. These include decisions such as crop sequence/rotation that dictate the length of the fallow and amount of stubble cover, how effectively fallow weeds are managed, stubble management and decisions to till/not to till at critical times.

While many factors influence how much plant available water is stored in a fallow period, good weed management consistently has the greatest impact.

PHOTO: Brad Collis

Early control of weeds during fallow periods has become a common practice with successful growers across the country. The science shows that early control of fallow weeds can lead to significant increases in the levels of stored plant available water and increased availability of nutrients (especially nitrogen), with corresponding increases in crop yield and grain quality. For many growers, the main benefits are often expressed in terms of better risk management and income stabilisation.

Herbicides provide more effective control of fallow weeds (no transplants) and maintain stubble cover better than grazing or cultivation. Uncontrolled weeds reduce soil moisture and nitrogen and can also lead to equipment blockages that impede efficient sowing operations. Flow on effects can include downtime, delays to sowing, missed strips and uneven incorporation of pre-emergent herbicides.

Soil water saved by killing fallow weeds is often stored deep in the profile and its value can be very high. It is often the water the crop uses later in a dry season to maintain grain number during the critical period of stem elongation to anthesis. As a result, in the right soil, deep stored soil water can have a water use efficiency of up to 60 kg of grain/mm of stored water.

Factors such as soil type, rainfall pattern and evaporation also influence the percentage of fallow rainfall stored for use by the next crop. Soils with higher clay content in the upper layers retain larger amounts of water near the surface and require larger rainfall events for water to wet them and infiltrate below the evaporation zone (top 30 cm). Isolated rain events of 20 mm or less falling over summer might all be lost to evaporation if insufficient follow-up rainfall occurs to wet the soil deeper than the evaporation zone. Fallow efficiency can range from 0-60%, with figures often closer to 20-30%.

Summer fallow rainfall is of most value to wheat in environments where it makes up a greater proportion of annual rainfall, where fallow efficiencies are high, the soils' plant available water holding capacity (PAWC) is large relative to growing season rainfall (GSR), and GSR is more variable.

In many environments, the contribution of the extra nitrogen made available to the next crop from control of summer weeds, is just as (and sometimes more) important than the contribution from extra water stored. An adequate supply of nitrogen is critical to capture the benefits of high levels of stored soil water and reciprocally, a high water supply is required to capture the benefits of nitrogen fertiliser. Trials in central NSW have illustrated that for every mm of moisture lost via summer weed growth, a further 0.64 kgN/ha was made unavailable to the following crop (McMaster, 2013).

Maintaining a weed-free fallow helps growers to sow on-time and minimise many disease and insect issues. With higher levels of stored soil water at sowing, many growers consider sowing a proportion of their crop earlier than the traditional sowing window if conditions suit. Maintaining a weed-free fallow reduces issues with soil borne diseases; some in-crop diseases whose aphid vectors survive on fallow weeds and cereal rusts, which need a live host on which to over summer.

The ability to sow a crop at the desired time into moisture also delivers yield, weed and risk management benefits. Moisture seeking tynes with press wheels and furrow seeding techniques enable a crop to be sown deeper into moisture while only covering seed with a minimal depth of soil, thus still allowing the seed to emerge. When furrow seeding techniques are coupled with high levels of stubble cover and minimal or no soil disturbance in the weeks/months prior to sowing, the duration of the available sowing window for many crops can be doubled or tripled. Yield is optimised by increased ability to sow into moisture at the optimum time, while the risk of not being able to sow at all is greatly reduced.

In several recent seasons in the southern and western grains regions, drier growing season conditions have been offset by higher than average fallow rainfall. In these situations, managing summer rainfall by controlling weeds and maintaining stubble cover has been a key management strategy to optimise profit.

Although there are many advantages to summer fallow weed control, there are some issues to consider when undertaking control measures.

Conditions for weed growth and spraying in the summer fallow are often hot and dry, leading weeds to enter moisture/heat stress faster than in cooler months. This often leaves a very narrow window for optimal spray timing, requiring the grower to be ready to spray as soon as conditions are right and to cover large areas quickly. There are implications here for boom spray size and efficiency, the use of nurse tanks and contractors, as well as for management planning. Some have responded by using more night spraying. Night spraying is a 'dual edge sword', as the frequency of unfavourable inversion conditions is far higher at night. Inversions and night time spraying dramatically increase the risk of spray drift.

Experience in the Northern Grains Region has shown that high reliance and use of glyphosate alone in the fallow will lead to an increase in glyphosate resistant weeds as well as a species shift to naturally less susceptible species. For some weeds, this is managed by the addition of an appropriate mix partner, while in others, the use of double knock strategies and/or pre-emergent herbicides is needed. High application rates applied using camera detection sprayers is another useful strategy for cost effective management of problem weeds. Alarmingly, in an increasing number of situations, tillage has to be used as cost effective herbicide options no longer exist.

Weeds that are not killed or only partially killed will remove a lot of moisture fast. Control weeds effectively and early and if possible, also conserve stubble to protect the soil from wind and water erosion – especially early in the fallow.

2 Storing soil water during the fallow period

Key issues:

- Early and total control of fallow weeds is essential for effective water storage
- Controlling fallow weeds greatly improves the probability of being able to sow a crop on time and into soil moisture
- The top layers of soil protect water stored deeper in the profile from evaporation. Unless cracks provide direct access to deeper levels in the soil, the top layers of soil must be wet before more water can be stored deeper in the profile, where it is protected from evaporation
- The main benefit of stubble for soil water is increased infiltration rates and slowing of runoff. Erosion control is also a primary benefit of stubble maintenance
- Stubble increases infiltration and slows evaporation. However, without follow-up rain after a smaller summer rain event (ie <approximately 20 mm), additions to deeper 'evaporation protected' soil water are unlikely to occur and may not lead to increased storage at the end of the fallow
- Maintaining stubble cover and avoiding soil disturbance in the weeks prior to sowing can mean the difference between sowing into moisture or not in a season with marginal sowing rains
- Soils with lighter textured top soils often need less rain to wet up the top soil and can as a result, have higher efficiency in storing summer rainfall events than soils with a heavier textured top soil. Heavier top soil requires more rain to wet the evaporation zone before an increase in deeper 'more protected' moisture is made, and
- Summer rainfall often occurs as higher intensity storm rainfall. Optimising soil water infiltration rates is critical to capture such rainfall. Management systems such as controlled traffic, no-tillage, avoidance of grazing (especially when wet) and farming system rotations and practices that leave soil cover in place all assist in maintaining infiltration rates.

The level of return on investment from controlling summer weeds depends on several factors. These include:

- How much extra water is stored, its position in the profile and value to the next crop given likely growing season rainfall
- How much extra nitrogen is available to the next crop and its value (i.e. cost if applied as fertiliser)
- The cost of weed control, and
- The extent and value of any crop establishment benefits when sowing the next crop.

Arguments for not controlling summer weeds often relate to:

- The competing value of weeds as livestock feed
- The low (or negative) value of extra stored soil water in areas with high winter growing season rainfall, and
- Problems arising from excessively wet soil profiles:
  - increased potential for deep drainage can add to salinity issues in some areas,
  - waterlogging induced nutrient loss (i.e. denitrification) and nutrient loss with leaching beyond the root zone.

How much extra moisture is stored depends on:

- The amount, timing, incidence and intensity of rainfall
- Soil type and its ability to receive and store the rainfall (i.e. infiltration and water holding capacity)
- Soil management which includes factors that influence the soils ability to capture and store rainfall
  Factors include:
  - Tillage/no-till
  - Maintenance of stubble/ground cover
  - Soil ameliorants such as gypsum or lime that will help reduce surface crusting and increase water infiltration rates
  - Grazing, and
- Weed control. If fallow weeds are not controlled throughout the fallow period, much of the potential benefit from storing fallow rainfall will be lost.

The value of extra stored soil water depends on:

- Where moisture is stored in the soil profile.
  - Water stored deep in the soil profile usually has a much higher value due to a higher water use efficiency (WUE)(kg grain/mm plant available water). Deep water has a higher WUE as it is more likely to assist during grain number determination and grain fill than water stored closer to the surface
  - Water stored deep is less prone to loss by evaporation (generally does not occur below 30 cm)
  - The value of water closer to the surface for seedbed/ crop establishment is of increasing value as sowing approaches. Sowing a variety at the optimum timing has significant value, (see Table 1 on page 8)
- How much is extra soil water needed?
  - Compare a drier area where growing season rainfall (GSR) often limits crop yield, with a high GSR area where a lack of water only occasionally limits crop production, and

- How efficiently can crop agronomy convert extra soil water to crop yield?

2.1 Impact of farming system, tillage and stubble cover

Retaining crop or pasture residues reduces the physical impact of raindrops on the soil surface, maintains structural integrity and infiltration rates and reduces run-off (Felton et al. 1987). Crop stubble slows surface runoff, allowing more time for infiltration as well as slowing soil evaporation after rainfall events (Freebairn & Boughton 1981). Stubble can slow evaporation, but in the absence of follow-up rainfall, this is unlikely to affect fallow efficiency significantly (Felton et al. 1987).

The impact of poor weed control usually has a far greater impact on fallow efficiency than the effects of no-till vs. tilled systems. The significant benefits of no-till on soil water capture and storage and erosion prevention remain key drivers for widespread use of no-till practices.

Maintaining weed control, stubble cover and a lack of soil disturbance close to sowing can extend the sowing window and can often, in less reliable rainfall zones, mean the difference between being able to sow or not sow a crop on time-or at all.

Research in NSW showed the extra soil moisture saved by controlling summer fallow weeds almost doubled the probability of being able to sow during the month of April (Fischer & Armstrong 1990). Having extra stored soil water improves the chance of successful crop establishment as it reduces the risk of failure associated with crops sown on limited soil water.

When summer weed control is associated with furrow or deep seeding technology and stubble cover, a much wider sowing window often eventuates.

For many growers, a more reliable/wider sowing window is seen as a one of the 'key benefits' of summer weed management in a no-tillage system. As a rule of thumb, there is approximately 4-7% loss in yield potential in wheat for each week after the ideal sowing date for a variety (Matthews, McCaffery & Jenkins NSW DPI Winter Crop Variety Sowing Guide 2013).

Research in southern Australia conducted as part of the GRDC WUE Initiative, shows that the major effect of stubble on fallow efficiency is through improved infiltration rather than reduction of evaporative losses. Stubble is of greatest benefit where summer rainfall intensity is high and soil infiltration rates low and on sloping country.

The impact of stubble retention on fallow water storage is greatest where rainfall is regular, i.e. multiple events within weeks of each other. The benefit of stubble residues is most apparent in the autumn period (Verburg et al. 2004) prior to sowing when evaporative demand is lower than in summer. In the less evaporative autumn conditions, significant levels of stubble residue reduce the rate of water loss from the surface zone of the soil. Slowing evaporation losses in this way is often reflected in a wider and more reliable planting window following autumn rain.

Simulation modelling at Wagga Wagga on the impacts of residue retention in autumn and winter showed that a 4 t/ha residue cover post sowing (early and mid-June) could reduce total evaporation losses by approximately 10-15 mm, while residue retention past May 1st can reduce evaporation losses by up to 45 mm, depending on residue levels and rainfall patterns. Residue levels of at least 2 t/ha would be required to conserve amounts of more than 5 mm. At 4 t/ha the average evaporation reduction was predicted to be 25 mm at Wagga Wagga (Verburg et al. 2007).

Brown C, & Jones B (2008) tested the hypothesis that no-till crops, grown on clay soils in the low rainfall Southern Mallee environment would yield better, if more straw/biomass could be retained from the previous crop. When 5 t/ha of wheat straw was added over summer to no-till plots in a rotation trial, crops with straw yielded 0.26 t/ha more than no-till crops without straw (0.72 t/ha, $p = 0.001$). The added straw increased surface soil water and early in the season reduced surface soil mineral nitrogen, but crops had similar nitrogen offtake in grain. They concluded that farmers should consider management to minimise the burial and breakdown of crop residues.

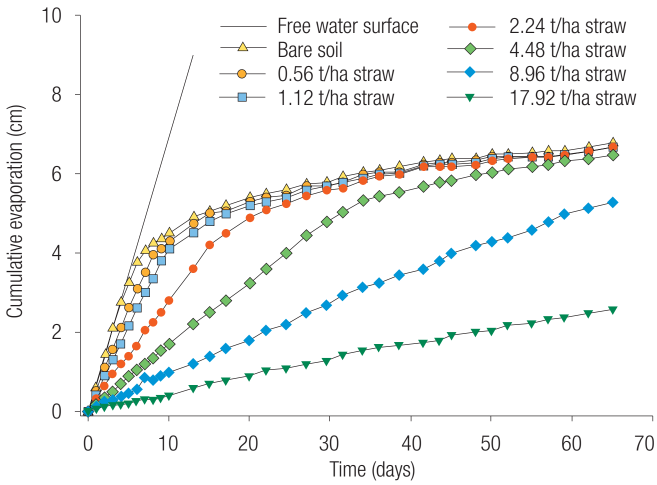
Yield benefits from increasing fallow efficiency are not always positive. In very wet seasons, nitrogen immobilisation caused by decomposing stubble, lowered temperatures and disease problems in residue retained systems can all impact negatively on crop vigour (Kirkegaard 1995).

Table 1: Average yield loss of wheat when sown later than the optimum sow date for a range of yield levels

Mean maximum yield	Yield loss/week	
(t/ha)	%	t/ha
1.09	11.5	0.116
1.73	12.2	0.209
2.31	7.8	0.178
3.35	8.7	0.285
4.34	4.5	0.197
6.20	4.0	0.239

SOURCE: (McDonald, 2009).

Figure 1: The effect of rate of applied wheaten straw on the cumulative evaporation from moist soil columns at an evaporative potential of 7 mm/day over 65 days.



SOURCE: (Bond & Willis as cited in Scott et al. 2010)

Stubble can slow soil evaporation after rainfall (Figure 1), but if conditions are dry for an extended period, total evaporation will be the same whether residues are retained or not.

A small reduction in evaporation loss due to maintaining stubble cover can sometimes have a big impact on crop establishment in dry conditions.

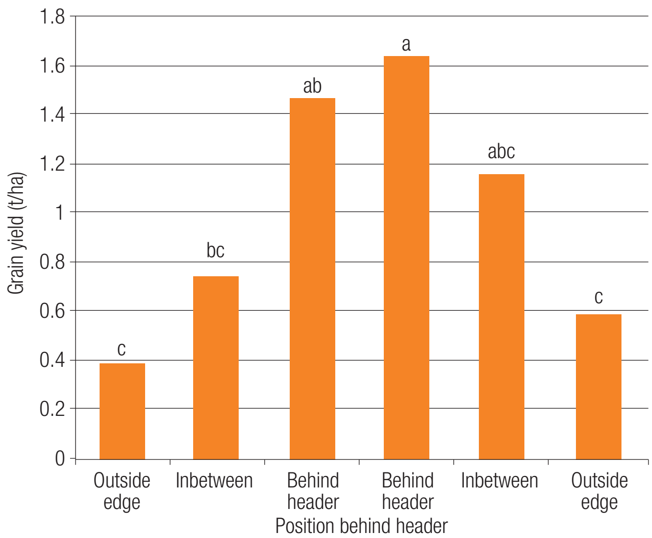
Reduced evaporation loss as a result of maintaining stubble cover was thought to be the reason for the observed increase in canola dry matter production at the clay site of the Birchip Cropping Group (BCG) and CSIRO trial site at Hopetoun in 2010 (Table 2).

In central-west NSW in 2009, wheat yield measured by NSW DPI at different positions across the header trail of the previous year's crop showed a very clear relationship with stubble distribution (Figure 2). It is unclear by what mechanism this was brought about, i.e. improved infiltration, reduced evaporation, faster emergence or all of these.

Table 2: Mean canola dry-matter at 70% flowered in grouped treatments with and without stubble at BCG and CSIRO's Hopetoun clay soil field site in 2010.

Treatment	Canola dry matter at 70% flowered (t/ha)
4.0 t/ha barley stubble	3.9
No stubble	3.3
P-value	0.01
LSD (p=0.05)	0.5

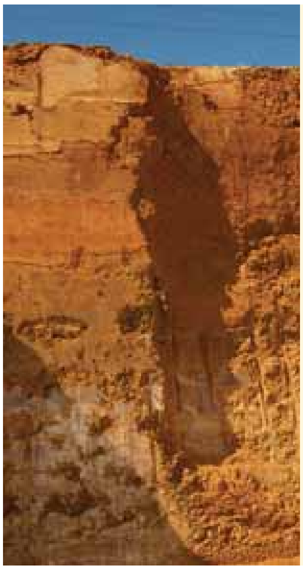
Figure 2: Impact of stubble distribution at harvest on grain yield in the subsequent wheat crop in central-west NSW in 2009. Bars with different letters are significantly different from each other (P<0.05).



SOURCE: (Hunt et al 2011)

2.2 Maximising the amount of moisture stored (fallow efficiency)

Figure 3: Evaporation prone surface layers of soil are a gateway to safer subsoil. To add water to the subsoil, the top approximately 30 cm must first be wet.



Surface zone
Approximately 30 cm (or less in non-cracking soils) is prone to evaporation. This needs to be wet before a water deposit is made to the subsoil where soil water is protected from evaporation loss.

Subsoil water
This is protected from evaporation loss and has a very high water use efficiency - up to 60 kg grain/mm plant available water (PAW) has been measured.

PHOTO: GRDC

Plant Available Water Capacity (PAWC): PAWC is the maximum amount of water available to the crop if the profile was full. It varies with soil and crop type.

- PAWC is the difference between the upper water storage limit (field capacity) of the soil and the lower extraction limit of a crop over the depth of rooting
- Units are typically expressed as mm PAW/metre of soil profile (ie 150 mm/m), or as a total for the soil that takes into consideration the depth of the soil profile. If the above example has a depth of 1.5 metres with no subsoil constraints, the PAWC would be 225 mm.

Plant Available Water (PAW): In many seasons, the maximum water storage capacity (PAWC) is not reached for several reasons including insufficient rainfall, fallow weeds, run-off and evaporation. In these cases, the actual water present is described in terms of the PAW, that is, *how full is the bucket.* It is expressed in mm of PAW

Fallow efficiency: The percentage of fallow rainfall still present at sowing.

Fallow efficiency (%) = (PAW at fallow commencement – PAW at fallow end (mm)) / Fallow period rainfall (mm) x 100

The top layer of soil can be compared to a teller at the bank, where a deposit to an account is only made once past the teller. Fallow rainfall is only saved for the next crop when it gets deep enough to be protected from evaporation.

In a heavier soil with a higher PAWC, it takes more water to wet the top layer than in a lighter textured soil. Hence in a lighter textured soil, less rain is needed to make a donation of water to the 'evaporation protected' subsoil, than in a heavier soil type. While heavier soils can usually hold a lot more PAW/metre of depth (i.e. a bigger bucket), the lighter soils often capture a higher percent of the fallow rainfall – until they are full. The 'best of both worlds' would be a sandy loam over a well-structured clay, so that there are minimum evaporation losses at the surface with a high storage capacity in the subsoil.

This was reflected in modelling work by Hunt and Kirkegaard (2011), where soils with a heavier top layer were less efficient at capturing summer rainfall than soils with a lighter textured top layer. Key exceptions are the non-wetting sands of WA.

This effect of soil texture is shown in Table 3 which shows several 'paired soils' at a range of locations (Morchard (SA), Hopetoun (Vic), Swan Hill (Vic) and Bogan Gate (NSW)). At these locations, heavier surface soils reduced fallow efficiency to one quarter or one half that of the lighter textured soil in the same environment.

Once weeds are controlled, evaporation is the overriding cause of fallow inefficiency. Losses due to runoff become an issue of increasing importance as the intensity and number of summer rainfall events increase.

The length of the growing season determines the length of the fallow period in which rainfall can be collected. Locations with a short growing season have a longer pre-crop fallow, which in turn increases the proportion of rain that falls in the fallow compared to within the growing season (Hunt & Kirkegaard 2011).

2.3 Measuring soil water

Prediction and measurement of stored soil water reserves has become a key issue for estimating potential crop yield and thus nutrient needs.

Many agronomists use a push probe to measure how deep the moisture profile extends. Combined with a knowledge of approximate soil water holding capacity, a rough estimate of how much PAW is available can be made. Not surprisingly, stronger/heavier agronomists often estimate higher amounts of PAW than their lighter colleagues – but an approximation

Table 3: Mean additional PAW at sowing, grain yield and water-use efficiency attributable to summer fallow rain (1889-2008). Years with no return on investment are defined as years in which sufficient rain fell to germinate weeds (25 mm in a single event) but additional yield was less that 0.1 t/ha.

State	Location	Mean additional PAW at sowing (mm)	Mean additional grain yield (t/ha)	Potential increase in WUE (%)	Years with no return on investment (%)
SA	Minnipa	31	0.7	17	3
SA	Cleve	21	0.8	31	8
SA	Cummins	8	0.2	5	18
SA	**Morchard (heavy soil)**	**14**	**0.6**	**69**	**17**
SA	**Morchard (light soil)**	**35**	**1.0**	**29**	**0**
SA	Hart	22	0.9	25	6
SA	Bordertown	33	0.8	15	8
SA	Waikerie	33	0.5	29	2
Vic.	**Hopetoun (clay)**	**17**	**0.7**	**67**	**12**
Vic.	**Hopetoun (sand)**	**41**	**1.2**	**45**	**2**
Vic.	Longerenong	24	1.0	46	6
Vic.	Yarrawonga	40	1.3	47	16
Vic.	Inverleigh	63	1.3	7	11
Tas.	Cressy	68	1.3	3	12
NSW	Urana	40	1.2	51	6
NSW	Temora	51	1.2	35	12
NSW	Cootamundra	84	1.7	27	12
NSW	Dubbo	78	2.1	93	8
NSW	**Bogan Gate (loamy sand)**	**106**	**2.3**	**49**	**1**
NSW	**Bogan Gate (loamy clay)**	**68**	**2.1**	**148**	**3**
NSW	Condobolin	57	1.7	173	1
NSW	Tottenham	60	2.2	210	2

SOURCE: (Hunt and Kirkegaard 2011).

based on some measurement is seen as better than a straight guess!

It is recommended that all growers map and characterise their key soil types so they clearly understand what soil types they have and have an accurate understanding of each soil's PAWC. This includes an understanding of any underlying subsoil constraints. There are few shortcuts to doing this properly using multiple soil cores with professional analysis. Professional assistance in this process is strongly recommended.

HOWWET is a computer simulation model that predicts the level of stored soil water for given soil types, environments, rainfall patterns and levels of soil stubble cover. It is available as a free download and is also a component program in the CliMate iPhone App.

Given the importance of soil water at planting, it is easy to get an estimate of how effective fallow rain was using the Howwet section of Australian CliMate on an iPhone/iPad or online at www.australianclimate.net.au

PHOTO: Neal Dalgliesh

Electromagnetic induction for measuring soil water.

PHOTO: Neal Dalgliesh

Gravimetric soil water testing.

3 Stored soil water – what's it worth?

Key issues:

- Significant yield responses from fallow weed management are very common
- Deep stored soil water usually produces more grain/mm than growing season rainfall and has been recorded returning 60 kg grain/mm stored soil water
- High rates of return on investment are almost always seen from timely management of fallow weeds Contributions to profit come from the additional soil water available to the crop as well as more soil nitrogen as less nitrogen is tied up in weed carcases
- Highest rates of return from extra stored soil water are usually seen in areas with low growing season rainfall and high fallow rainfall, and
- Converting extra stored water to grain and profit requires an understanding of the interactions between plant available water and crop nutrition. Decision support tools such as Yield Prophet can assist.

The highest return on investment from summer weed control is likely to be on soils with a high PAWC (i.e.> 100mm) as these soils have the capacity to store a lot of water. This is particularly the case when there is already significant soil water to protect – i.e. after a pulse crop or long fallow, or when there has been a large rainfall event of sufficient size to have contributed to deep stored water early in the fallow phase. Storing extra soil water is most likely to translate to a yield increase in seasons when there is low growing season rainfall. Low rainfall zones have a 70-99% chance of making a profit from summer weed management based on the value of the extra water alone. These figures improve when nutritional benefits are also included.

By contrast, in high-rainfall areas, the potential for an economic return from more stored water is lower and more variable than in low-rainfall areas. The chance of making a profit from summer weed control is estimated at 30-80% (water effects only). Despite this, it is important to still manage summer weeds, as the nutrient tie-up effects and build-up of weeds and disease, are likely to provide significant returns in the short to medium term.

As controlling summer weeds results in both more soil water and nitrogen, yield responses are very reliable. In a multi season and site trial (Hunt et al. 2012), it was found that in seasons with high growing season rainfall, the yield increase from managing summer weeds was driven primarily by nitrogen availability. By contrast, in seasons with low growing season rainfall, the yield increase was driven by additional water, and in average seasons, the yield increase was driven by both water and nitrogen. Across all experiments in this

PHOTO: Colin McMaster

The extra moisture and nitrogen stored by controlling fallow weeds can have a big impact on the yield and reliability of the next crop.

trial series between 2008-2011, complete control of summer weeds returned an average of $6.07/ha for every $1/ha invested. (Table 4)

In modelling work by Hunt & Kirkegaard (2011) across 37 sites in the southern and western grain regions, they estimated a return on investment (based on soil water) of between 6 and an enormous 1,328%! This was based on wheat at $200/t and spray costs of $20/spray. Depending on the rainfall pattern multiple sprays were allowed for.

This APSIM modelling suggests an additional 8 to 106 millimetres of plant available water (PAW) could be provided to winter crops by storing summer rain, providing a yield boost of 0.2 to 2.3 t/ha (average approximately 1 t/ha). In low-rainfall areas, subsoil moisture at sowing significantly reduces production risk. For example, at Quorn in the upper north of SA (average annual rainfall 330 mm), the chance of achieving wheat yields above 2 t/ha (when PAW is below average at sowing) is one year in ten. If PAW is above average, the odds are better than six in ten years. (See Table 5, page 14) The benefits from subsoil moisture are highest in years or sites with low growing season rainfall.

The biggest benefits from summer weed management were predicted where:

- There is more summer rainfall to store
- Soils were lighter but still had good water holding capacity, and
- There was generally less growing season rainfall.

In this study, the most northerly area included was Dubbo in central New South Wales. Here, an additional 2 t/ha average increase in wheat yield was predicted as a result of controlling summer weeds. By comparison, locations in the north western grain belt of Western Australia with a strongly winter dominant rainfall pattern, low soil water holding capacity and generally reliable growing season rainfall pattern benefited by as little as 0.1 t/ha. With less reliable GSR and higher incidence of fallow rainfall in recent years, this benefit is likely to be much greater.

Increasing PAW at seeding improves crop reliability in low rainfall areas.

APSIM modelling was used to simulate yields for 100 years on a loamy Mallee soil in a low rainfall cereal area (Port Germein SA) with full summer weed control. When summer weeds were controlled, increases in PAW at sowing significantly increase the percentage of years when above average yields are obtained (Figure 4).

Observations from other authors:

- Fromm and Grieger (2002) in the Mallee of SA found an increase of between 6-21 mm soil water at sowing as a result of managing weeds in the summer fallow. This resulted in a yield impact of between 0 and 0.68 t/ha, depending on the amount and distribution of in-crop rainfall and soil N status.
- Verburg et al. (2007) found summer weed control could result in up to 35 mm (average of 11 mm) of additional stored water with wheat yield benefits of up to 1.3 t/ha (average 0.3 t/ha for 1960-2006 climate history). Potential gains need to be considered against

Table 4: Experimental results from various WUE Initiative sites. Additional pre-sowing plant available water and nitrogen, crop yield and return on investment due to summer weed control. Figures in bold are statistically significant ($p<0.05$), figures in plain text are non-significant ($p>0.05$). Return on investment assumes chemical and grain prices in the year of the experiment.

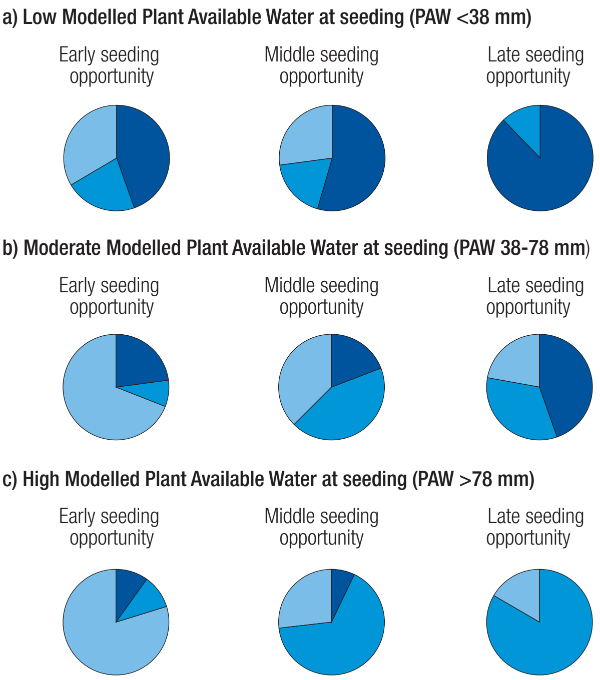
Site	Year	Subsequent crop	Summer fallow rain (mm)	Additional PAW pre-sowing (mm)	Additional mineral N pre-sowing (kg/ha)	Additional yield (t/ha)	Yield of complete weed control (t/ha)	Return on investment in weed control ($ per $ invested)
NSW DPI & CWFS Gunningbland	2010	Wheat	270	**53**	**57**	**1.7**	**3.7**	**$5.67**
NSW DPI & CWFS Gunningbland	2011	Canola	488	**98**	**85**	**1.0**	**2.2**	**$17.67**
NSW DPI & CWFS Tottenham	2010	Wheat	417	**21**	**32**	**1.4**	**2.4**	**$4.67**
NSW DPI & CWFS Rankin Springs	2010	Wheat	304	0	**57**	**1.0**	**3.7**	**$3.18**
NSW DPI & CWFS Rankin Springs	2011	Wheat	384	-	-	**0.7**	**1.7**	**$9.91**
NSW DPI & CWFS Condobolin	2011	Wheat	290	NA	**36**	**1.1**	**2.2**	**$3.33**
BCG & CSIRO Curyo, Vic	2008	Wheat	76	24	**14**	**1.3**	**2.5**	**$5.00**
BCG & CSIRO Hopetoun, Vic (sand)	2009	Barley	90	11	-3	0.2	3.4	$1.20
BCG & CSIRO Hopetoun, Vic (clay)	2009	Barley	90	3	10	0.3	2.8	$1.80
BCG & CSIRO Hopetoun, Vic (sand)	2010	Canola	224	**40**	**45**	**0.4**	**3.1**	**$4.76**
BCG & CSIRO Hopetoun, Vic (clay)	2010	Canola	254	**52**	**43**	**0.6**	**2.7**	**$7.16**
BCG & CSIRO Hopetoun, Vic (sand)	2011	Wheat	387	**29**	**41**	**1.6**	**3.7**	**$7.62**
BCG & CSIRO Hopetoun, Vic (clay)	2011	Wheat	387	**36**	**53**	**1.4**	**2.8**	**$10.09**
UNFS & CSIRO Quorn, SA (heavy soil)	2009	Wheat	175	10	-	**0.2**	**1.3**	**$0.98**
UNFS & CSIRO Port Germein, SA (light soil)	2009	Field pea	89	**30**	-	**0.4**	**1.5**	**$2.09**

SOURCE: (Hunt et al 2012)

the potential increased risk of deep drainage in wetter seasons (>300 mm growing season rain). More efficient capture and retention of rainfall, comes with the risk of increased levels of deep drainage. This is a potential issue with significant impact in seasons with above average growing season rainfall. This can have subsequent impacts on water tables, particularly where subsoil salinity is an issue.

- Fromm and Grieger (2003) found at Wokurna, Upper Yorke Peninsula SA on a sand over sandy clay loam and growing season rainfall of 109 mm in 2002, fallow weed management (2 sprays) increased wheat yield by 1.1 t/ha. The yield benefit came from an extra 8.6 mm of moisture between 20 and 70 cm and an extra 20 kg/ha of available soil nitrogen in the top 45 cm compared to the untreated plots.

Figure 4: Effect of variations in PAW and seeding opportunity on percentage of modelled yields in upper tercile ( ), middle tercile ( ) and lower tercile ( ) loamy Mallee soil at Port Germein, SA. (The upper tercile represents a crop yield in the top 33% of yield over time for this region)



SOURCE: (Mudge & Whitbread 2010).

Table 5: Modelled effects of PAW at seeding (categorised as above or below median simulated levels) against simulated yields at Quorn 1900-2009

Site and Soil Type	All Years	Years with above median PAW at seeding	Years with below median PAW at seeding
Quorn- clay loam			
- Number of observations	110	55	55
- Median Yield (t/ha)	1.3	2.6	0.4
- No. of years < 0.7 t/ha	39 (35%)	6 (11%)	34 (62%)
- No. of Years > 2.0 t/ha	49 (45%)	37 (67%)	12 (22%)

SOURCE: (Mudge & Whitbread 2010).

Table 6: Key factors affecting the return on investment (ROI) from summer fallow weed management as it affects soil water (Does not include the significant nitrogen benefits)

	Lower ROI from summer fallow weed management	Higher ROI from summer fallow weed management
Growing season rainfall total	High growing season rainfall	Low growing season rainfall
Growing season rainfall variability	Low variability/reliable	High variability/ unreliable
Fallow rainfall as a % of total rainfall	Low	High

Table 7: Soil factors contributing to soil water responses from summer fallow weed management

	Generally less response	Generally higher response
Soil type – total Plant Available Water Capacity (PAWC)	<100 mm	>100 mm
Soil type – surface structure	Heavy clay surfaces need relatively more rain to wet below the surface protected zone *	Lighter surface needs less rain to wet below the evaporation protected zone

* Most arable soils in the northern grains region have heavy clay top soils and responses to fallow weed management are almost always positive in these soils as the amount of fallow rain is a high percentage of total rain and growing season rainfall is highly variable. Having a heavy top soil is NOT a reason to not control summer fallow weeds!

3.1 Value of stored soil water depends on where its stored

Water stored deep in the soil profile at sowing usually has a higher WUE than water stored closer to the surface. Figures of up to 60 kg grain/mm have been cited for deep stored water.

Kirkegaard (2007) found that under moderate post-anthesis stress, 10.5 mm of additional subsoil water used in the 1.35 – 1.85 m layer after anthesis increased grain yield by 0.62 t/ha, representing an efficiency of 59 kg/ha/mm. The additional yield resulted from a period of higher assimilation 12–27 days after anthesis and was related to an increase in grain size rather than other yield components. Under more severe stress with earlier onset, extra water use below 1.25 m was accompanied by additional water use in upper soil layers and it was more difficult to isolate and quantify the benefit of deep water to grain yield.

The additional water used from all layers from the time the stress was imposed was converted to grain at 30–40 kg/ha/mm, but this increased to 60 kg/ha/mm for water used after anthesis. The high efficiency for subsoil water use is 3 times that typically expected for total seasonal water use, and twice that previously estimated for total post-anthesis water use in a similar environment. The results demonstrate that relatively small amounts of subsoil water can be highly valuable to grain yield.

Recent work by Sadras et al. (2012) placed greater emphasis on yield impacts of the combined impact of both extra water and nitrogen in the pre anthesis period. Adequate nitrogen supply was critical to capture the benefits of additional water from summer rainfall and reciprocally adequate water supply was required to capture the benefits of nitrogen fertilisation. This highlights the resource co-limitation for wheat production in these environments.

3.2 Subsoil constraints

Deep stored water is not always available for crop use, as subsoil constraints in some soils restrict crop root access to deep soil water. Subsoil constraints have a critical impact on soil PAW and PAWC and a crops ability to access it and should be a key focus of any soil characterisation process. Failing to adequately identify, understand and manage the impacts of subsoil constraints, will lead to poor and costly management decisions and adversely impact on profit.

Some key subsoil constraints include:

- High salt levels (saline)
- High sodium levels (sodic)
- Acid subsoils commonly associated with boron toxicity or toxicity from other minor nutrients, and
- Physical barriers such as parent material (rock) in shallow soils, layers of high soil strength (i.e. due to compaction or occurring naturally).

Identifying and understanding the nature of any subsoil constraint is critical to good water budgeting and crop resourcing decisions. For example, a soil that is wet to 1.2 M and holds 150 mm PAW/m holds 180 mm of PAW. When added to a GSR of 150 mm and an average WUE of 20 kg grain/mm PAW, this gives a yield potential of approximately 6.6 t/ha. If however there was a subsoil constraint at 60 cm that stopped root access to water deeper in the profile, the yield potential would be lower at 4.8 t/ha.

Further reading on the identification and management of subsoil constraints can be found at:

http://www.farmlink.com.au/ Look under past project reports.

http://www.csu.edu.au/research/grahamcentre/downloads/Canola_&_subsoil_constraints.pdf

3.3 The need for extra soil water

Return on investment derived from the soil water benefits of summer weed management will be largest and most consistently seen in areas such as central-west of New South Wales, the north-east Wimmera and Mallee of Victoria, and the Mallee and upper north regions of South Australia where a high proportion of summer fallow rain, higher PAWC and unreliable growing season rainfall combine to increase the value of storing summer fallow rain. In higher rainfall zones such as the high rainfall zones of Victoria, lower Eyre Peninsula and south-west Western Australia, which have a traditionally more reliable growing season rainfall, a Mediterranean rainfall pattern and/or soils with low PAWC, the value of additional stored water to crop production is reduced, but would be likely to be significant in drier seasons (Hunt and Kirkegaard 2011).

The value of storing fallow rainfall depends on the amount and reliability of the growing season rainfall and on the soil PAWC. For example, Borden in WA and Longerenong in Victoria have similar summer fallow rainfalls (121 & 139 mm) and growing season rainfalls (388 & 413 mm) respectively, yet they differ markedly in the contribution of summer fallow rainfall to yield 1.0 t/ha (32% of yield) at Longerenong and only 0.2 t/ha (7% of yield) at Borden. The reasons for this difference are the high PAWC and more variable growing season rainfall at Longerenong.

At sites with high and relatively reliable growing season rainfall, the effect of storing summer fallow rainfall is often outweighed by the effects of in season rainfall. At sites with high levels of growing season rainfall, extra water stored in the fallow could lead to negative effects associated with water logging, denitrification and leaching of nitrate. However, the significant nitrogen benefits from summer fallow weed management usually outweigh the downsides and can result in a significant return on investment even in areas with higher GSR where the soil water benefits are of reduced benefit.

In locations where predicted yield responses to storing summer rainfall are low, the response in some seasons can still be highly significant. Greatest benefits will be seen in seasons where there is more summer rain to store and when growing season rainfall is low.

No-till fallows for water storage have been in widespread use for many years in the Northern Grains region. Many northern advisers say that at sowing, they ‘look down rather than up’ to determine how they will resource the crop and estimate yield potential. In other words, they value stored soil water at sowing more than any seasonal forecast or outlook.

In the Southern and Western grains regions, some of the really big differences in grain yield, due to additional soil water stored in the fallow, have been due to the crops ability to establish well and survive initial dry periods. In seasons when later season in-crop rainfall is high, some very large difference in yield can result.

In modelling of economic returns on predicted increases in soil water, Hunt & Kirkegaard (2011) found that the mean return on investment was high in almost all locations in Victoria and NSW and many locations in SA and WA, but at some locations (e.g. Wongan Hills, Borden, Cummins, Morchard (heavier soil) and Maitland), there was a higher risk of not receiving an economic return based on extra stored water alone.

3.4 Converting extra soil water to crop yield

Good crop agronomy is required to convert extra soil water to crop yield. Some questions that need to be answered are:

- Has crop nutrition been adapted to meet additional nutrient demands that come with higher yield potential?
- Has crop agronomy and time of sowing been optimised to match the PAW at sowing and expected in-crop rainfall? (See case study on ‘An earlier sowing window’ on page 52.)
- Has crop sequencing been planned to provide a soil environment where issues such as nematodes, crown-rot, take-all or other diseases will not limit crop yield?
- Is in crop management of insects, foliar diseases and weeds planned and adequate? Extra soil water can exacerbate problems with all these.
- Has the farming system been set up to optimise crop root growth using techniques such as controlled traffic and no or minimum tillage?

PHOTO: Colin McMaster

A clean fallow starts with good in-crop weed management and planning.

PHOTO: Colin McMaster

Poor fallow management will lead to lost soil water. Large weed carcases can lead to problems or delays in sowing resulting in poor crop establishment.

3.5 Assessment questions

1. **Fallow efficiency is measured by:**
   a. The % of fallow rainfall that is captured and stored for use by the next crop
   b. The amount (mm) of plant available water stored at the end of the fallow period (i.e. at sowing)
   c. The cost of managing weeds vs. the amount of water conserved
   d. The time taken for the crop to use the stored water in the soil

2. **Which of the following statements about fallow water efficiency is correct?**
   a. Soils with a heavy clay content in the topsoil tend to have higher fallow efficiency than soil with a lighter topsoil and clay subsoil
   b. Heavy clay soils are always more fallow efficient than lighter structured soils
   c. Soils with a lighter structured topsoil and clay subsoil tend to have higher fallow efficiency than soils with a heavier clay topsoil
   d. There is no evidence of difference in fallow efficiency of soils based on soil type

3. **Summer fallow efficiency is likely to be higher in seasons when:**
   a. There are a few smaller rainfall events
   b. Fallow efficiency does not vary much between seasons for a particular soil type and region
   c. There are drought conditions
   d. There are several larger rainfall events that occur within a period of several weeks

4. **Which of the following statements about return on investment (ROI) is incorrect?**
   a. The likely ROI from fallow weed management in a high growing season rainfall zone can sometimes be due more to nitrogen benefits than from extra stored soil water
   b. The ROI from summer fallow weed management is likely to be highest when there is good fallow rainfall and low growing season rainfall
   c. The ROI from summer fallow weed management is likely to be highest when there is low fallow rainfall and high growing season rainfall
   d. The ROI from summer fallow weed management is usually higher when there is significant existing soil moisture to protect

5. **Which of the following statements about Water Use Efficiency (WUE) is correct? (There may be more than one correct response):**
   a. Water stored deep in the soil profile is very valuable due to its contribution later in the season when yield is being determined and set. WUE's of up to 60 kg grain/ mm for water that is stored deep in the profile have been recorded
   b. Surface moisture is just as important as deep stored water to grain fill and has a similar WUE to deeper stored water - typically up to but rarely exceeding 20 kg grain/mm stored water
   c. If after a 25 mm summer rainfall event on a heavy clay soil there is no follow-up rainfall for 8 weeks, it is likely that most if not all the rainfall will have evaporated – even if weeds are controlled
   d. Water stored deep in the soil profile is most likely to be used early in the cropping season

6. **True or false?**
   a. A heavy cracking clay holds approximately 175 mm PAWC/metre of depth. Soil that is wet to a depth of 1.2 metres will have a PAW of 210 mm. With a growing season rainfall of 150 mm, total water supply is 360 mm. At an average WUE of 20 kg/mm, the crop yield potential is calculated at approximately 7.2 t/ha
   b. A red loam soil holds approximately 100 mm PAWC/ metre of depth. Soil that is wet to a depth of 0.8 metres will have a PAW of 80 mm. With a growing season rainfall of 150 mm, total water supply is 230 mm. At an average WUE of 20 kg/mm, the crop yield potential is calculated at approximately 4.6 t/ha
   c. A heavy cracking clay soil holds approximately 175 mm PAWC/metre of depth. Soil that is wet to a depth of 0.3 metres will have a PAW of 52 mm. With a growing season rainfall of 200 mm, total water supply is 252 mm. At an average WUE of 20 kg/mm, the crop yield potential is calculated at approximately 5 t/ha.
   d. A red loam soil holds approximately 100 mm PAWC/ metre of depth. Soil that is wet to a depth of 0.3 metres will have a PAW of 30 mm. With a growing season rainfall of 150 mm, total water supply is 180 mm. At an average WUE of 20 kg/mm, the crop yield potential is calculated at approximately 3.6 t/ha
   e. An extra 30 mm of deep stored water at sowing could in a lower rainfall growing season have a WUE of 60 kg grain/mm and equate to extra yield of 1.8 t/ha

7. **A red loam soil is wet to 1 metre when a cereal crop is sown. The grower has based yield expectations and nitrogen resourcing on growing season rainfall of 150 mm and stored soil water of 100 mm (PAWC of 100 mm/metre soil) = 250 mm. At an average WUE of 20, a yield potential of 5 t/ha is forecast. This does not eventuate and crop yield is only in the order of 3 t/ha. Measurement of soil water at harvest showed water levels below a depth of 50 cm to be similar to levels recorded at sowing, while the top 50 cm is bone dry. What is likely to have happened?**
   a. Root growth was limited by dry conditions and never reached into the subsoil zone
   b. Crop nutrition was sub-standard
   c. A subsoil constraint at approximately 50 cm appears likely to have limited root growth and access to water deeper in the soil profile

4 The effect of summer weeds on nitrogen

Key issues:

- Uncontrolled fallow weeds tie up a lot of nitrogen that would otherwise be available to the next crop
- The higher levels of soil water in fallows where weeds are controlled are likely to see more nitrogen mineralised in the fallow period that will be available for use by the following crop
- Extra nitrogen available to a crop through fallow weed control is reflected in both yield and potentially also in grain protein, and
- Every 1 mm of moisture lost via summer weed growth also reduced mineral nitrogen levels by approx 0.64 kgN/ha (McMaster, 2013).

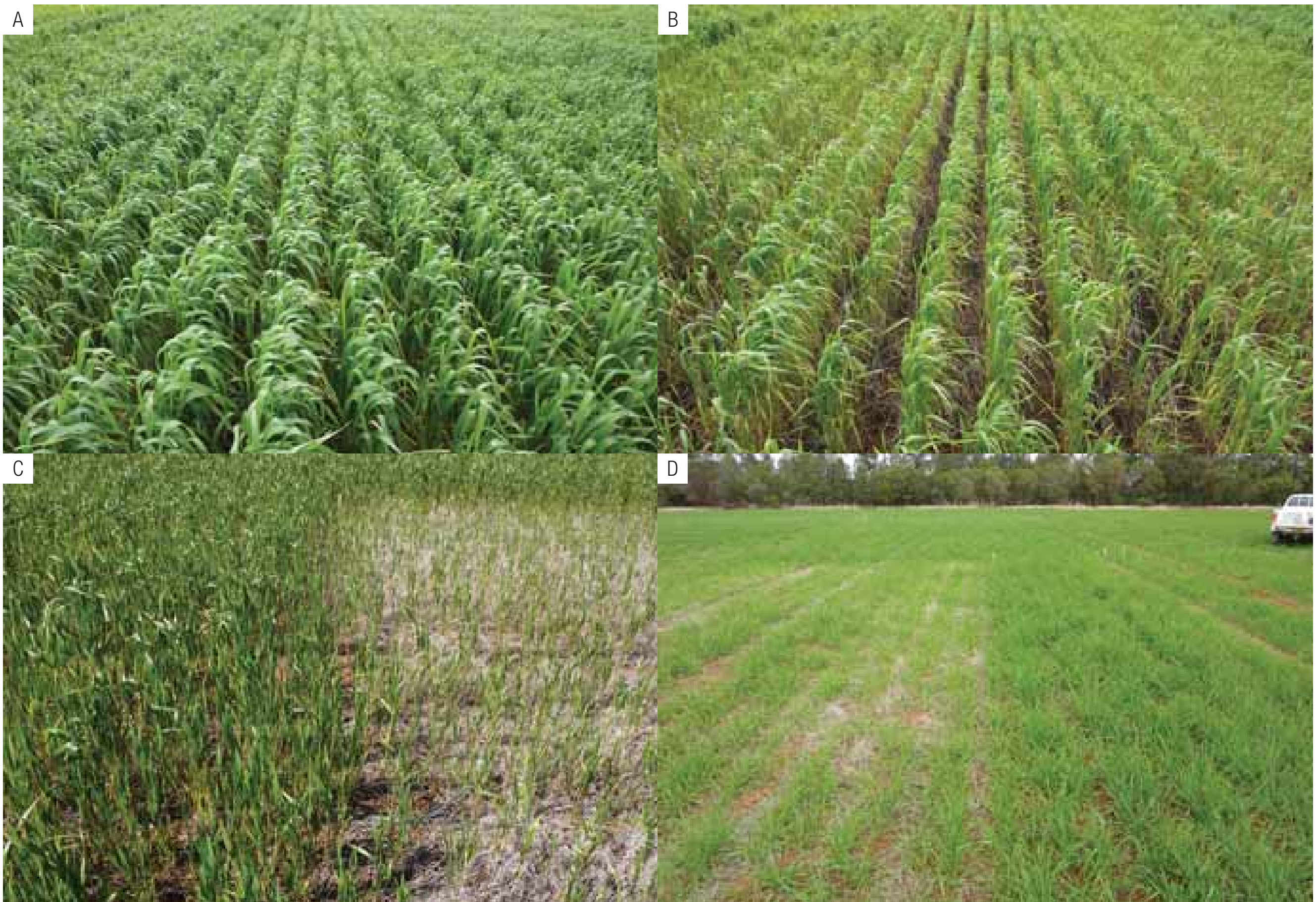
In addition to depleting soil water, large amounts of nitrogen are tied up and are unavailable to the next crop due to weeds growing in the fallow. Also, by killing weeds and storing more soil water, modest increases in the levels of soil water will increase the amount of soil nitrate mineralised in the fallow period – further increasing nutrient availability to the next crop (Table 8).

The extent of the co-relationship between extra stored soil water and nitrogen is highlighted in Figure 5, which shows the

Table 8: Changes in soil nitrogen and water status +/- weeds.

	Wet - irrigated			Dry – rain fed		
	+ Weeds	No weeds	Difference	+ Weeds	No weeds	Difference
Change in plant avail N in top 300 mm (kg/ha)	-11	+13	24	+10	+17	7
Total water loss during summer fallow (mm)	-212	-120	92	-66	-58	8

SOURCE: (Osten et al. 2006)

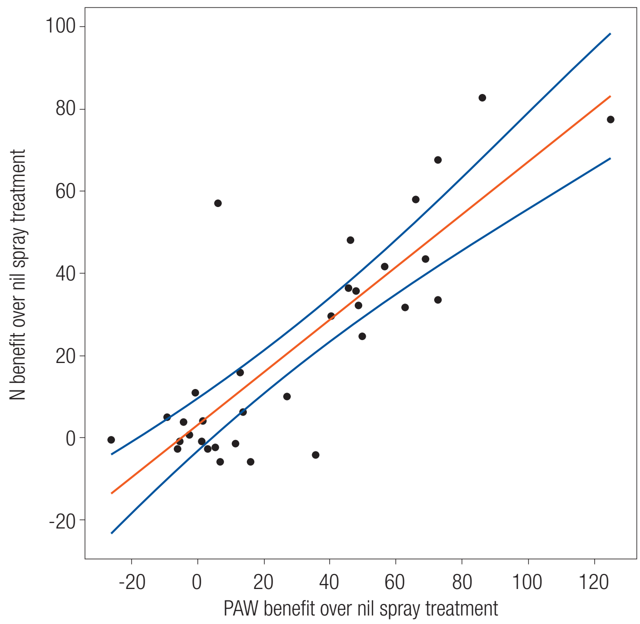


PHOTOS: Colin McMaster

The value of extra nitrogen for the next crop from managing fallow weeds can be just as important as the benefits from extra stored water. Nitrogen benefits are evident in the above pictures which depict: (A) : Value of extra N - Gunningbland trial complete weed control over summer compared with (B) : Gunningbland trial with fallow weeds not controlled; (C) : The value of extra N and water at a trial at Tottenham where summer weeds were sprayed (LHS) and not sprayed (RHS) and (D) : Spraying of fallow weeds was delayed by several weeks (LHS) vs complete fallow weed control (RHS) in a trial at Tottenham.

strong relationship between nitrogen benefit and PAW benefit where weeds were controlled, compared to control treatments where weeds were allowed to grow. These results clearly show that as more water is stored as a result of fallow weed management, the size of the nitrogen benefit also increases.

Figure 5: Fitted and observed relationships between moisture (PAW mm) and nitrogen (Mineral N kgN/ha) loss via summer weed growth with 95% confidence intervals (across 2011 and 2012).



SOURCE: (McMaster & Graham, 2013)

In a trial at Merredin WA, grain yield and protein were generally lower where summer weeds were uncontrolled due to differences in nitrogen rather than PAW (Osten at al. 2006). This outcome reflects the generally lower PAW holding capacity of many WA sands, the often more reliable growing season rainfall and the often limited N supply status of many WA soils. These factors combine to often allow many WA sandy soils to fill during the growing season with lowered reliance on stored summer rainfall (Table 9).

In a multi-year trial near Hopetoun Victoria, the impact of weed management in the summer fallow on following crop yield and protein was assessed (Hunt, unpublished data). Rainfall, soil water and crop performance data are summarised in Tables 10 and 11.

Summer fallow weeds reduced both PAW and mineral N at both sites prior to sowing in 2011. This effectively halved yields in treatments where summer weeds had not been controlled at both sites (Table 11).

In 2009 enough rain fell to establish weeds but not to be stored. In 2010 and 2011 summer fallow rain was above average. In 2010, growing season rainfall was above average, but was below average in 2011, yet a large yield response was seen in both years. This indicates a larger N response in the higher growing season rainfall year and a larger water response in the season with a lower growing season rainfall.

4.1 Assessment questions

1. Both yield and protein can be affected by controlling weeds in summer fallow. This is explained by: (There is more than one correct response)

a. Weeds in the summer fallow use both water and nutrients such as nitrogen
b. More nitrogen is available to the crop if weeds are controlled
c. Water availability influences both the yield and protein of the grain
d. Nitrogen is more likely to stay in the top part of the soil if weeds are present in the fallow.

2. Controlling summer fallow weeds leads to more stored water at sowing. Which statements are likely to be consistently true?

a. The higher levels of soil water in the fallow are likely to have led to more nitrogen being mineralised than would have been the case if weeds were not controlled
b. The higher levels of water at sowing raise crop yield expectations which then need to be balanced by an increased supply of nitrogen
c. As weeds have been controlled during the fallow period, its is unlikely that extra nitrogen would be needed to optimise yield
d. Having more water at sowing can often mean a higher response to applied nitrogen.

Table 9: Wheat yield and protein as influenced by fallow weed management in dry and wet conditions at Merredin.

Site	Fallow conditions	Summer weed biomass (kg/ha)	Yield (t/ha)		Protein content (%)	
			No weeds	+ weeds	No weeds	+ weeds
2003	Wet	1001	2.9	1.8	9.2	7.5
	Dry	444	3.0	2.7	9.9	9.3
2004	Wet	553	1.5	1.4	8.2	8.1
	Dry	0	1.6	1.7	8.7	8.9
2005	Wet	2250	1.4	1.4	9.0	8.4
	Dry	0	1.4	1.5	9.9	9.9

SOURCE: (Osten et al. 2006)

Table 10: Total summer fallow (November-March) and growing season (April-October) rainfall for the seasons of the experiment at the sand and clay sites.

Season	Summer fallow (November-March) rainfall (mm)		Growing season (April-October) rainfall (mm)	
	Sand	Clay	Sand	Clay
2008-2009	90	90	213	202
2009-2010	224	254	264	264
2010-2011	387	387	198	198

SOURCE: (Hunt unpublished)

Table 11: Plant available water (PAW) and mineral N measured prior to sowing, grain yield and grain protein content (oil for canola) + or - weeds at each site 2009-2011.

	Sand				Clay			
	PAW (mm)	Total mineral N (kg/ha)	Grain yield (t/ha)	Grain protein/oil (%)	PAW (mm)	Total mineral N (kg/ha)	Grain yield (t/ha)	Grain protein/oil (%)
2009 - BARLEY								
No weeds	8	125	3.5	11.3	-2	173	2.8	12.2
Weeds	-17	123	3.3	11.2	-10	160	2.8	12.1
P-value	0.029	0.575	0.126	0.691	0.529	0.406	0.28	0.947
LSD	22	28	0.3	0.8	29	33	0.1	1.7
2010 - CANOLA								
No weeds	76	149	3.1		104	167	2.8	
Weeds	36	103	2.7		30	115	2.1	
P-value	0.001	0.002	0.068		0.002	0.008	0.001	
LSD	20	24	0.5		37	34	0.3	
2011 - WHEAT								
No weeds	99	118	3.7	9.7	135	144	2.7	12.0
Weeds	73	74	2.3	10.0	98	104	1.4	12.5
P-value	0.035	0.002	<.001	0.394	0.025	<.001	<.001	0.012
LSD	24	24	0.3	0.7	31	15	0.2	0.4
No stubble	84	88	2.9	9.7	111	125	2.2	12.1
Stubble	88	104	3.1	10.0	122	121	2.0	12.5
P-value	0.757	0.161	0.113	0.355	0.439	0.138	0.044	0.03
LSD	24	24	0.3	0.7	13.8	15	0.2	0.4

SOURCE: (Hunt unpublished)

PHOTO: Colin McMaster

High density weed populations remove a lot of soil water - particularly deeper more valuable water. They also tie up significant amounts of soil nitrogen – making it unavailable to the following crop.

5 Weed type and density

Key issues:

- The more weed biomass, the greater the potential to remove moisture and tie up nutrients, and
- Even relatively low weed densities can remove significant amounts of high value subsoil water.

Widespread commercial experience over many years in the northern grains region has found that even relatively low weed populations of a few plants/metre can significantly deplete soil moisture. In the northern region, there is no debate as to the relative impact/importance of weeds growing early or later in the fallow. All weeds are controlled while still young and susceptible to control before they have been allowed to deplete soil water. Similarly all weeds are treated with zero tolerance with no differentiation made between weed species based on how much water they will use, or N they will tie up. If such distinctions were to be made, the following formulae logically relates weed biomass (plant population x size of individual plants) and whether the plant is a C3 or C4 (See box below) as the key issues affecting their water use.

Norris (1996) describes a formula for estimating water use by weeds. For C3 plants (e.g. canola, wheat, fleabane, milk thistle)

Water use (mm) = (666 x dry matter biomass kg/ha)/10000.

For example canola growing after a fallow may grow about 500 kg/ha dry matter after 2 weeks, with this growth using 33 mm of water. (Note: for C4 plants, the coefficient of '666' changes to '300').

Work in WA by Borger et al. (2010) showed a yield loss in wheat of 0.3 t/ha (1.2 t/ha with summer weed control and 0.9 t/ha with no summer weed control) where windmill grass (*Chloris truncata*) was allowed to use water during the summer fallow. Weed density in the untreated plots was approximately 11.4 plants/m^2.

Hunt J. et al. (2011) found that increasing densities of common heliotrope had a massive impact on cereal yield when not controlled (Figure 6).

C3 and C4 plants

A C4 plant is better adapted than a C3 plant in hot dry environments. Changes to their leaf structure and the process C4 plants use to fix carbon mean they do this in a more energy efficient manner than C3 plants. Examples of C4 plants include corn, sorghum and a number of summer grass and broad-leafed weed species.

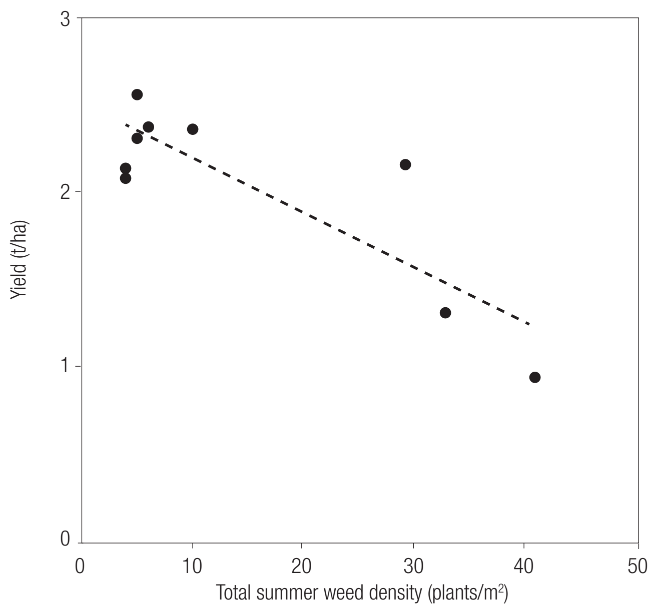
5.1 Assessment questions

1. **Which statement best describes the relationship between weed density during summer fallow and yield in the subsequent crop?**
   a. At low weed densities there is no significant effect on crop yield
   b. There is a similar positive effect on yield across all weed densities measured
   c. There is a similar negative effect on yield across all weed densities measured
   d. There is an effect on crop yield at low weed densities and this negative effect increases as the weed density increases

2. **Which statement is most correct?**
   a. The amount of water used by weeds is directly related to weed height
   b. The amount of water used by weeds is directly related to weed biomass (kg/ha)
   c. Weeds in a biodynamic system don't use soil water–they make if from the atmosphere using magic

3. **Which statement about weed type and moisture depleting effect is the most correct?**
   a. All weeds have a similar moisture depleting effect during the summer fallow
   b. C3 plants use more soil water than C4 plants at similar densities
   c. C4 plants use around twice as much soil water as a similar density of C3 plants
   d. Windmill grass has little moisture depleting effect during the fallow as its windmill effect acts to pump water into the soil

Figure 6: The relationship between summer weed density (common heliotrope and volunteer cereals) on 11 February 2008 and subsequent wheat grain yield in 2008 at Curyo, Vic (R^2=0.72).



SOURCE: (Hunt J. et al. (2011))

6 Other ‘weed effects’ on following crops

Key issues:

- Weed management – particularly in the period immediately prior to sowing can assist by removing the green bridge needed to vector a range of insect pests and diseases. Rust diseases and aphids are good examples
- Weed-free-fallows are often easier to sow into with better more even crop establishment and fewer blockages at seeding
- Grazing when used alone tends to provide a sub-standard level of weed control that results in continuing weed growth and moisture loss, while overgrazing can remove too much ground cover and lead to increased levels of evaporative loss and erosion. Often the economic benefit of grazing is far outweighed by the opportunity cost of the lost soil water
- Cultivation can be an effective tool for fallow weed management, but opens country up for wind and water erosion and can reduce water infiltration rates leading to increased levels of runoff and erosion and water loss if/when heavy storm rainfall occurs
- Cultivation is increasingly being needed in no-till cropping systems where glyphosate resistant or tolerant weeds cannot be cost effectively controlled using herbicides alone
- Some early work on mainly surface germinating weeds suggests that periodic inclusion of tillage in the farming system may reduce the weed seedbank of some weeds. This is countered by the risk that weed seed burial is likely to increase seedbank dormancy for some weeds and that tillage is also likely to spread patches of resistant weeds around the paddock. There are pros and cons to consider from a weed perspective
- Crop rotation can provide options for alternate and possibly more effective weed management tactics to be deployed, and
- The benefits of higher PAW and higher stubble levels are likely to be best expressed in crop sequences that include cereals grown in rotation with pulse, oilseed or summer cropping.

6.1 Green bridge

Several diseases and insects that damage crops are vectored on weeds in the summer fallow. These include: cereal rusts, wheat streak mosaic virus, crown rot, barley yellow dwarf virus, beet western yellow virus, bean leaf roll virus, diamondback moth, mites and Rhizoctonia.

The ideal situation is to have a long period of no green bridge during the summer period. The critical period is often the four to six weeks prior to sowing. All weeds and crop volunteers should be killed before and during this window.

6.1.1 Cereal rusts

All rust diseases are biotrophic pathogens requiring a live host to survive. The rusts are very social diseases and even small amounts of inoculum present at the start of a season can lead to a widespread epidemic if conditions are favourable.

For cereal rusts, the most common host enabling the disease to survive over the summer are crop volunteers, but some rusts also survive on some weed species. If weeds and crop volunteers are killed, the green bridge does not exist and the level of rust inoculum at the start of the following season will be severely depleted and the commencement of epidemics delayed.

6.1.2 Wheat streak mosaic virus (WSMV)

WSMV is a viral disease transmitted by the wheat curl mite (WCM) or by infected seed. It infects wheat, oats, rye and a range of grasses. Like the rusts, WSMV and its vector need a green bridge to survive between seasons. Hosts for WSMV and WCM include; wheat, barley grass, annual ryegrass, small burr grass, stink grass and witch grass. With no effective miticide available for the control of WCM, an effective green bridge is essential to prevent the spread of WSMV.

6.1.3 Barley yellow dwarf virus (BYDV)

BYDV is a viral disease transmitted by oat aphids and infects all cereals.

6.1.4 Beet western yellow virus (BWYV) and Bean leaf roll virus (BLRV)

These aphid vectored viruses affect oilseed and pulse crops and rely on a green bridge for survival between crops. Hosts include crop volunteers as well as some broadleaved weeds, and pasture legumes including lucerne, medic and clover.

6.1.5 Diamondback moth (DBM)

DBM is a later season caterpillar pest of canola which is resistant to several key insecticides and is difficult to control. DBM multiplies over summer on canola and several weeds including wild radish.

6.1.6 Mites

Green bridges can sustain high populations of mite pests that increase the need for control measures when susceptible crops such as canola are sown. Some mite species such as redlegged earth mite are relatively easy to control with insecticides, while others such as Balaustium and Bryobia mites are more difficult.

6.1.7 Rhizoctonia

The survival of Rhizoctonia in high numbers is assisted by a green bridge. Rhizoctonia is a soil borne disease affecting the root system of cereals, pulse crops, pasture species and weeds. It is more likely to be a severe problem when grass weeds have been present in the weeks prior to sowing.

6.2 Weed physical impacts on crop establishment

Some weeds become quite 'ropey' and can become tangled in sowing equipment, causing stubble blockages that can in turn lead to gaps in plant establishment or other issues at sowing. Melons (*Cucumis spp.*), bell vine and cowvine (*Ipomoea spp.*), wireweed (*Polygonum aviculare*) and to a lesser extent caltrop (*Tribulus terrestris*) are all examples.

Large weed carcasses or ropey weeds at sowing can cause stubble blockages in sowing equipment. This can lead to sowing delays, missed strips, uneven application/ incorporation of soil applied herbicides – all of which can affect crop yield.

Prior to the release of chlorsulfuron in 1982, many summer fallows started life at winter crop harvest with an already impenetrable weed mat – often of *Polygonom spp.*. Such incidences reduced in frequency after this product was released. This experience highlights the value of good in-crop management to fallow weed management.

6.3 Grazing

Heavy grazing can help reduce summer weed biomass. Used in isolation from other weed management tactics, it almost always allows weeds to grow for longer than if controlled by herbicides, leading to significant loss of moisture and potential yield loss.

Grazing can also compact soil (especially when clay soils are grazed when wet), reduce infiltration rates with subsequent loss of fallow efficiency, close soil cracks and lose the ability to efficiently capture heavy summer storm rainfall in cracking clays. Grazing is also likely to leave any weed survivors in a stressed state with a larger root system relative to their leaf area. Such weeds are often difficult or near impossible to kill with herbicides and tillage may be needed.

Grazing sheep on summer fallows often does not reduce summer fallow efficiency or yield, providing weeds are sprayed before grazing and 70% stubble cover (2-3 t/ha of cereal stubble) is maintained (J. Hunt personal communication)).

Weedy fallows are still seen, even in regions where the benefits from summer weed control are clear and large in magnitude. Providing feed for livestock and avoiding the input cost of a spray are often given as reasons for not controlling fallow weeds. Hunt and Kirkegaard (2011) felt that in many

PHOTO: John Cameron

Rust diseases must have a live host/green bridge to survive.

instances this is likely to be false economy. They argue that if weeds are controlled, the extra N and water preserved would provide more biomass for in-crop grazing, or more grain yield for later supplementary feeding. This would lead to more efficient conversion of water to stockfeed than the grazing of weedy stubbles. (Table 12)

This view is supported by Krause (2008) who states; *"Do not rely on sheep for weed control. If sheep are to be part of the control program they are best used to clean up misses and take out later germinations after a paddock has been sprayed".*

The downsides of spraying over grazing were seen as:

- Cash flow/money up front
- Possible loss of some summer grazing
- Potential increase in herbicide resistance

Upside from spraying:

- Easier and more timely seeding
- Fewer weed seeds carried over to the following season
- Better-quality grain (more nitrogen available because less was used and tied up by weeds over summer)

Weeds in cropping country are often grazed by livestock during summer months. Modelling shows a small increase in meat and wool production and a decrease in supplementary feeding that is more than offset by a very large decrease in crop yields (1.0 t/ha, 0.7 t/ha and 1.3 t/ha for wheat, canola and barley respectively). Mixed farmers are financially better off controlling summer weeds and using the water and nitrogen they save to grow more grain and fodder which they can carry over for summer feeding (Hunt et al. 2012).

Residue management

In a review of the impacts of livestock on crop performance, (Bell et al 2011), while livestock can reduce soil porosity and infiltration rate and increase soil bulk density and soil strength, most effects are in the top 5-10 cm. Despite these effects, few research experiments have documented reductions in crop performance after grazing. Crop simulations with reduced root growth and surface conductivity suggest average grain yield would be reduced by < 10% in all but the most severe cases of soil damage. The risk of compaction can be reduced by removing stock during wet conditions and maintaining soil organic matter. As compaction from livestock is shallow, it is not long-lasting and is rectified by natural processes or tillage. However, tillage operations on soils compacted by livestock may require extra draught, which will increase fuel consumption.

Providing 70% ground cover is maintained (approximately 2-3 t/ha of cereal stubble) and weeds controlled, grazing does not appear to significantly reduce summer fallow efficiency or yields (J. Hunt personal communication).

Table 12: AusFarm simulated whole-farm production values for a mixed farm at Temora from 1960 to 2010.

	Stubble grazed, weeds controlled	Stubble grazed, weeds uncontrolled
Mean wheat yield (t/ha)	3.6	2.6
Mean canola yield (t/ha)	2.2	1.5
Mean barley yield (t/ha)	3.5	2.2
Mean pasture utilisation (%)	38	36
Clean wool (kg/farm ha/year)	13.0	13.1
Meat sold (LW/farm ha/year)	69	70
Supplementary feed (kg/ewe unit/year)	17	16
Deep drainage (mm/year)	66	51
Frequency cover <70%	0.11	0.08

Table 13: Mean plant available water from 10 to 180 cm depth at FarmLink and CSIRO's Temora field site during the 2009-2010 fallow period. Total fallow rainfall during that period was 310 mm with significant individual events of 43 mm late Nov/early Dec, 48 mm at Christmas, 18 mm early Feb, 104 mm mid Feb and 82 mm early Mar.

Treatment	Plant available water (mm)			
	16 Dec 09	13 Jan 10	23 Feb 10	16 Mar 10
No graze (5.4 t/ha wheat stubble)	13	14	105[a]	155[a]
Stubble graze (0.8 t/ha wheat stubble)	14	14	77[b]	110[b]
Stubble & winter graze (0.8 t/ha wheat stubble)	15	16	66[b]	99[b]
LSD (P=0.05)	NS	NS	13	19

Note: Values that are followed by different superscript letters are significantly different at a 5% confidence level according to least significant difference (LSD) statistical analyses.

SOURCE: (Hunt et al. 2011).

Figure 7 shows that the additional 50 mm of water stored in the no-graze treatment is present at depth, implying the difference is due to improved infiltration rather than reduced evaporation. It should be noted that overgrazing of the grazed treatment had reduced stubble levels down to approximately 0.8 t/ha (Hunt et al. 2011).

In a trial at Temora, grazing by sheep led to a reduction in infiltration rate at the end of the 2009-2010 fallow (Table 14). Treatment effects were seen as due to reduced stubble cover rather than compaction from grazing. Fallow efficiency was reduced as a result, but a very wet growing season meant that there were no significant effects on crop yield.

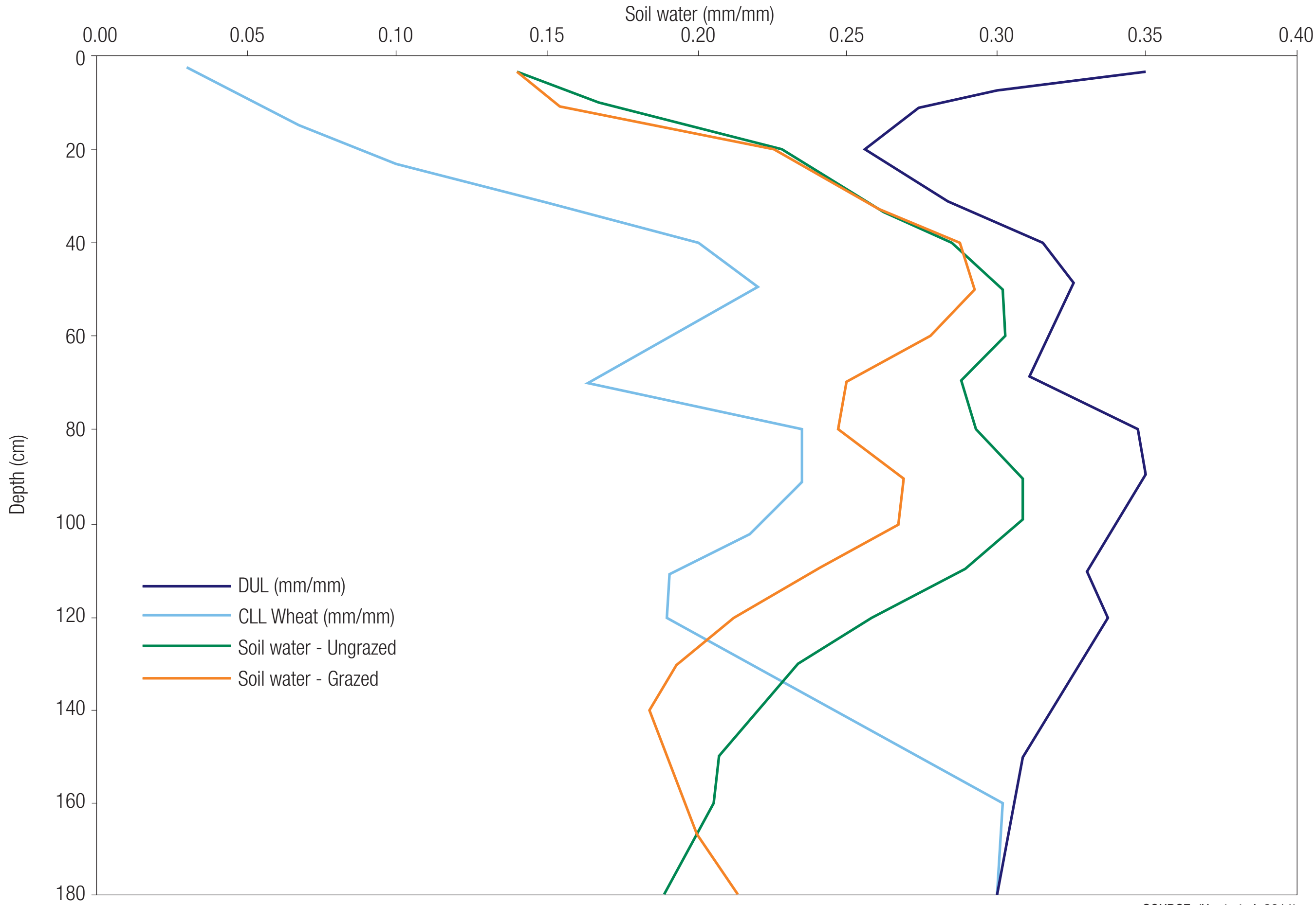
In a trial at Condobolin, wheat yield was significantly reduced by heavy stubble grazing, but this could not be attributed to less stored water at sowing (Table 15).

Table 14: Infiltrometer measurements under different grazing treatments and the surrounding canola stubble at the FarmLink and CSIRO site at Temora in early 2010.

Treatment	Amount of water to ponding (mm)	Steady-state infiltration rate (mm/h)
No graze (5.4 t/ha wheat stubble)	19[a]	36[a]
Stubble graze (0.8 t/ha wheat stubble)	8[ab]	20[b]
Stubble & winter graze (0.8 t/ha wheat stubble)	6[ab]	16[b]
Un-grazed canola stubble (approximately1.6 t/ha)	5[b]	11[b]
LSD (P=0.05)	14	11

SOURCE: (Hunt et al. 2011).

Figure 7: Volumetric soil water content down the soil profile at Temora of the ungrazed — and grazed treatments — from Table 13 on 16 March 2010 relative to Drained Upper Limit (DUL) — and Crop Lower Limit (CLL) — for wheat.



SOURCE: (Hunt et al. 2011)

Table 15: Available water prior to sowing and subsequent wheat yield under different grazing and stubble treatments at NSW DPI and CWFS site at Condobolin applied during the summer of 2009-2010.

Treatment	Available water 4 May 2010 (mm)	Grain yield (t/ha)
Ungrazed (2.6 t/ha stubble)	127	4.6
Ungrazed stubble added (5.6 t/ha stubble)	135	4.7
Light graze (1.7 t/ha stubble)	123	4.7
Heavy graze (1.0 t/ha stubble)	122	4.4
LSD (P=0.05)	NS	0.2

SOURCE: (Hunt et al. 2011).

6.4 Cultivation

Tillage is an effective method for killing fallow weeds. In areas affected by *Rhizoctonia*, it has the added benefit of reducing the severity of that disease if conducted around and below the zone of seedling emergence in the weeks prior to sowing. It also has the added benefit that as yet there is no resistance to 'Mode of Action Group S' (S=Steel).

However, tillage has significant downsides.

- It is usually far more costly than spraying, requires more labour and time as well as a higher capital investment.
- Tillage can affect the ability to sow on time and into moisture – particularly in drier seasonal starts when compared to 'no-till' practices.
- Tillage can lead to higher levels of soil/stubble interface and more tie up of soil nitrogen as soil microbe populations increase in response to the high carbon/low nitrogen food source.

Tillage can reduce the efficiency of the fallow to capture and store rainfall (particularly higher intensity summer storm rainfall) and leave the soil exposed to evaporation losses as well as to wind and water erosion. Cracks in cracking clay soils were once seen as something to be 'closed up' to stop evaporation losses. Many years of experience in the Northern Grains Region has demonstrated that the cracks are actually very useful when left open. They provide the ability in a heavy clay soil to accept high intensity summer storm rainfall, thus minimising runoff and erosion. Additionally, they provide a pathway to put water deep into the soil profile – essentially filling the profile in part from the bottom up. Single tillage events have been demonstrated to be sufficient to close off cracks, leading to massive runoff and erosion losses when high intensity storm rain occurs.

In some soils and situations, the reverse has also been demonstrated where tillage has been used to increase soil water infiltration, particularly in mixed crop/livestock systems where livestock have compacted soil surface layers.

PHOTO: Colin McMaster

Tillage is making a comeback in fallow weed control in some areas due to herbicide resistant weeds.

Tillage can affect the performance of the fallow in several ways:

- Rainfall infiltration rates can be reduced.
  - Tillage reduces soil cover leaving it more exposed to the impact of rain drops. This leads to much faster surface sealing and runoff than when protected by stubble.
  - Stubble cover slows runoff – leaving more time for water to infiltrate.
  - Soil cover slows evaporation after rainfall events which can be of significant value if there is follow-up rainfall, or closer to sowing, but is not of great use if a rain event in the heat of summer is followed by a prolonged dry spell.
  - Tillage disrupts the macropore structure in the soil created by root channels, earthworms and other insects and the natural aggregation of soil particles that occurs in a healthy no-till soil over time.
  - In cracking clay soils, tillage can lead to premature closure of cracks. Open cracks provide a pathway to accept high intensity summer storm rainfall and to potentially place large amounts of water deep in the profile.
  - In some soil types, tillage might assist water infiltration – e.g. in non-wetting sands.
- Maintaining stubble cover and leaving the soil undisturbed in the weeks and months prior to sowing, often results in a longer window for sowing where soil water is near the surface and able to be sown successfully. In drier seasons, this significantly increases the probability of planting at or close to the optimum sowing date.

While tillage and reducing stubble load has downsides for optimising the fallow's ability to store soil water for the next crop, the reduced stubble load as a result of tillage has some benefits. These include:

- Easier stubble clearance and fewer blockages with some sowing implements.

Weed and other effects of tillage:

- Pre-emergent herbicides can be easier to incorporate when there is less stubble, but this is usually more than offset by the poorer contact of herbicide to weed seed in tilled systems. Tillage re-distributes weed seed at various depths in the soil profile compared to no-till which leaves most weed seed in a concentrated band near or on the soil surface. Where pre-emergent herbicides are used in a no-till system, the weed seeds are usually in far closer proximity to a more concentrated herbicide band than is possible in a tilled system. The result is generally higher levels of weed control in no-till systems.

- Tillage also acts to bury weed seed at a range of depths. Weeds have a generally far higher rate of natural mortality when left on the soil surface. Burial often reduces natural mortality as well as increasing the seedbank dormancy of many weed species – thus increasing the number of seasons needed to deplete the seedbank.
- Tillage enhances options for pre-sowing application of fertiliser.

Experiments in the southern grains region have found no difference in fallow efficiency or subsequent crop yield between chemical or mechanical control of weeds by cultivation. Relative to a soil with good residue cover, destruction of soil structure by cultivation exposes soil to wind and water erosion. However, relative to a bare soil (e.g. drought-affected pulse stubbles, pastures etc.) cultivated soil may be preferable as the increased micro-relief can improve infiltration and reduce wind erosion (Hunt et al. 2011).

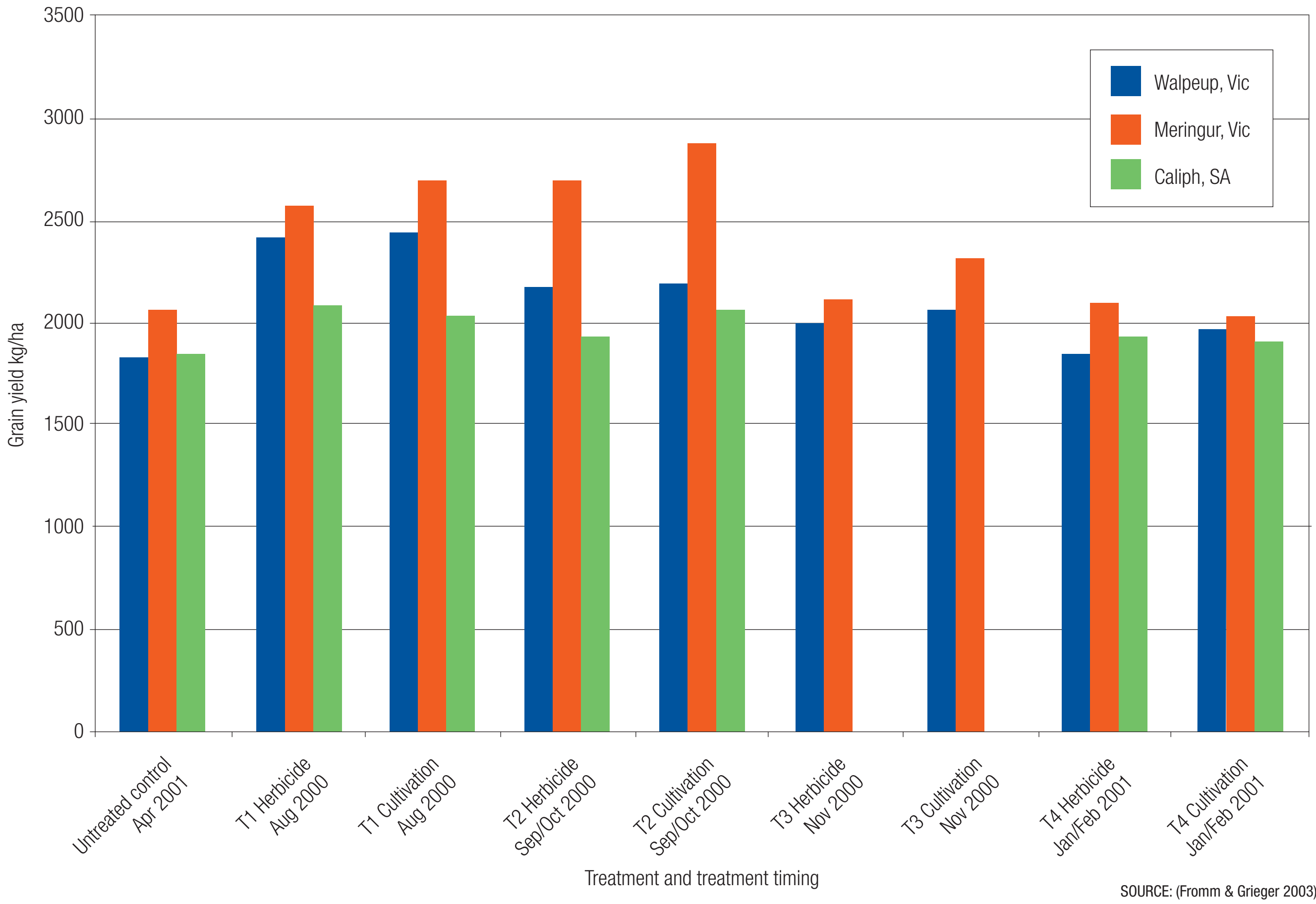
Work done comparing tillage vs. herbicides for weed management in summer fallow at Caliph (SA), Meringur (Vic), Euston (NSW) and Walpeup (Vic), showed the greatest influence on final grain yield was the timing of weed control rather than how weeds were controlled. The earlier the weeds are taken out, the better the yield response (Fromm & Grieger 2003).

6.5 Crop rotational issues

PHOTO: John Cameron

Different crops extract water in different ways. For example, canola often extracts water from deeper in the soil profile than wheat or barley, often leaving soil drier at depth and with less

Figure 8: Grain yield (kg/ha) for chemical vs. mechanical sites 2001 with different commencement times for weed management.



SOURCE: (Fromm & Grieger 2003)

PHOTO: Andrew Storrie

stubble to reduce evaporation in the subsequent fallow than wheat. But canola is sown and harvested earlier than wheat, enabling an earlier start to the fallow period for the next crop.

Some pulse crops such as chickpeas extract less water than wheat or canola. The deep soil water not used by the chickpea can be of benefit to the subsequent crop.

Barley is often harvested a week or two earlier than wheat and soil probes often indicate more soil water is left after barley than wheat. Barley has a potential soil water rotational benefit over a comparable wheat crop.

Perennial pasture legumes such as lucerne dry out the soil profile, are hard to kill and leave only modest levels of stubble cover. Thus replenishing soil water after a several year lucerne phase is a significant task and one that should budget for a lower crop yield in the year after a lucerne phase - especially if growing season rainfall is low.

In the northern grains region, grain sorghum is a common crop. As soon as grain sorghum has reached physiological maturity, most crops are sprayed with glyphosate. This stops late tiller development and evens up crop maturity for a more efficient harvest. The main benefit however, is conservation of water that the crop is still extracting from the soil profile. This water often has a very high WUE for subsequent crops and unless the system is subject to deep drainage or an excess of water, this is regarded as secure water stored below the evaporation zone and significant money in the bank for the next crop.

The analogy of the above for southern and western region crops, is simply that if it's growing in the paddock and it's not contributing to yield, then its depleting moisture that could contribute yield to the current or next crop.

Storing additional moisture creates a yield opportunity for the next crop, but if the rotation is wrong, diseases such as yellow leaf spot or other stubble or soil vectored diseases reduce the ability to translate extra water into yield.

Where stubble retention and summer fallowing is practiced for the first time, growers are often disappointed with results. Often this is due to an over reliance on wheat in their rotation. In a higher water, higher yield potential stubble retained system where fallow weeds are not permitted to remove soil moisture, the impact of rotation and planned nutritional management are far more important than in a less geared system, where tillage, livestock and weeds act to the remove soil moisture.

Similarly, the availability of additional soil water and nitrogen, means that in most environments the yield potential is increased. This in turn has implications for crop nutrition, with requirements for amended levels of N fertiliser to achieve upwardly revised yield targets.

6.6 Assessment questions

1. **What is the most critical period for weeds and crop volunteers to be killed to prevent survival of diseases and pests in the 'green bridge' between crops?**
   a. The entire summer fallow
   b. 4-6 weeks before sowing of the new crop
   c. 4-6 weeks after sowing of the new crop
   d. 1 week before and after sowing of the new crop

2. **Cereal rust is a biotrophic pathogen. This means that:**
   a. It needs a live host to survive
   b. It consumes other pests to survive
   c. It can survive for long periods without a live host
   d. It makes its own food using photosynthesis

3. **Wheat streak mosaic virus and its vector, wheat curl mite, can survive between crops using which of the following as hosts. (There may be more than one correct response).**
   a. Barley grass
   b. Annual ryegrass
   c. Small burr grass
   d. Witch grass

4. **Other diseases that can affect crops following fallow with green bridge conditions include: (There may be more than one correct response).**
   a. Barley yellow dwarf virus
   b. Diamondback moth
   c. Dengue fever
   d. Bean leaf roll virus

5. **Which of the following mites are generally more difficult to control?**
   a. Balaustium and Bryobia mites
   b. Redlegged earth mites
   c. Pink spotted pond mites
   d. Queensland green striped vampire mites

6. **Which of the following is true for canola in relation to its water use compared to wheat?**
   a. Canola is more shallow rooted and does not use the soil water at depth
   b. Canola is harvested later than wheat usually thus making the following fallow shorter and less productive
   c. Canola is harvested earlier than wheat, so the summer fallow starts earlier but canola often leaves the soil very dry as it accesses and uses water at a greater depth than wheat
   d. Canola and wheat are essentially identical in water use and harvest timing

7. **Which of the following is true of perennial pasture species such as lucerne in relation to crop rotation and fallow requirements?**
   a. They leave large amounts of stubble to protect the soil surface from evaporation
   b. They often lead to crop yield increases in the following year especially if the growing season rainfall is low in the following year
   c. They leave larger amounts of soil moisture than corresponding wheat crops
   d. They are known to dry out the soil profile, be difficult to kill and leave only modest levels of stubble cover

8. **In the Northern Region, grain sorghum crops are often sprayed with glyphosate once they reach physiological maturity. Reasons for this are (There may be more than one correct response).**
   a. This stops late tiller development
   b. This evens up crop maturity for a more efficient harvest
   c. This helps conservation of water that the crop is still extracting from deep in the soil for use in the next crop
   d. This stops crop plants from continuing their growth in the fallow

9. **Gaining most advantage from extra stored water depends on which of the following factors? (There may be more than one correct response)**
   a. Adapting nutrition adequately to allow for the extra soil water
   b. Planning crop sequencing to provide a soil environment where issues such as nematodes, crown-rot or other soil diseases will not limit crop yield
   c. Good crop agronomy and management of insects, foliar diseases and weeds
   d. Optimising crop root growth using techniques such as controlled traffic and minimum tillage.
   e. Adapting the sowing date and variety to a system with higher amounts of PAW

10. **Which of the following are economic reasons to control weeds during the summer fallow? (There may be more than one correct response).**
   a. Controlling weeds may lead to higher water storage and greater yields in the subsequent crop
   b. Fewer weeds means nitrogen is not used and tied up in weed carcasses before the sowing of the next crop
   c. Controlling weeds during the fallow may assist in stopping the spread of diseases and pests through 'green bridges'
   d. The return on investment from killing weeds in summer fallow is usually very high in a wide range of environments
   e. Controlling weeds and storing more soil water, provides greater options for earlier sowing using longer season varieties as well as capitalising on a greater likelihood of a return from applied nitrogen fertiliser

7 Herbicides for the fallow

Key issues:

- Kill weed germinations in the fallow soon after emergence when they are small and actively growing as weeds will stress fast in hot summer growing conditions
- Residual herbicides have a role – particularly in the face of increasing levels of resistance to post-emergent herbicides
- Care is needed when using pre-emergent herbicides especially in relation to plant back intervals
- Many weeds can only be adequately controlled by using well timed double knock tactics. This adds logistical stress to spray planning and implementation as well as cost, and
- A clean fallow starts clean after good in-crop weed planning and management.

7.1 Strategy

Weeds can and will germinate after each significant rainfall event in the summer fallow. In high summer rainfall areas (such as NNSW or Qld) in wet seasons, as many as 5 sprays may be required to maintain a clean fallow between winter crops.

Growers in southern systems may be tempted to 'wait and see' if there is follow-up rainfall and potentially save the cost of a spray, but this is a high risk strategy.

If weeds are unsprayed and there is no follow-up rain, some may die before setting seed, but often viable seed will be set and *'one year's seed is seven years weed!'* Without follow-up rainfall, small rainfall events will evaporate, but if there is follow-up rainfall, a decision to not spray will have come at a very significant cost.

- If weeds are not killed, they will use whatever soil water is not lost to evaporation
- Weeds are generally much easier to kill at the seedling growth stage when young and fresh, while larger weeds often require far higher dose rates or a double knock approach for adequate weed control, if indeed they can still be controlled with herbicides
- Weed growth ties up soil nitrogen – reducing unavailability to the following crop
- Weeds that are left to set seed cause bigger problems for following seasons.

PHOTO: Andrew Storie

Spray weeds before they deplete moisture and become difficult if not impossible to control.

In the vast majority of situations, controlling weeds when they are young is easier, more reliable and more cost effective. If sprays are missed or delayed, some weeds can quickly reach a stage where herbicides are no longer effective.

A four-year project in SA set out to determine cost-effective management strategies for the control of summer-growing weeds. Weeds included caltrop (*Tribulus terrestris*), innocent weed (*Cenchrus longispinus*), prickly paddy melon (*Cucumis myriocarpus*) and afghan melon (*Citrullus lanatus*).

In addition to increasing crop yield, spraying weeds in summer fallow also decreased weed seed reserves (Fromm & Grieger 2003). (Table 16).

Table 16: Weed emergence for each summer, Copeville site (Initial weed numbers were 162 for all plots).

Treatment	Weed number on first fallow rainfall plants/m²		
	Dec 2000	Nov 2001	Dec 2002*
Untreated	133	179	23
Herbicide applied as needed	125	60	3
Herbicide late	143	125	27
Herbicide early	181	125	15
Untreated +trifluralin in-crop	51	110	8
Fallow weeds controlled +trifluralin	65	65	0.5

* Partial weed germination in 2002 due to drought
At another site at Wokurna, fallow management in the previous summer reduced weed numbers in Afghan and prickly paddy melon from 2.5 and 2.2 plants/m² in the untreated fallow, down to 0.4 and 0.6 respectively in the 'fallow herbicides as needed' treatment.

SOURCE: (Fromm & Grieger 2003).

7.2 Weed control tables

NOTE: Specific weed and rate registrations will vary on a state-by-state basis and the information in Table 17 (pages 32-35) is not accurate for all states, formulations or labels. Always check the registered product labels before use. Shading in Table 17 reflects that at least one product label for the active ingredient cited is registered for the control of that weed. Not all weeds that appear on all herbicide labels are included. For example, several key summer weeds in the northern grains region are not included as this manual is primarily intended for use in the GRDC Southern and Western regions.

Several products with registrations for use in fallow were not included in Table 17. An attempt has been made to include representative labels of key herbicide actives, but have not sought to include information on the myriad of different formulations available. For example: there are many different formulations of glyphosate. At the time of writing, the Roundup Attack label was highly developed and was included alongside glyphosate 450 CT. Several other products were not included as they had very limited weeds registered or were only registered for use in one or two states. Some products not included in Table 17 are:

- Atrazine. Some formulations have registration allowing use at low rates in some southern states prior to planting wheat, TT canola or peas.
- Several paraquat products (such as Gramoxone®) are registered for use prior to sowing for 'annual grass and broadleaved weeds'. These were not included in the weed specific Tables 17 and 18 (pages 32-36) due to the very 'generic/non weed specific' nature of description of weeds on paraquat labels. Label states: "Aid to cultivation to minimise cultivation and prepare a clean bed for sowing".
- Some herbicides registered for use in fallow in NSW and Qld only are not included.
  - Imazapic (e.g. Flame®) Grass and broadleaved weeds.
  - Aminopyralid + fluroxypyr (e.g. Hotshot®) Red pigweed and climbing buckwheat (northern NSW and Qld. only.
  - 2,4-D, picloram & aminopyralid (e.g. FallowBoss®) Registered for fleabane in NSW and Qld only for use prior to sowing winter cereals or sorghum
- Some formulations of diuron have a registration on potato weed (SA only)
- Some formulations of terbuthylazin (NSW and Qld only).
- Tribenuron (e.g. Express®) NNSW and Qld only for a range of broadleaved weeds.

Table 17: Key broadleaf fallow weeds and herbicides for their control for the GRDC Southern and Western Grains Regions. Weed botanical names are listed in the glossary at the end of this report.

Weeds on at least one product label. Various trade names often available under these formulations. See specific labels.	tribenuron methyl e.g. Express® NSW and Qld only	Oxyfluorfen e.g. Goal®	Carfentrazone ethyl e.g.Hammer® 400EC	Dicamba e.g. Cadence® WG	paraquat + diquat e.g. Spray.Seed® 250	amitrole + paraquat e.g. Alliance®	amitrole e.g. Amitrole® T	Glyphosate e.g. Roundup® Attack™	Glyphosate CT 450	Isoxaflutole e.g. Balance® 750 WG	Flumioxazim e.g. Valor
Herbicide group	B	G	G	I	L	L + Q	Q	M	M	H	G
Amaranthus (check labels for species)								a			+K
amsinckia								p5 or %	p5		
bedstraw											
bifora											
blackberry nightshade								a			
black bindweed	+K			+K							
burrs – Bathurst											
burrs – noogoora				+K							+K
caltrop/yellow vine				+K							+K
canola – volunteer								a or p5			+K
capeweed			+K	+K							+K
charlock								a			
chickpea – volunteer											
chickweed			+K								
clover				+K	p			c	c		
corn gromwell; sheepweed											
cotton, volunteer								p5			
crassula/stonecrop			+K								
cudweed											
datura (thornapple)	+K										+K
deadnettle	+K										
docks											
erodium (storksbill)		+K	+K								+K
fat hen								a			
field pea – volunteer				+K	P or +M			a			
fleabane								a p5 p4	a p5 p4	j	+K
fumitory								a	%		
goosefoot (mintweed WA)											
heliotrope – white (potato weed SA)					r (SA only)			a			
Hexham scent (melilotus)								a			
hoary cress				a							
horehound								a			
ivy-leaf speedwell								a			
Lincoln weed											
lucerne (established)											+K (seedling only)
lupin – volunteer					p or +M			a or % or p5	%		
mallow (marshmallow)		+K	+K		**			a or p5			+K
medic				+K	p or +M			a or p5			+K
Melons (check labels for species)								a or k2 l	a or k2 or +M l		
mintweed	+K										
muskweed								p5			
mustards				+K							
New Zealand spinach								a			

Table 17: (contd.) Key broadleaf fallow weeds and herbicides for their control for the GRDC Southern and Western Grains Regions Weed botanical names are listed in the glossary at the end of this report.

Weeds on at least one product label. Various trade names often available under these formulations. See specific labels.	tribenuron methyl e.g. Express® NSW and Qld only	Oxyfluorfen e.g. Goal®	Carfentrazone ethyl e.g.Hammer® 400EC	Dicamba e.g. Cadence® WG	paraquat + diquat e.g. Spray.Seed® 250	amitrole + paraquat e.g. Alliance®	amitrole e.g. Amitrole® T	Glyphosate e.g. Roundup® Attack™	Glyphosate CT 450	Isoxaflutole e.g. Balance® 750 WG	Flumioxazim e.g. Valor
Herbicide group	B	G	G	I	L	L + Q	Q	M	M	H	G
Paterson's curse		+K	+K	+K							+K
peppercress											
pigweed	+K										
plantain								%			
radish – wild			+K					% &/or a or p5			+K
rough poppy											
saffron thistle				a							
shepherd's purse								a			+K
skeleton weed								a or % S	a or % S		
slender thistle											
sorrel				a +K							
soursob											
sowthistle				+K						j	+K
spear thistle											
spiny emex			+K					p5 or %	%		+K
spurge											
stemless thistle											
stinging nettle (dwarf)		+K									
stinking goosefoot											
sub. clover			+K	+K	P or +M			a or p5 or %	% c		+K S
sunflower, volunteer								a			+K
turnip weed				+K							
variegated thistle											
vetch								a			
Ward's weed								a			
Wild/prickly lettuce	+K			+K				a	a or +M		
wild turnip								a			
wireweed											+K
Rec. Water Vol L/ha Boom	>50	30–200	50–150	50 min	50–200	50–200	50 - 100	80 max	80 max	Min 50L	Min 80L

* = A number of weeds are controlled by 2,4-D without the need to be mixed with a knockdown. As this varies between product label and formulation, we have simplified the above table by flagging the need for a mix partner on all weeds

% = When followed by full disturbance cultivation or sowing with a tyned implement

a = Add 2, 4-D as/label for control

c = Tankmix with dicamba for improved control

DK = Follow with a robust rate of a Group L herbicide within a time as specified on the relevant label(s) from the date of the first application. While some products are registered for control of fleabane as stand-alone treatments, a double knock is often needed for commercial level results and especially when weeds are past the seedling growth stage.

j = Isoxaflutole has significant label constraints on soil types on which it can be used – check label for details. Mixing with glyphosate can reduce the efficacy of glyphosate.

+K = Add knockdown as/label

k2 = Add Garlonv Invader® or Surpass® at label rates on established weeds

l = Use glyphosate alone for camel melon only

+M = Add metsulfuron for control

p = Add dicamba at label rate for control

p4 = Double knock for improved control

p5 = Tank mix with Sharpen®

r = Add diuron South Australia only

S = Suppression only

t2 = See label for rates for controlling Roundup Ready® canola volunteers

u2 = Add MCPA amine. Consult label rate

** = Use with Goal herbicide

@ = Cotton volunteers – other than Liberty Link®

Table 17: (contd.) Key broadleaf fallow weeds and herbicides for their control for the GRDC Southern and Western Grains Regions Weed botanical names are listed in the glossary at the end of this report.

Various trade names often available under these formulations. See specific labels.	metsulfuron-methyl e.g. Ally®	Pyraflufen-ethyl e.g. Ecopar® Forte	pyraflufen-ethyl + 2,4-D LVE e.g. Pyresta®	2,4-D amine e.g. Amicide® Advance *	2,4-D LV ester e.g. Estericide® Xtra 680 *	2,4-D amine + picloram e.g. Tordon™75D	triclopyr + picloram + aminopyralid e.g. Grazon™ Extra NSW only	Fluroxypyr e.g. Starane™ Advanced	triclopyr e.g. Garlon™ FallowMaster 755	clopyralid e.g. Lontrel™ 750 SG	Saflufenacil e.g. Sharpen WG®	Glufosinate-ammonium e.g. Basta®
Herbicide group	B	G	G + I	I	I	I	I	I	I	I	G	N
Amaranthus (check labels for species)	+K	+K		+K	+K							
amsinckia	+K		+K								+K	
bedstraw												
bifora												
blackberry nightshade				+K			+K S					
black bindweed												
burrs – Bathurst			+K	+K	+K							
burrs – noogoora				+K	+K							S
caltrop/yellow vine			+K	+K	+K			+K				
canola – volunteer				+K	+K t2						+K	
capeweed			+K		+K						+K	
charlock	+K			+K	+K							
chickpea – volunteer	+K		+K									
chickweed	+K		+K									
clover	+K		+K	+K	+K							
corn gromwell; sheepweed												
cotton, volunteer												@
crassula/stonecrop												
cudweed												
datura (thornapple)				+K	+K							
deadnettle	+K	+K	+K		+K							
docks	+K		+K	+K	+K							
erodium (storksbill)	+K	+K	+K	+K	+K						+K	
fat hen		+K		+K	+K							
field pea – volunteer	+K			+K								
fleabane				+K DK		+K DK					+K DK	DK
fumitory	+K			+K	+K							
goosefoot (mintweed WA)					+K							
heliotrope – white (potato weed SA)				+K								
Hexham scent (melilotus)				+K	+K							
hoary cress				+K	+K							
horehound				+K	+K							
Indian hedge mustard	+K			+K								
ivy-leaf speedwell				+K								
Lincoln weed	+K			+K	+K							
lucerne (established)							+K					
lupin – volunteer	+K			+K	+K						+K	
mallow/marshmallow		+K	+K	+K							+K	
medic	+K		+K	+K							+K	
melons (check labels for species)		+K	+K	+K	+K		+K					
muskweed					+K						+K	
Mustards (check labels for species)	+K		+K	+K	+K						+K	

Table 17: (contd.) Key broadleaf fallow weeds and herbicides for their control for the GRDC Southern and Western Grains Regions Weed botanical names are listed in the glossary at the end of this report.

Various trade names often available under these formulations. See specific labels.	metsulfuron-methyl e.g. Ally®	Pyraflufen-ethyl e.g. Ecopar® Forte	pyraflufen-ethyl + 2,4-D LVE e.g. Pyresta®	2,4-D amine e.g. Amicide® Advance *	2,4-D LV ester e.g. Estericide® Xtra 680 *	2,4-D amine + picloram e.g. Tordon™75D	triclopyr + picloram + aminopyralid e.g. Grazon™ Extra NSW only	Fluroxypyr e.g. Starane™ Advanced	triclopyr e.g. Garlon™ FallowMaster 755	clopyralid e.g. Lontrel™ 750 SG	Saflufenacil e.g. Sharpen WG®	Glufosinate-ammonium e.g. Basta®
Herbicide group	B	G	G + I	I	I	I	I	I	I	I	G	N
Paterson's curse	+K		+K	+K	+K						+K	
peppercress												
pigweed			+K									
plantain												
radish – wild		+K	+K	+K	+K						+K	
rhynchosia												
rough poppy	+K			+K	+K							
saffron thistle				+K	+K					u2		
shepherd's purse	+K			+K	+K							
silverleaf nightshade					+K S			S				
skeleton weed	+K (s)			S +K	+K							
slender thistle				+K	+K					u2		
sorrel	+K			+K								
soursob	+K											
sowthistle	+K		+K	+K			+K				+K	
spear thistle				+K	+K					u2		
spiny emex	+K			+K							+K	
spurge												
stemless thistle												
stinging nettle (dwarf)					+K							
stinking goosefoot					+K							
sub. clover	+K		+K	+K	+K						+K	
sunflower, volunteer	+K			+K	+K							
turnip weed	+K		+K	+K	+K						+K	
variegated thistle				+K	+K					u2		
vetch				+K	+K							
Ward's weed				+K	+K							
wild/prickly lettuce	+K	+K		+K								
wild turnip	+K		+K	+K	+K							
wireweed	+K	+K		+K	+K							
Rec Water Vol L/ha Boom	50 min	Not given	60–150	50–250	30–100	50–100	50 min	50 min	50 min	50-100	80-250	

* = A number of weeds are controlled by 2,4-D without the need to be mixed with a knockdown. As this varies between product label and formulation, we have simplified the above table by flagging the need for a mix partner on all weeds

% = When followed by full disturbance cultivation or sowing with a tyned implement

a = Add 2, 4-D as/label for control

c = Tankmix with dicamba for improved control

DK = Follow with a robust rate of a Group L herbicide within a time as specified on the relevant label(s) from the date of the first application. While some products are registered for control of fleabane as stand-alone treatments, a double knock is often needed for commercial level results and especially when weeds are past the seedling growth stage.

j = Isoxaflutole has significant label constraints on soil types on which it can be used – check label for details. Mixing with glyphosate can reduce the efficacy of glyphosate.

+K = Add knockdown as/label

k2 = Add Garlonv Invader® or Surpass® at label rates on established weeds

l = Use glyphosate alone for camel melon only

+M = Add metsulfuron for control

p = Add dicamba at label rate for control

p4 = Double knock for improved control

p5 = Tank mix with Sharpen®

r = Add diuron South Australia only

S = Suppression only

t2 = See label for rates for controlling Roundup Ready® canola volunteers

u2 = Add MCPA amine. Consult label rate

** = Use with Goal herbicide

@ = Cotton volunteers – other than Liberty Link®

Several products with registrations for use in fallow were not included in the following table. We have sought to include representative labels of key herbicide actives, but have not sought to include information on the myriad of different formulations available. For example: there are many different formulations of glyphosate. At the time of writing, the Roundup Attack label was highly developed and was thus included alongside Roundup 450 CT. Several other products were not included as they had very limited weeds registered and/or or were very limited in the number of states. Some products not included in tables include:

- Atrazine. Some formulations have registration allowing use at low rates in some southern states prior to planting wheat, TT canola or peas.
- Several paraquat products (such as Gramoxone®) are registered for use prior to sowing for 'annual grass and broadleaved weeds'. These were not included in the weed specific tables below as a direct result of the very 'generic/non weed specific' nature of description of weeds on paraquat labels. Label states: "Aid to Cultivation to minimise cultivation and prepare a clean bed for sowing".
- Some grass active herbicides registered for use in fallow in NSW and Qld only are not included.
  - Imazapic (e.g. Flame®) Grass and broadleaved weeds.

Table 18: Key grass weeds of fallow and herbicides for their control. (Weed botanical names are listed in the glossary at the end of this report).

Various trade names often available under these formulations. See specific labels.	paraquat + diquat e.g. Spray.Seed®	Amitrole + paraquat e.g. Alliance®	Glyphosate e.g. Roundup® Attack™	Glyphosate 450 CT	Isoxaflutole e.g. Balance® 750 WG
Herbicide group	L	Q + L	M	M	H
annual phalaris					
annual ryegrass			a	a	
barley grass					
barnyard grass					J S
brome grass					
button grass					
cereals – volunteer					
couch			b f	b f	
liverseed grass					
nut grass/nutsedge			c f	c f	
phalaris – perennial					
stinkgrass					
summer grass					
vulpia			a	a	
wild oats					
winter grass					
Yorkshire fog					
Rec. water vol L/ha boom	50 - 200	50 – 200	80 max	80 max	50 min

Balance and products containing paraquat, paraquat/diquat, or paraquat/amitrole cannot be applied by air.

a = The addition of Wetter TX® may improve control of annual ryegrass, silver grass and perennial grasses. Good coverage is critical for control of silver grass. Wetter TX is not a general purpose surfactant and should only be used where specified on the label. Recommendations for the use of Wetter TX vary between some different formulations of glyphosate. Consult the product label

b = Best in conjunction with multiple applications and/or cultivation

c = See label for program

f = Apply summer followed again in autumn on any regrowth

j = Isoxaflutole has significant label constraints on soil types on which it can be used – check label for details. Mixing with glyphosate can reduce the efficacy of glyphosate

S = Suppression

Permits

At the time of writing, several permits existed in NSW and Queensland to enable use in these states of a slightly wider range of products in fallow situations, under specific situations. These permits cover several weeds, including feathertop Rhodes grass (*C. virgata*) and windmill grass (*C. truncata*), as well as a wider range of products and weeds when applied using a WeedSeeker. As permits do not constitute a registration and are transitory in nature, no detail has been included in this manual. Permit numbers applicable at the time of writing include: PER12941; PER13460 and PER11163.

7.3 Resistance issues

Most summer fallow herbicides have traditionally come from three mode of action groups (MOAs): Group M (glyphosate), Group I (phenoxies) and Group B (sulfonylureas and imidazolinones). In recent times, there has been a significant increase in the number of weed populations resistant to glyphosate. This has led to increased use of other MOA Groups/sub groups including: L (bipyridyls) and I (pyridines); A (Fops)*, B (SUs and imidazolinones) and C (triazines).

**At the time of writing, specified fop herbicides (Group A) are used in fallow under permits in NSW and Qld. There are significant restrictions on their use – including plant back and rotational restrictions due to soil residuals and the need for a double knock strategy. Use in a double knock is needed both for efficacy and to reduce the selection pressure for resistant weeds. Permits are temporary and will expire.*

Glyphosate has been widely used since the late 1970s and has been subjected to immense selection pressure for resistance. Since the first population of glyphosate resistant annual ryegrass was found in 1996, the frequency of glyphosate resistant weed populations has risen exponentially.

In addition to the increase in resistant weeds, there has also been species shift to weeds such as feathertop Rhodes grass (*Chloris virgata*) and flaxleaf fleabane (*Conyza bonariensis*) with high levels of natural tolerance to glyphosate. In the case of fleabane, many populations are now considered resistant; there have been documented increases in the lethal dose (LD50) of glyphosate needed to kill many populations.

PHOTO: John Cameron

Resistance to glyphosate is becoming widespread in Australian populations of several key grass and broadleaved weeds including: barnyard grass, liverseed grass, annual ryegrass, windmill grass and fleabane.

In 2007, glyphosate resistance was recorded in populations of awnless barnyard grass (*Echinochloa colona*) in New South Wales. This was followed in 2008, with liverseed grass (*Urochloa panicoides*) in New South Wales, in 2010 in fleabane (*Conyza bonariensis*) in Queensland and New South Wales and in windmill grass (*Chloris truncata*) in New South Wales. In 2011, glyphosate resistance was documented in great brome (*Bromus diandrus*) in South Australia.

In July 2013, there are 363 recordings of glyphosate-resistant populations of annual ryegrass, 76 of awnless barnyard grass, 57 of fleabane, 10 of windmill grass, 3 of liverseed grass and 2 of great brome. There are many more sites that have not been confirmed.

Phenoxy herbicides are widely used in fallow. Phenoxy's are usually added to glyphosate to enhance the weed spectrum on specific broadleaved weeds. While resistance has been slow to develop, phenoxy resistance in wild radish is very widespread in the Western Australian wheat belt. Populations of other brassica species including Indian hedge mustard have also been recorded as having developed resistance to phenoxy herbicides.

No herbicide mode of action group is immune to resistance, with populations of barley grass, annual ryegrass, capeweed and silver grass all recorded with resistance to paraquat.

7.4 Knockdown herbicides – notes on use

7.4.1 Glyphosate

- Must be applied using coarse droplets. (Label requirement)
- Highly translocated and not overly sensitive to application coverage. Coverage issues can arise with small targets (1-2 leaf upright and narrow leaved grasses) and large droplets
- High levels of clay binding makes it unavailable to roots with no effective soil residual
- Requires good quality water as it is inactivated by divalent and trivalent cations and clay dispersed in water

7.4.2 Paraquat

- Contact activity makes it sensitive to application coverage
- Medium/coarse droplets are recommended, with high carrier volumes to maintain the level of coverage needed
- Requires good quality water
- No effective soil residual

7.4.3 Phenoxies

- Must be applied using coarse droplets. (Label requirement)
- Highly translocated and not overly sensitive to application coverage
- Plant back restrictions apply to most products
- Activity at low dose rates makes droplet drift to non-target crops a significant issue. Some products also have vapour drift (particularly ester formulations)

7.5 Double knock tactics

Much of the information presented here is derived from the GRDC 2012 Factsheet titled 'Effective double knock herbicide applications'.

A double knock is where two weed control tactics with different modes of action, are applied to a single germination of weeds to stop weed survivors from setting seed. Both tactics do not need to be herbicides. Cultivation or seed destruction or removal could also be used as a second knock. The intent of the second knock is to stop seed set of any survivors of the first application.

The most common double knock is to apply a systemic herbicide (e.g. Group I or M are frequently used) when conditions are most suitable for maximum translocation. This is then followed by a contact herbicide such as the bipyridyls (Group L).

The following table represents some products frequently used for double knock applications in fallow. This list is not exhaustive. **Always refer to the registered product label.**

Table 19: Examples of herbicides for double knock applications.

Group A*	haloxyfop (Verdict®); quizalofop (Targa®)
Group G	saflufenacil (Sharpen®)
Group I	2,4-D; aminopyralid (Hotshot®); clopyralid (Lontrel®); dicamba (Cadence®); picloram (Tordon®)
Group L	paraquat (Gramoxone); paraquat + diquat (Spray.Seed®)
Group M	glyphosate (Roundup®)
Group N*	glufosinate (Basta®)
Group Q	amitrole
Group Q+L	amitrole + paraquat (Alliance®)

* Haloxyfop (PER 12941), quizalofop (PER 13460) and glufosinate (PER 11163) are at the time of writing permitted to be used in certain fallow situations as set out under the respective APVMA permits.

(First registered brand included in brackets) Herbicides that are shaded work by rapid contact activity so are normally restricted to the second application when used in a double knock program.

Reasons for adopting a double knock approach are:

1. Very high levels of weed control which drive down weed seed banks
2. If implemented well before resistance is apparent, double knock can delay the onset of herbicide resistance
3. Improved levels of control of difficult to kill weeds such as feathertop Rhodes, fleabane, sowthistle and glyphosate resistant windmill, barnyard and liverseed grass
4. Certain combinations of herbicides need to be applied as sequential applications where they cannot be tank mixed due to physical or biological incompatibility

Maximising the performance of double knock applications

Weeds targeted by the first knock should be small, (e.g. pre-tillering for grass weeds and still in the rosette stage for broadleaf weeds) and actively growing. Robust application rates and good coverage are required.

The second application controls any survivors. Contact products, such as paraquat are often used as the second knock. Paraquat is not highly systemic and does not move easily through the plant. It is best targeted to small seedlings only and must have a high level of coverage to achieve good results. As a result, it cannot always be relied upon to achieve 100% weed control. It is important to ensure the first application is robust and well timed.

Application timing

Generally, the second application should be applied before symptoms from the first application are evident. Poor results are often seen when application of the second knock is delayed until the first application is showing symptoms of failing.

The interval between applications affects the efficacy of the double knock. The ideal interval depends upon a number of factors which include:

- The type of herbicide being used for each application
- The species being targeted
- The size and age of the weeds, and
- The climatic conditions.

As a general rule, the smaller the weed the less time it will take for the first systemic herbicide product to translocate throughout the plant and intervals at the shorter end of the range can be employed. For example, a small pre-tillered susceptible barnyard grass seedling may fully translocate a Group A or Group M herbicide within as little as 2 or 3 days. Conversely, a fleabane plant that has started stem elongation may take 7 to 10 days to translocate a Group I or Group M herbicide.

If rain is forecast and access may be an issue, it is usually preferable to apply the second application a day or two earlier than the ideal timing. This reduces the risk of being kept off the paddock for an extended period of time due to wet conditions. This is especially important when using Group L products as the second knock, as these cannot be applied by air.

Application of contact herbicides used as the second knock

Contact herbicides require excellent plant coverage to achieve good results as they are not well translocated within the plant. To obtain the levels of coverage required by contact herbicides using medium to coarse droplet sizes, a much higher application volume is needed than is the case for translocated products such as glyphosate. The product label should always be consulted. A minimum carrier volume of 75 L/ha is suggested. Very coarse and extremely coarse droplet sizes are unlikely to provide sufficient spray coverage and should not be used.

7.6 The role of residual herbicides

Residual herbicides can be used in the fallow to reduce the level of selection pressure on knockdown herbicides and to potentially also reduce the number of sprays needed in wetter seasons/regions.

The downsides of residual herbicides are:

- Their residue places plant back restrictions on what crops can be sown and when
- They are often more subject to weed escapes than post emergent herbicides, and
- The cost is incurred whether weeds germinate or not.

PHOTOS: Andrew Storrie

Ideally weeds should be small enough when the second double knock (often paraquat) is applied as a contact herbicide will only provide poor control of plants with larger established root system. The fleabane illustrated are too large and woody for reliable control with any spray program.

Double knock results on fleabane are best when applied when the plant is still in the rosette stage before stem elongation. While the plants in the above picture are actively growing, they are well into stem elongation and good control cannot be guaranteed.

Table 20: Suggested intervals for some common double knock herbicide combinations.

Weed	First application	Second application	Recommended Timing	Comments
BROADLEAF WEEDS				
Most broadleaf weeds	Group M (e.g. glyphosate)	Group L (e.g. paraquat)	7 to 21 days. Optimal timing is generally 10 to 14 days	
Difficult to control broadleaf weeds such as fleabane (*Conyza bonariensis*)	Group I (e.g. 2,4-D, Tordon®) with or without a Group M (e.g. glyphosate) tank mix	Group L (e.g. paraquat)	7 to 21 days. Optimal timing is generally 10 to 14 days	
	Group M (e.g. glyphosate) plus saflufenacil	Group L (e.g. paraquat)	7 to 21 days. Optimal timing is generally 10 to 14 days	Only target small rosettes
Difficult to control broadleaf weeds such as sowthistle/ milk thistle (*Sonchus oleraceus*)	Group M (e.g. glyphosate)	2,4-D	2 to 4 days	Recommended to split applications due to incompatibility. As both products are systemic, the interval needs to remain tight.
	Group M (e.g. glyphosate)	Group L (e.g. paraquat)	7 to 10 days.	Only target small rosettes
	Group M (e.g. glyphosate) plus saflufenacil	Group L (e.g. paraquat)	7 to 21 days. Optimal timing is generally 10 to 14 days	Only target small rosettes
GRASS WEEDS				
Most annual grass weeds	Group M (e.g. glyphosate)	Group L (e.g. paraquat)	3 to 14 days. Optimal timing is generally 5 to 7 days	
Feathertop Rhodes grass (*Chloris virgata*)	haloxyfop	Group L (e.g. paraquat)	3 to 14 days. Optimal timing is generally 5 to 7 days	Refer to APVMA permit 12941 (valid to August 2016 - Qld. only)
Windmill grass (*Chloris truncata*)	quizalofop	Group L (e.g. paraquat)	3 to 14 days. Optimal timing is generally 5 to 7 days	Refer to APVMA permit 13460 (Valid to March 2017 - NSW only)
Mildly stressed grass or broadleaf weeds	Group L (e.g. paraquat)	Group L (e.g. paraquat)	Allow plants to put on new regrowth before applying the second application. This will usually be 3-4 weeks	Herbicide application to stressed weeds is usually not recommended. However if application is necessary it is generally advisable to avoid systemic products.

PHOTO: Andrew Storrie

A clean fallow starts with good in-crop weed management and planning.

7.7 Plant back

Plant back restrictions provide guidance when it is safe to sow a particular crop after using a herbicide with soil residual activity. It is not just the pre-emergent herbicides that have plant back restrictions. Many post-emergent herbicides also have sufficient soil residual activity that could damage a susceptible crop sown too early after use.

7.8 Starting with a clean fallow

It is a lot easier to manage weeds if the fallow starts clean and weed-free. Prior to the use of effective combinations of pre and post emergent herbicides in the early/mid 1980's, it was a common occurrence for a fallow to commence immediately after harvest with an existing deep and almost impenetrable mat of weeds. Wireweed, musk weed and Heliotrope were

Table 21: Guidelines for re-crop intervals - fallow herbicides (November 2013). Always check the product label before use as detail may change. Detail on a broader range of crops and pastures can be found on the product labels.

	Ally® (600g/kg metsulfuron) @	Amicide® Advance 700 (700g/L 2,4-D amine) ##			Estericide® Xtra 680 LV (680g/L 2,4-D LVE) ##			Kamba® 500 (500g/L dicamba) ##			Garlon® FallowMaster (755g/L triclopyr	Grazon Extra 300g triclopyr, 100g picloram, 8g aminopyralid (BW) **	Hotshot 10g aminopyralid, 140g fluroxypyr **	Lontrel® Advanced (600g/L clopyralid) ^^			Starane® Advanced (333g/L fluroxypyr) %%			Sharpen® WG (700 g/kg saflufenacil)	Pyresta® (2.1g/L pyraflufen-ethyl + 421g/L 2,4-D LVE) ##		Balance® (750g/kg isoxaflutole)	Goal® (240 g/L oxyfluorfen $$
MOA Group	B	I			I			I			I			I			I			G	G + I		H	G
Application rate/ha		<500 mL	500-980 mL	980– 1500 mL	<510 mL	510 mL-1L	1L-1.6L	200 mL	280 mL	560 mL	up to 130 mL	<500 mL	500 mL	<150 mL	150- 250 mL	>250 mL	225 mL	450 mL	900 mL	34g	250-500 mL	900 mL		75 mL
Barley	6w	1d	1d	3d	1d	1d	3d	1d	7d	14d	7d	9m**	9m**	7d	7d	7d	7d	7d	7d	1h	1d	1d	10w ! (100 mm ~)	1d
Canola	9m*	14d$	21d$	28d$	14d$	21d$	28d$	7d	10d	14d		9m**	9m**	7d	7d	7d				16w	14d	21d	9m (350 mm ~)	1d
Chickpea	9m	7d$	14d$	21d$	7d$	14d$	21d$	ND	21d	28d	7d	24m**	20m**	9m	12m	24m	7d	7d	7d	1h	7d	14d	0h	
Cotton		10d	14d	21d	10d	14d	21d	7d	7d	14d	14d						14d	14d	28d	6w	10d	14d	7m (350 mm ~)	7d
Fababean	9m	7d	7d	10d	7d	7d	10d					24m**	20m**	9m	12m	24m				1h	7d	7d	9m (250 mm ~)	1d
Field pea	9m	7d	14d	14d	7d	14d	14d	ND	14d	21d		24m**	20m**	9m	12m	24m				1h	7d	14d	9m (250 mm ~)	1d
Lentils	9m	7d	7d	10d	7d	7d	10d							9m	12m	24m				1h	7d	7d	21m (500 mm ~)	
Lucerne	9m	7d	7d	10d	7d	7d	10d					24m**	20m**								7d	7d	9m (350 mm ~)	1d
Lupins	9m	7d +W	14d +W	21d +W	7d +W	14d +W	21d +W	7d	14d	21d		24m**	20m**	9m	12m	24m				1h	7d Z	14d Z		1d
Medics	9m#	7d	7d	10d	7d	7d	10d	7d	14d	21d		24m**	20m**	9m	12m	24m					7d	7d	21m (500 mm ~)	1d
Oats	9m	3d	3d	7d	3d	3d	7d	1d	7d	14d				7d	7d	7d				1h	3d	3d	10w ! (100 mm ~)	1d
Sorghum	14m	3d	7d	10d	3d	7d	10d	1d	3d	7d	7d						7d	7d	7d	1d	3d	7d	7m (250 mm ~)	
Sub clover	9m#	7d	7d	10d	7d	7d	10d	7d	14d	21d		24m**	20m**	9m	12m	24m				1h	7d	7d	21m (500 mm ~)	1d
Triticale	6w	1d	3d	7d	1d	3d	7d	1d	7d	14d											1d	3d		1d
Wheat	10d	1d	3d	7d	1d	3d	7d	1d	7d	14d	7d	9m**	9m**	7d	7d	7d	7d	7d	7d	1h	1d	3d	10w ! (100 mm ~)	1d

Legend: h=hours, d=days, w=weeks, m=months, ND=Not Determined

@ = re-crop intervals for Ally apply for soils within a pH range of 5.6 to 8.5

* = re-crop intervals of 10 days apply for imidazolinone tolerant varieties as specified on the Ally Label

= Natural regeneration of sub clover and medics

= When applied to dry soils, at least 15mm of rain must fall prior to the commencement of the plant back period

$ = In Qld. Sowing of canola, chickpeas and safflower must be delayed by at least 14 days following rainfall of at least 15mm.

+W = In WA the plant back for lupins is 28 days

** At all plant back intervals for Grazon and Hotshot: Consult the product label for plant back intervals for NNSW and Qld as these differ from those presented for SNSW and or other states for Hotshot. Plant back periods are based on a normal rainfall pattern. During drought conditions (or when rainfall is less than 100 mm for a period of 4 months or greater) the plant back period may be significantly longer.

(BW) = Blanket wiper applications of Grazon Extra re-crop intervals are 18 months for broadleaf crops and 6 months for lucerne

^^ = Lontrel Advanced: Consult the product label for plant back intervals for NNSW and Qld as these differ from those presented for SNSW and or other states. A minimum 25 mm rain event in the post-harvest summer to autumn period, with a subsequent extended period of at least 1-week where the top 10cm of the soil stays moist is required to enable breakdown of soil residues. Fastest residue breakdown will occur under good soil moisture and warm conditions which promote microbial activity. The plant back intervals as presented apply where significant rain (>25 mm) has fallen in summer to autumn, with soil wetting for at least one week.

%% = Starane Advanced: DO NOT plant susceptible crops, including cotton, pigeon peas and other pulse crops, into irrigated fields with soils containing less than 25% clay content, within 12 months of treatment with Starane Advanced.

! = If Balance has been tank mixed with simazine, observe the re-cropping interval for simazine for wheat, barley, oats and maize

~ = minimum rainfall total from application of Balance until planting of the subsequent crop. Do not include flood or furrow irrigation in the minimum rainfall requirement.

$$ = Goal 240 gai oxyfluorfen: At rates up to 75mL can be safely applied 1-day prior to planting wheat, barley, oats, triticale, canola, lupins, fababeans, field peas and under sown pastures (lucerne, clover, medics, ryegrass, phalaris, cocksfoot) and 7 days minimum prior to planting cotton or soybeans, provided minimum tillage planting equipment is used with minimal soil disturbance. Inversion, mixing of surface soil with that in the planting zone or covering seed may result in injury to emerging crop seedlings. Avoid covering the seed with soil treated with Goal herbicide during the planting operation to minimise crop injury.

Z = in Western Australia, the plant back period for Pyresta in lupins is 28 days common offenders. These large dense stands of weeds were often un-economic to control with fallow herbicides and required tillage. Indeed, their skeletons if not smashed up with multiple tillage passes would be an impediment to crop establishment. Looking back – the seed bank was 'over the top'!

In more recent times, most growers run their in-crop weed management a lot better, with most fallows starting relatively clean and weed-free.

Of particular concern has been the occurrence of glyphosate resistant or tolerant grass weeds already established prior to harvest in recent wet springs (i.e. *Chloris truncata, Chloris virgata, Urochloa panicoides* and *Echinochloa colona*). Such hard to kill weeds that are already established when the crop is harvested and are too big for cost effective treatment with a double knock tactic, are likely to require a return to tillage early in the fallow period.

Work is underway to evaluate a range of 'in-crop' management strategies (including several pre-emergent herbicides) to reduce the chance/frequency of these problem weeds becoming established prior to harvest.

Good in-crop management of weeds such as fleabane and milk thistle is critical to starting the fallow clean. For the two weeds mentioned, often weed escapes are germinating later in the season in spring. Preliminary research evaluating the use of a number of in-crop residual herbicides is yielding promising results. Better results can be achieved from early rather than later in-crop applications of pre-emergent herbicides. It appears that the earlier applications are getting to the soil (the target) with less interception by the younger crop canopy than later applications.

7.9 Assessment questions

1. **The 'wait and see' approach to spraying during summer fallow after rainfall is a high risk strategy because (There may be more than one correct response)**
   a. All rainfall events add significant moisture to the soil profile
   b. All rainfall events lead to weed germination and seed set
   c. Uncontrolled weeds will deplete moisture, may become difficult to control if not controlled when young and may set seed causing a worse weed problem for future years
   d. Weeds grow more quickly after isolated rainfall events and are most likely to set seed

2. **Costs of the 'wait and see' approach can be higher due to (There may be more than one correct response)**
   a. Higher rates of fertiliser may be required as weeds that are allowed to grow larger tie up greater amounts of nitrate
   b. Higher rates of herbicide are needed to kill larger and potentially more stressed weeds
   c. More than one herbicide spray may be required to kill larger weeds
   d. Weed escapes could interfere with sowing operations

3. **There has been resistance demonstrated in fallow weeds to which of the following herbicide groups?**
   a. Group M (glyphosate)
   b. Group I (e.g. phenoxies)
   c. Group B (sulfonylureas and imidazolinones)
   d. Group L (e.g. paraquat)
   e. All of the above

4. **Due to widespread use of glyphosate since the late 1970s, which of the following is true?**
   (more than one correct response)
   a. Since the first population of glyphosate resistant annual ryegrass was found in 1996, the frequency of glyphosate resistant weed populations has risen significantly
   b. There has been species shift to weeds such as feathertop Rhodes grass due to high levels of natural tolerance to glyphosate
   c. Levels of resistance to glyphosate of weeds has remained unchanged – species shift to less susceptible species is all that has occurred
   d. Fence lines, roadsides and long term no-till paddocks where there has been extensive use of glyphosate over a prolonged number of years are key areas where glyphosate resistant weeds are likely to be first seen

5. **In applying glyphosate herbicide, it is important to (select one answer)**
   a. Use coarse droplets in accordance with the label requirements to reduce drift
   b. Use a fine mist to ensure complete coverage
   c. Use any droplet size as there are no issues related to droplet size
   d. Use as much water as possible to ensure maximum coverage

6. **Which of the following statements are true in relation to spraying glyphosate? (There may be more than one correct response)**
   a. Highly translocated and not overly sensitive to application coverage. Issues can arise with small targets (1-2 leaf upright and narrow leaved grasses) when using low carrier volumes and large droplets
   b. High levels of clay binding makes it unavailable to roots with no effective soil residual
   c. Requires good quality water as it is inactivated by divalent and trivalent cations and clay dispersed in water
   d. There are no restrictions or considerations in the use of glyphosate

7. **Which of the following statements are correct regarding the application of bipyridyl herbicides during fallow spraying?**
   a. Contact activity makes it sensitive to application coverage
   b. Medium/coarse droplets are recommended, with high carrier volumes to maintain the level of coverage needed
   c. Does not require good quality water
   d. There is no effective soil residual

8. **Which of the following statements are correct regarding the application of phenoxies during fallow spraying?**
   a. Must be applied with coarse droplets. (Label requirement)
   b. Contact activity makes it sensitive to application coverage
   c. Plant back restrictions apply to most products.
   d. Activity at very low dose rates makes droplet drift to non-target crops a significant issue

9. **A Double Knock is where two weed control tactics, with different modes of action are applied to a single germination of weeds to stop weed survivors from setting seed. Which of the following would represent a Double Knock situation? (There may be more than one correct response)**
   a. Two sprays of glyphosate a week apart to control difficult weeds
   b. Spray of glyphosate followed by a spray of paraquat one week later
   c. Spray using a Group A herbicide followed by a bipyridyl
   d. Spray using a Group M herbicide followed by tillage before any weed survivors have set seed

10. **The reasons for adopting a Double Knock approach can include which of the following? (There may be more than one correct response)**
   a. Very high levels of weed control which drive down weed seed banks
   b. If implemented well before resistance is apparent, double knock can delay the onset of herbicide resistance
   c. Improved control of difficult to control weeds such as feathertop Rhodes grass, fleabane and sowthistle

11. **Which of the following is NOT a factor in determining the interval between the successive treatments in a Double Knock tactic for weed control?**
   a. The type of herbicide being used for each application
   b. The species being targeted
   c. The yield of the last crop grown
   d. The climatic conditions

8 Spray application

Key issues:

- Plan spray capability to cater for double knock capacity on a proportion of country
- Night spraying can take pressure off spray logistics, but extreme care is needed as inversion and high drift risk conditions are far more common at night, and
- WeedSeeker and Weedit technologies can greatly reduce the volumes of herbicide needed when targeting low density weed populations in fallows. Reductions of up to 90% are commonly reported.

8.1 Spray timing and logistics

With increasing use of double knock to achieve adequate control, there is logistical stress on the grower's ability to cover country in the available window before weeds become too large or moisture stressed.

Example:
Objective: to cover all fallow area in 7 x 8 hour days with a farming area of 5,500 ha

- ☐ Max. fallowed area = 4,400 ha
- ☐ Need to cover 78 ha/hr
- ☐ Assuming ground speed of 16 km/hr is needed with a spray width of 49 metres
- ☐ *Covered with 2 x 24 metre linkage booms*

The above example can be modified in the following ways to reflect extra stress placed on the system by harder to kill weeds.

- Double knock e.g. treating 30% of fallow area twice over 7 days adds a needed capacity increase of 30%
- Residual herbicide e.g. on all fallow area in front of a 4 day rainfall forecast adds a 76% increase to the required spray capability

Some of the key options to address this include:

- More multiples of 24 metre linkage booms - but need more drivers
- Wider and faster trailing booms 36 – 48 m. – but problems with contour banks, melon holes, trees etc.
- Faster and wider self-propelled booms can assist, but are very expensive ($400 k +) and single use
  - ☐ Generally 3 metre centres - promotes a change to whole equipment layout
  - ☐ Boom speeds above approximately 20-25 kph are not recommended
- Employ a contractor

Wider and faster boom sprays need more room and changes to layout may be required:

- ☐ Remove old fence lines/strip layout
- ☐ Increase management unit size
- ☐ Appeal at the deity level seeking lightning strikes to take out isolated trees.

Growers already in a full no-till system may need to consider increasing their cultivation capacity to:

- Remove stressed escapes (weeds once wounded are near impossible to kill with herbicides)
- Remove heavily clumped weeds (e.g. well established windmill or feather top Rhodes)
- Bury short lived surface germinating weed seeds to manage the seed bank (fleabane, windmill grass & feather top Rhodes grass)
- Stimulate a more uniform germination of the seed bank and
- Provide a better bed for pre-emergent herbicides.

PHOTOS: John Cameron

Onboard weather stations and 'smokers' can help drivers identify inversion conditions and determine when conditions are no longer suitable for spraying.


PHOTO: John Cameron

WeedSeeker/WEEDit technology can reduce the fallow herbicide bill on some sprays by up to 90%.

8.2 Spraying at night

Accurate night spraying is now far easier with the advent of GPS and self-steer technologies. There is evidence that weed stress due to heat is somewhat less at night and this can on occasion lead to slightly better kill rates when under marginal stress conditions.

However, in many areas near to sensitive crops such as vineyards or cotton, night spraying has led to a significant increase in off-target drift issues. Inversion conditions are far more likely to occur at night and if present, spraying should not occur. Even when using a coarse droplet spectrum, it takes effort to eliminate all droplets that could drift under inversion conditions.

8.3 Precision spray application

WeedSeeker and WEEDit technologies enable far more cost effective use of fallow herbicides as only a small percent of the paddock is sprayed. These technologies are ideal when weed populations are very low or when targeting weed escapes from previous sprays with robust rates.

8.4 Assessment questions

1. **Accurate night spraying is now far easier with the advent of GPS and self-steer technologies. What are the risks of spraying at night? (There may be more than one correct response)**
   a. Off target drift issues in cotton and vineyards
   b. Increased chance of inversion conditions
   c. Reduced heat stress on weeds
   d. All of the above

2. **The double-knock strategy can cause logistical stresses to growers. Which statement is NOT appropriate for increasing spray capacity?**
   a. Increase boom speed above 20-25 km/h
   b. More multiples of 24 metre linkage booms
   c. Employ a contractor
   d. Purchase a self-propelled spray rig

3. **When there are only a small number of weeds in a fallow, spraying the whole paddock is expensive. What technology is available to reduce the amount of chemical applied whilst spraying all survivors? (There may be more than one correct response)**
   a. WeedSeeker
   b. WEEDIt
   c. Aerial application
   d. Self-propelled spray rig

4. **Growers already in a full no-till system may need to consider increasing their capacity to cultivate. Which statement(s) below demonstrates the benefit of cultivation to control hard to kill summer weeds?**
   a. Potential to spread weed seed throughout the paddock as well as prolonging seedbank dormancy
   b. Stimulates a more uniform germination of the seed bank
   c. Provide a bed for pre-emergent herbicides
   d. Bury short lived surface germinating weed seeds to manage the seed bank e.g. (fleabane, windmill grass & feathertop Rhodes grass)

5. **Which of the following statements are correct concerning night time spraying?**
   a. Under conditions of marginal weed stress, kill rates from sprays applied in the cooler night time temperatures can sometimes be slightly better than when applied during the heat of the day
   b. The risk of drift from night time spraying is generally lower than spraying in the heat of the day
   c. The risk of drift from night time spraying is generally much higher than spraying in the heat of the day, as temperature inversions that can lead to widespread drift are far more likely at night time

9 Case studies

9.1 Research case study - nitrogen and soil water – Southern NSW 1

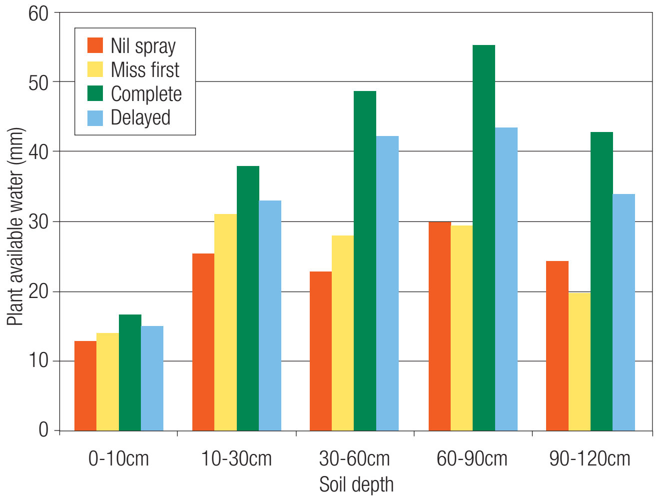
Research at Gunningbland in 2011 and 2012, (McMaster personal communication) evaluated the impact of summer weed growth during a short fallow period on stored moisture, nutrient retention and grain yield. In 2011, an unusually wet harvest/summer period (323 mm of fallow rain) allowed moisture to be stored at depth very early in the fallow period. Consequently, early weed control was vital to store and keep valuable subsoil moisture.

Key issues:

- In 2011, 50% of the yield of the next crop (canola) was derived from water retained by controlling summer weeds
- For every millimetre of moisture lost via summer weed growth, nitrogen levels were also reduced by approximately 0.67 kg/N/ha
    a. Where weeds were controlled, plant available nitrogen levels at sowing increased by 156% (69 kg N/ha) in 2011 and by 40% (32.5 kg N/ha) in 2012
    b. To replace this amount of nitrogen with urea would cost approximately $180/ha (2011) and $46 (2012) (at 50% efficiency)
- Stored moisture at sowing increased by 74% (85 mm) in 2011, and by 51% (50 mm) in 2012
- Uncontrolled weeds extracted soil moisture to a depth of at least 1.2 m
- Weed control had no significant impact on topsoil phosphorus and potassium levels, or sulphur levels to a depth of 90 cm
- Every dollar invested in fallow sprays returned $8. Longer term the return/$1 spent on fallow weed management is consistently in the $4-$8 range, and
- Stored moisture improved the profitability of nitrogen topdressing three-fold. Despite poor topdressing conditions, the profitability of additional nitrogen fertiliser increased from $1 return on every $ invested after the weedy fallow, to a $3 return for every $ invested after the weed-free-fallow.

In this trial, growing season rain was 199 mm in 2011. Delays to spraying weeds or 'missed spray strategies' resulted in losses of PAW at sowing – particularly at depth.

Figure 9: Distribution of PAW (mm) within the profile at sowing.



SOURCE: (McMaster et al 2011).

Table 22: Impact of summer weed control on PAW (mm) measured at sowing.

Spray treatment	2011 PAW (mm)	2012 PAW (mm)
Nil spray	115.5	97.3
Miss first	121.6	155
Full spray	201.3	147.3
Delayed spray	167.6	158.7
LSD (p-0.05)	43.15	37.18

Similarly, complete control of weeds resulted in higher levels of soil mineral N at sowing than in treatments where weeds were less well controlled (Table 24).

Table 23: Mineral nitrogen data.

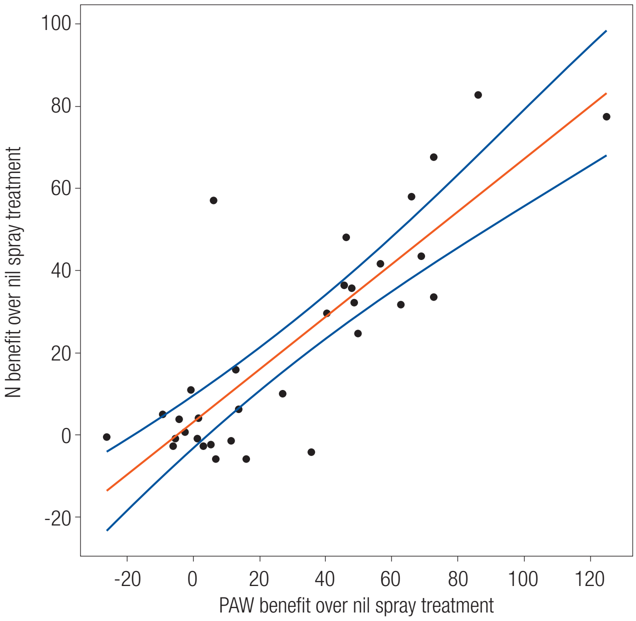
Spray treatment	2011 Nitrogen (kgN/ha)	2012 Nitrogen (kgN/ha)
Nil spray	44.4	80.4
Miss first	72.2	120.6
Full spray	113.8	112.9
Delayed spray	81.7	125.5
LSD (p-0.05)	36.04	20.9

Note: Mineral N only tested to 90 cm depth

SOURCE: (McMaster et al. 2011) (2012 data McMaster personal communication).

As PAW increased, so did the amount of N available for plant uptake. It was believed this result related to both less tie up by weeds as well as higher levels of N mineralisation where there was more soil water (Figure 10).

Figure 10: Fitted and observed relationships between moisture (PAW mm) and nitrogen (Mineral N kgN/ha) loss via summer weed growth with 95% confidence intervals (across 2011 and 2012).



SOURCE: (McMaster personal communication 2013).

Fallow weed management increased crop yield by an average of 0.83 t/ha in 2011. Table 24 shows gross margin calculations in more detail.

Table 24: Economic analysis of fallow treatments and benefits to subsequent canola crop.

Spray treatment	Fallow spray details			Nitrogen rate (N kg/ha)	Cost of nitrogen ($/ha)	Partial analysis[b]			Total variable ($/ha)	Yield (t/ha)	Income ($/ha)[a]	Gross margin ($/ha)
	No of sprays	Herbicide rate low	Cost ($/ha)			Cost ($/ha)	Benefit ($/ha)	Benefit cost ratio[c]				
Nil spray	1	H	$24	0 70 140	$0 $119 $238	$24 $143 $262	 $196 $267	 1.4 1.0	$406 $580 $699	0.65 1.04 1.18	$323 $519 $590	-$83 -61 -$109
Miss first	2	H, L	$42	0 70 140	$0 $119 $238	$42 $161 $280	$120 $299 $501	2.9 1.9 1.8	$479 $598 $717	0.89 1.25 1.65	$443 $623 $825	-$36 $25 $108
Complete spray	3	L, L, L	$54	0 70 140	$0 $119 $238	$54 $173 $292	$441 $500 $767	8.2 2.9 2.6	$491 $610 $729	1.53 1.65 2.18	$764 $823 $1,091	$273 $213 $362
Delayed spray	3	H, H, H	$72	0 70 140	$0 $119 $238	$72 $191 $310	$352 $571 $727	4.9 3.0 2.3	$509 $628 $747	1.35 1.79 2.10	$675 $895 $1,050	$166 $267 $303

SOURCE: (McMaster et al. 2011).

Notes

[a] Canola valued at $500/t

[b] Partial analysis in benifit and cost related to treatment change

[c] Ratio compares the benefit of treatments over the Nil spray/Nil N fertiliser treatment

[d] Total variable costs have been sourced from I & I NSW Farm Gross Margin Guide 2011 (Canola, short fallow (No-till) Central zone - West)

[e] H = High herbicide rate required ($24/ha including application)
L = Lower herbicide rate required ($18/ha including application)

[f] Ezy N was the form of nitrogen applied at $1.70/unit of N

9.2 Research case study - nitrogen and soil water – Southern NSW 2

Key observations:

- At three sites in Central NSW (Gunningbland, Tottenham and Rankin Springs) in 2010, summer weed control increased grain yield up to 137%
- Stored moisture at sowing was by up to 49 mm (60%) and nitrogen levels by up to 32 kg/ha, and
- Clean weed-free-fallows had relatively low cost for high potential returns due to improved moisture and nitrogen use efficiency. Every dollar invested in fallow sprays on average returned $3.90 (Haskins & McMaster, 2012).

2010 was an extremely wet year at all sites. Good rainfall in Feb/Mar and May enabled sowing at the ideal time with good levels of stored subsoil moisture. Good rain in September provided ideal conditions during flowering and grain fill, making 2010 one of the best years on record.

At the Gunningbland site, an extra 49 mm of PAW was retained when weeds were controlled, while at Tottenham only an extra 22 mm was stored. This was under excessively wet summer conditions (467.9 mm) **where most treatments had a full profile of moisture at sowing despite the various stubble and weed control treatments.**

Stubble treatments such as stubble standing/slashed/ cultivation or deep ripping had no significant impact on moisture or nutrient retention at the Gunningbland or Tottenham sites in 2010, but differences were seen at the Rankin Springs site.

Unusually high fallow efficiencies where achieved at Gunningbland in 2010, ranging from 29% to 46%. This is significantly higher than the typical range of 20-30% and is believed due to much of the rainfall occurring in the latter half of the fallow period (Feb/Mar/Apr) when soil evaporation losses were much lower than in the peak of summer.

Table 25: Impact of fallow management on moisture and nutrient retention at Gunningbland in 2010.

Treatment	PAW (mm)			Fallow efficiency	Mineral nitrogen (kg/N/ha)		
Nil spray	81	100%	a	29%	54.8	100%	a
Miss first spray	114	141%	b	40%	98.1%	179%	c
Complete spray	130	160%	c	46%	103.3	189%	c
Delayed spray	118	146%	b c	42%	82.3	150%	b
P-value	<0.001				<0.001		

Note: * PAW was measured to a depth of 1.2m, and mineral nitrogen was measured to 90cm.

SOURCE: (Haskins & McMaster, 2012).

At Tottenham in 2010, differences in moisture retention between treatments were far lower. This site has a PAW holding capacity of only approximately 100 mm in the top 1.2 m and with very wet conditions, all treatments except the nil spray treatment achieved full profiles at sowing.

Table 26: Impact of fallow management on moisture retention at Tottenham in 2010.

Treatment	PAW (mm)			Fallow efficiency %
Nil spray	78.8	a	100%	17%
Miss first spray	96.3	b	124%	21%
Complete spray	100.1	b	129%	21%
Delayed	104	b	134%	22%
P-value	0.03			

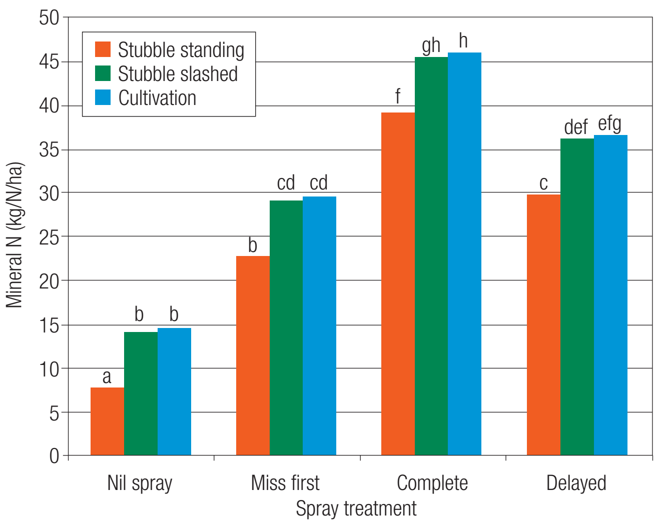
Note: *PAW was measured to a depth of 1.2m.

SOURCE: (McMaster et al. 2010).

At the Gunningbland site in this very wet fallow season, there was no significant moisture penalty between the 'complete spray' and 'miss first spray' treatments. A zero tolerance to summer weeds did however increase nitrogen availability for plant uptake by 89% (48.5 units of nitrogen). To replace this amount of nitrogen via urea fertiliser, would cost approximately $136/ha (urea at $650/t on farm) if the fertiliser was 50% efficient.

At the Tottenham site in 2010, controlling summer weeds increased nitrogen availability to the following crop by approx. 31 kg/ha of nitrogen over nil weed control, with an additional 5-7 kg/ha of nitrogen made available via cultivation or by stubble removal treatments. This small increase in nitrogen availability is thought to be due to increased soil residue contact (cultivation treatment) or reduced nitrogen tie-up (stubble removed treatment).

Figure 11: Impact of summer fallow management on nitrogen at Tottenham.



SOURCE: (Haskins & McMaster, 2012).

Zero tolerance of summer weeds gave the greatest response to both grain yield and profit with the yield at Gunningbland in 2010 increasing by 65% over the nil weed control treatment. The most profitable treatment was stubble standing/complete weed control with a return on investment of $5 for every $1 invested on fallow herbicide sprays.

Controlling summer weeds at the Tottenham site in 2010 also gave the greatest response to both grain yield (by up to

237%, see Table 29, page 50) and profitability. Similar to the Gunningbland site, every dollar invested in summer sprays returned an additional $4.60.

Stubble treatments (stubble slashed, removed or cultivated) had no significant impact on yield.

Table 27: Impact of fallow management on yield (t/ha) Tottenham 2010.

Treatment	Yield (t/ha)		
Nil spray	101	a	100%
Miss first spray	1.69	b	167%
Complete spray	2.39	c	237%
Delayed	2.11	d	209%
P-value	<0.001		

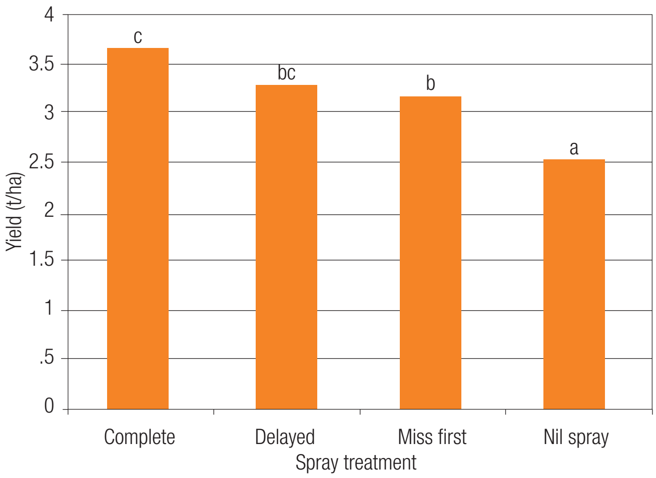
SOURCE: (Haskins & McMaster, 2012).

At the Rankin Springs site in 2010, there was a significant impact of both stubble management and weed control on yield and gross margin. There was no significant interaction between stubble management and weed control.

Crop waterlogging, nitrogen tie up and foliar disease from yellow leaf spot led to some yield loss in the standing stubble treatment.

Weed control was the major influence on yield at Rankin Springs, with the full control treatment yielding 145% of the unsprayed treatment. Each dollar spent on herbicides returned an average of $2.20 when the stubble was left standing. This return was lower than at the other two sites due to increased herbicide costs associated with 2 additional herbicide applications in a longer fallow period.

Figure 12: Impact of weed control treatments on yield at Rankin Springs.



SOURCE: (Haskins & McMaster, 2012).

Table 28: Economic analysis of Gunningbland site.

Stubble treatment	Spray treatment	Cost of stubble treatment ($/ha)	Fallow spray details			Partial analysis[b]			Total Variable costs ($/ha)[d]	Yield (t/ha)	Income ($/ha)[a]	Gross margin ($/ha)
			No of sprays	Herbicide rate (high or low)[e]	Cost ($/ha)	Cost ($/ha)	Benefit ($/ha)	Benefit cost ratio[c]				
Stubble standing	Nil spray	$0	1	H	$24	$24			$202	2.16	$389	$187
	Miss first spray	$0	2	H, L	$42	$42	$272	6.5	$220	3.67	$661	$441
	Complete spray	$0	3	L, L, L	$54	$54	$266	4.9	$232	3.64	$655	$423
	Delayed spray	$0	3	H, H, H	$72	$72	$158	2.2	$250	3.04	$547	$297
Stubble slashed	Nil spray	$12	1	H	$24	$36	-$43	-1.2	$214	1.92	$346	$132
	Miss first spray	$12	2	H, L	$42	$54	$229	4.2	$232	3.43	$617	$385
	Complete spray	$12	3	L, L, L	$54	$66	$221	3.4	$244	3.39	$610	$366
	Delayed spray	$12	3	H, H, H	$72	$84	$115	1.4	$262	2.80	$504	$242
Cultivation	Nil spray	$30	1	H	$24	$54	$54	1.0	$232	2.46	$443	$211
	Miss first spray	$30	2	H, L	$42	$72	$326	4.5	$250	3.97	$715	$465
	Complete spray	$30	3	L, L, L	$54	$84	$319	3.8	$262	3.93	$707	$445
	Delayed spray	$30	3	H, H, H	$72	$102	$212	2.1	$280	3.34	$601	$321
Deep ripping + cultivation[f]	Nil spray	$120	1	H	$24	$144	$67	0.5	$322	2.53	$455	$133
	Miss first spray	$120	2	H, L	$42	$162	$340	2.1	$340	4.05	$729	$389
	Complete spray	$120	3	L, L, L	$54	$174	$333	1.9	$352	4.01	$722	$370
	Delayed spray	$120	3	H, H, H	$72	$192	$225	1.2	$370	3.41	$614	$244

SOURCE: (Haskins & McMaster, 2012).

Table 29: Economic analysis of Tottenham site.

Stubble treatment	Spray treatment	Cost of stubble treatment ($/ha)	Fallow spray details			Partial analysis[b]			Total Variable costs ($/ha)[d]	Yield (t/ha)	Income ($/ha)[a]	Gross margin ($/ha)
			No of sprays	Herbicide rate (high or low)[e]	Cost ($/ha)	Cost ($/ha)	Benefit ($/ha)	Benefit cost ratio[c]				
Stubble standing	Nil spray	$0	1	H	$24	$24			$202	1.01	$182	-$20
	Miss first spray	$0	2	H, L	$42	$42	$122	2.9	$220	1.69	$304	$84
	Complete spray	$0	3	L, L, L	$54	$54	$248	4.6	$232	2.39	$430	$198
	Delayed spray	$0	3	H, H, H	$72	$72	$198	2.8	$250	2.11	$380	$130
Stubble slashed	Nil spray	$12	1	H	$24	$36	$0	0.0	$214	1.01	$182	-$32
	Miss first spray	$12	2	H, L	$42	$54	$122	2.3	$232	1.69	$304	$72
	Complete spray	$12	3	L, L, L	$54	$66	$248	3.8	$244	2.39	$430	$186
	Delayed spray	$12	3	H, H, H	$72	$84	$198	2.4	$262	2.11	$380	$118
Cultivation	Nil spray	$30	1	H	$24	$54	$0	0.0	$232	1.01	$182	-$50
	Miss first spray	$30	2	H, L	$42	$72	$122	1.7	$250	1.69	$304	$54
	Complete spray	$30	3	L, L, L	$54	$84	$248	3.0	$262	2.39	$430	$168
	Delayed spray	$30	3	H, H, H	$72	$102	$198	1.9	$280	2.11	$380	$100

SOURCE: (Haskins & McMaster, 2012).

Table 30: Economic analysis of Rankin Springs site.

Stubble treatment	Spray treatment	Cost of stubble treatment ($/ha)	Fallow spray details			Partial analysis[b]			Total Variable costs ($/ha)[d]	Yield (t/ha)	Income ($/ha)[a]	Gross margin ($/ha)
			No of sprays	Herbicide rate (high or low)[e]	Cost ($/ha)	Cost ($/ha)	Benefit ($/ha)	Benefit cost ratio[c]				
Stubble standing	Nil spray	$0	2	L, H	$30	$30			$172	2.34	$421	$249
	Miss first spray	$0	4	L, H, L, H	$72	$72	$76	1.1	$214	2.76	$497	$283
	Complete spray	$0	5	L, H, L, H	$72	$72	$104	1.5	$214	2.92	$525	$311
	Delayed spray	$0	4	L, L, L, H, H	$84	$84	$183	2.2	$226	3.36	$604	$378
Stubble slashed	Nil spray	$12	2	H	$42	$42	$31	0.7	$184	2.51	$452	$268
	Miss first spray	$12	4	L, H, L, H	$84	$84	$103	1.2	$226	2.92	$525	$298
	Complete spray	$12	5	L, H, L, H	$84	$84	$170	2.0	$226	3.29	$591	$365
	Delayed spray	$12	4	L, L, L, H, H	$96	$96	$261	2.7	$238	3.79	$682	$444
Cultivation	Nil spray	$30	2	H	$72	$72	$3	0.1	$214	2.36	$425	$210
	Miss first spray	$30	4	L, H, L, H	$114	$114	$239	2.1	$256	3.67	$660	$404
	Complete spray	$30	5	L, H, L, H	$114	$114	$151	1.3	$256	3.18	$572	$316
	Delayed spray	$30	4	L, L, L, H, H	$126	$126	$278	2.2	$268	3.89	$700	$431
Deep ripping + cultivation[f]	Nil spray	$110	2	H	$152	$152	$101	0.7	$294	2.91	$523	$229
	Miss first spray	$110	4	L, H, L, H	$194	$194	$179	0.9	$336	3.34	$600	$264
	Complete spray	$110	5	L, H, L, H	$194	$194	$241	1.2	$336	3.68	$662	$326
	Delayed spray	$110	4	L, L, L, H, H	$206	$206	$228	1.1	$348	3.61	$650	$302

SOURCE: (Haskins & McMaster, 2012).

Notes

[a] Grain quality reduced to feed due to weather damage - assumed value of $180/t

[b] Partial analysis in benefit and cost related to treatment change

[c] Ratio compares the benefit of treatments over the standing stubble/nil spray treatment

[d] Total variable costs have been sourced from NSW DPI Farm Gross Margin Guide 2010 (Wheat, short fallow central west zone)

[e] H = High herbicide rate required ($24/ha including application)
L = Lower herbicide rate required ($18/ha including application)

[f] Cultivation required to level deep ripping

[g] Fallow commencement herbicide added to all treatments, hence why Nill spray treatment had 2 herbicides (fallow commencement and knockdown prior to sowing)

9.3 Research Case Study - Seasonal rainfall patterns and soil types - Victoria

At sites 13 km south of Hopetoun in Victoria, Browne et al. (2010) started a several year +/- summer weed trial on two soil types;

- A sand over sandy loam and
- A clay loam over medium clay with subsoil constraints (sodosol) typical of the region.

Key observations:

- In 2008-9, most of the 90 mm fallow rainfall evaporated, leaving a difference of only + 10 mm PAW in the no weeds treatment at sowing. With good growing season rainfall of 213 and 202 mm at the sand and clay sites respectively, no difference was seen in barley yield after the fallow, and
- In 2009-10, 224 and 254 mm of fallow rain fell at each site during the fallow (sand and clay respectively). Much of this came in one event of 128 and 163 mm (sand and clay sites respectively). This big rainfall event penetrated the evaporation zone, storing water deep and safely in the soil profile. In 2009-2010 there were far larger differences in PAW at sowing, with the no weeds sites having 43 mm and 69 mm more PAW than the + weeds sites (see Table 31).

Analysis of Mallee summer rainfall patterns shows that events large enough to store water for a subsequent crop occurred in 74% of years from 1976-2002, and whilst water storage was highly variable over that period, the mean was +24 mm. Analysis with APSIM at the Hopetoun site indicated the 2008-2009 outcome, where enough rain fell to establish weeds but there was no yield benefit from control, occurs only in a minority of years, but would be more frequent on the Sodosol (26% of years in the last 120) than the Calcarosol (2%). (Hunt J. Pers. Comm.)

Table 31: Mean plant available water (PAW) at 30 March 2010 (0-130cm) for all treatments at both sites.

Treatment	PAW Sand (mm)	PAW Clay (mm)
Standing Stubble	75 a	110 a
Standing Stubble + Summer Weeds	32 b	41 b
Slashed Stubble	85 a	116 a
Bare Earth	75 a	104 a
Bare Earth + Summer Weeds	40 b	28 b
Stubble retained and cultivated	70 a	100 a
P Value	0.01	0.05
LSD (P=0.05)	29	53

SOURCE: (Browne et al. 2010).

9.4 Research case study - An earlier sowing window?

Good summer fallow management often enables crops to be planted earlier and on more marginal rainfall events with reduced risk of crop failure. Storing soil water through better fallow management and early sowing complement each other, resulting in increased yield and WUE more than if practised in isolation (Kirkegaard & Hunt 2010).

Can management be tweaked to optimise the opportunities of a more reliable earlier sowing window?

Key observations:

- There are potential benefits to use longer season varieties and an earlier start to sowing to take advantage of stored soil water
- Logistically across a farm program, more of the main season crop can be planted on time leading to an increase in farm average yield, and
- APSIM simulations over 50 years comparing planting strategies show that average farm yield is significantly increased and production risk reduced if some slow varieties are included in the sowing program (Tables 32 & 33). (Hunt et al. 2012).

The simulation results in Tables 32 & 33 are for farms at Temora and Condobolin where it is assumed the total area of wheat sown each year takes twenty days to plant (20 paddocks each taking 1 day to sow). Other crops are not considered in the simulation and nitrogen, weeds and disease are assumed not to limit yields. A yield reduction for frost and heat damage based on screen temperatures was applied. Yields are farm average wheat yield across all sowing dates and varieties.

The strategies used in the simulation were as follows;

1. Mid-fast varieties only, sown after the break

Only varieties from the mid-fast maturity group (e.g. Spitfire⍉, Lincoln⍉, and Livingstone⍉) were sown. Sowing started on 5 May at the earliest and only if there was seed-bed moisture (i.e. after the autumn break). If the break had not arrived by 25 May, sowing started on that date and finished on 13 June regardless of seed bed moisture.

2. Mid-fast varieties only, sown by the calendar

Only varieties from the mid-fast maturity group (e.g. Spitfire⍉) were sown. Sowing started on 5 May and finished on 24 May regardless of seed bed moisture i.e. the whole crop could be sown dry before 24 May.

3. Very slow + mid-fast varieties, sown after the break

Two varieties of differing maturity were grown on the farm - very slow (e.g. Wedgetail⍉, Eaglehawk⍉ – planted 10 April to 4 May), and mid-fast (e.g. Spitfire⍉ – 5 May onward). Each variety was planted within its appropriate window, but only if there was seed-bed moisture, and in the case of the very slow variety, only if there was also 25 mm of stored soil water in the top 25 cm of the profile. If the break had not arrived before 25 May, sowing started on that date and finished on 13 June and only the mid-fast variety was sown. In this scenario the area planted to each variety could change from year to year e.g. if the break fell by 15 April, 100% of the farm was be sown to the very slow variety. If the break fell on 5 May or later, only the mid-fast variety would be planted.

4. Very slow + mid-fast varieties, sown by the calendar

Two varieties of differing maturity were sown by the calendar over 40 instead of 20 days. 50% of the farm area was sown to each variety in the window specified; very slow (e.g. Wedgetail⍉– planted 15 April to 4 May) and mid-fast (e.g. Spitfire⍉ – 5 May to 24 May).

Table 32: Average farm wheat yield, % of paddock yields <1.0 t/ha and % area of each maturity type planted for the four different strategies at Temora from 1962-2011.

Strategy	Average yield (t/ha)	Paddock yields <1.0t/ha (%)	Average % area of each variety sown	
			Very slow (e.g. Wedgetail⍉)	Mid-fast (e.g. Spitfire⍉)
1	2.9	22%	-	100%
2	3.0	19%	-	100%
3	3.8	14%	66%	34%
4	3.7	12%	50%	50%

SOURCE: (Hunt et al. 2012).

Table 33: Average farm wheat yield, % of paddock yields <1.0 t/ha and % area of each maturity type planted for the four different strategies at Condobolin from 1962-2011.

Strategy	Average yield (t/ha)	Paddock yields <1.0t/ha (%)	Average % area of each variety sown	
			Very slow (e.g. Wedgetail⍉)	Mid-fast (e.g. Spitfire⍉)
1	1.5	48%	-	100%
2	1.5	44%	-	100%
3	2.2	34%	59%	41%
4	2.1	33%	50%	50%

SOURCE: (Hunt et al. 2012).

Including a very slow variety in the simulation, allowed early sowing increased average yield and reduced production risk (% of paddocks yielding less than 1.0 t/ha) at both locations. Sowing by the calendar rather than waiting for the break did not change average yield much, but did reduce production risk.

The % area planted to the very slow variety in Scenario 3 was high, indicating that planting opportunities for long-season wheats are quite frequent in southern NSW. (Hunt et al. 2012).

9.5 Grower Case Study – Central Zone WA

Name: Scott and Ann Dixon
Consultant: Geoff Fosbery & Ryan Pearce, ConsultAg, Northam, WA
Farm name: Doheny Pty Ltd
Location: Kellerberrin, WA Central wheat belt
Size of operation (ha): 5500 ha; 4650 ha arable; 4,300 cropped each year; in four properties
Enterprises: Wheat, barley, triticale, canola, lupins, chickpeas
Typical Rotation: canola – 3 to 4 cereal crops – lupin if early break or triticale if late break. Triticale on acidic soils with aluminium toxicity
Yields: 1.6 t/ha for wheat, canola 0.6 t/ha, triticale 1.2 t/ha, barley 1.6 t/ha
Climate (rainfall pattern, growing season rainfall, AAR): winter dominant – 330 mm AAR; 180-210 mm growing season rainfall; frost in spring is a significant issue
Soil types: white sand plain, sand over gravel, sandy loam – hardpan at 20 cm (low areas); 'Jam country' (Jam soil is a duplex sand over rock with moderate to high production potential) around granite outcrops.
Herbicide resistance status and details: A weedy area was tested for resistance in 2011 and all tests came back negative.
Weeds usually found in the fallow: afghan melons (*Citrullus lanatus*) and caltrop (*Tribulus terrestris*) are the main species. Also some prickly paddy melon (*Cucumis myriocarpus*), small patches of fleabane (*C. bonariensis*), and some windmill grass (*Chloris truncata*), kerosene grass (*Aristida contorta*) and roly-poly (*Salsola tragus*).

The operation

Scott and Anne run a 100% cropping enterprise at Kellerberrin in the central cropping zone of Western Australia (Agzone 4 L3). The total area of operation is 5,500 ha with 4,650 ha arable over four properties. The plan is to crop approximately 4,600 ha and fallow 300 ha each year.

Scott's rotation consists of triazine-tolerant canola followed by 3 cereal crops then lupins (if the break is early enough), or a feed cereal when the break is late. Triticale is an important crop on soils with high levels of aluminium in the topsoil.

The main limitations on crop production are soil constraints, weeds and plant available water.

Soils range from white sand plain, shallow loamy duplex (sand over gravel) to low lying 'heavy' (red clay) country and 'Jam' soils near large granite rock formations with elevation. The heavy soils have a sodic hardpan at about 20 cm and the duplex soils have high levels of soluble aluminium.

Liming is used to lift the soil pH and reduce aluminium toxicity. Scott has observed that melon problems are worse where he has applied the most lime. Gypsum is also applied on heavier soil types as needed.

Scott seeds with a Flexicoil™ 820 double shoot system with knife points on 22.5 cm spacings and press wheels. He isn't afraid to chase soil moisture by sowing long coleoptile wheat varieties down the fertiliser tube, placing the fertiliser on top of the seed.

Scott has used a consulting agronomist since 1996, who has helped greatly in planning paddock rotations and fertiliser and chemical usage.

Climate

On average they receive 330 mm rainfall/year with a growing season (April to October) rainfall of 180 to 210 mm. The 2011-12 and 2012-13 summers have seen around 150 mm of rain between November and January. Frost is a major problem in spring.

A review of the climate at Merredin (Farre et al. 2010), 57 kilometres north-east of Kellerberrin, has shown that since the mid-1970s south western Western Australia has seen a 10% decrease in growing season rainfall and an increase in average temperatures. During this period there was also an increase in the amount and intensity of summer rainfall, particularly in December to February.

This trend highlights the increasing importance of summer weed control to store moisture to buffer for low growing season rainfall.

Significant falls of rain between December and February are not uncommon at Kellerberrin as can be seen in Figures 13 to 16.

This changing pattern to rainfall and temperature increases the challenges of growing profitable crops.

History

Sheep were a major part of the operation until 1997 when Scott made an agronomic and business decision that sheep were compromising his push towards no-till farming. His topsoil had become softer since going to 100% cropping. He hasn't totally lost his connection with sheep as he agists neighbours' sheep on his crop stubbles for three to four months after harvest.

Scott had also been unhappy with the level of weed control he had been getting over summer, with wheel tracks being a constant problem caused by dust when he used a tow-behind boomspray.

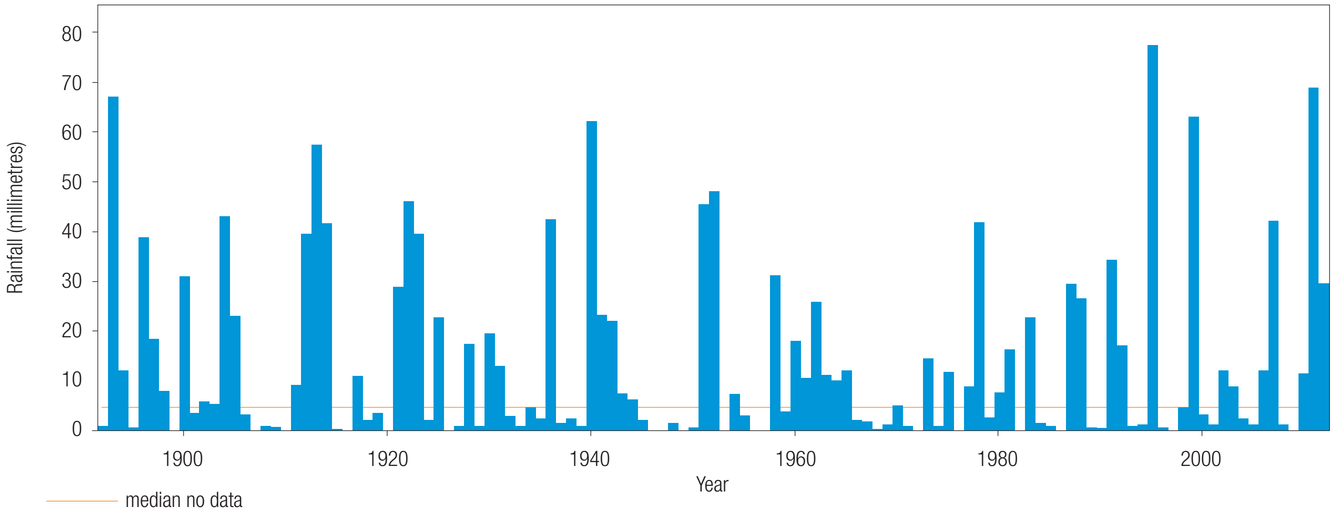
Weeds

Major winter weeds are annual ryegrass, brome grass and wild radish. Ryegrass numbers are under control, but brome grass and radish are a concern. Also, after limiting the sheep to agistment after harvest, Scott found that his non-crop phases and stubbles were often a lot greener than when he had full-time sheep, so the summer spray operation became more important. Wild radish could also either carry through from the winter crop or establish from seed in summer and autumn with sufficient rain.

The summer weed problem

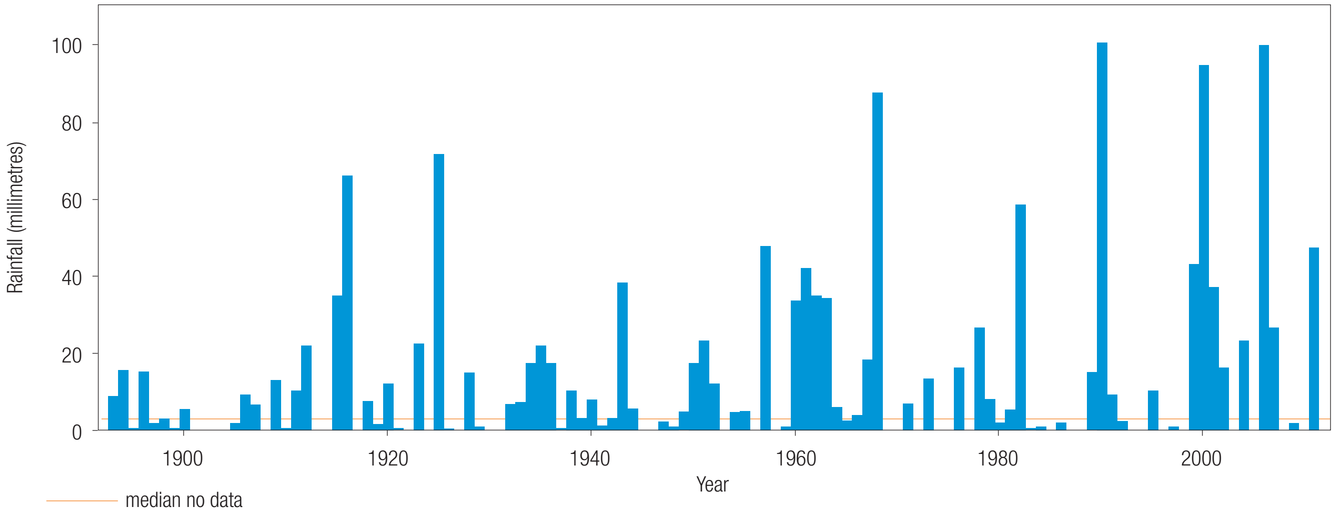
His main summer fallow weeds are Afghan melon (*Citrullus lanatus*) and caltrop (*Tribulis terrestris*) which create havoc at seeding if not controlled when small, along with windmill grass (*Chloris truncata*), kerosene grass (*Aristida contorta*) and roly-poly (*Salsola tragus*) in certain seasons. There are small patches of flaxleaf fleabane (*Conyza bonariensis*) that Scott is currently keeping under control.

Figure 13: **Monthly rainfall at Kellerberrin for December.**



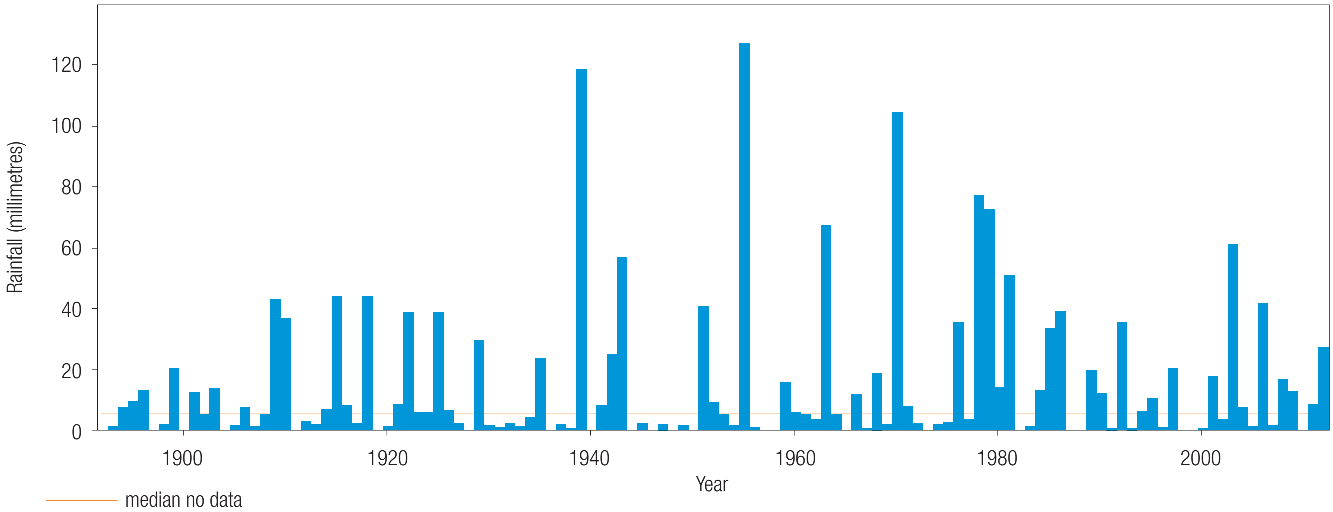
SOURCE: Climate Data Online, Bureau of Meteorology, Copyright Commonwealth of Australia, 2013.

Figure 14: **Monthly rainfall at Kellerberrin for January.**



SOURCE: Climate Data Online, Bureau of Meteorology, Copyright Commonwealth of Australia, 2013.

Figure 15: **Monthly rainfall at Kellerberrin for February.**



SOURCE: Climate Data Online, Bureau of Meteorology, Copyright Commonwealth of Australia, 2013.

A problem gives food for thought

A Kellerberrin grower was night spraying in December 2011 and he didn't notice a 6 m section of his boom wasn't working. When he came back from holidays there were 6 m strips of healthy melons and other weeds over a 100 ha paddock.

The paddock was resprayed six weeks after the first spray (early February 2012) to kill all weeds.

This problem provided an opportunity to actually see how much water the weeds had used. Caroline Peek from DAFWA Merredin measured the plant available water in the weedy and clean strips in March and found 30 mm less PAW in the weedy strips, while the clean strips were at the soil's upper limit.

These soils (Salmon gum loam) normally require 40 mm rain before seeding can occur.

Benefits of controlling summer weeds

Significant summer rain over a number of years stimulated farmer interest in what these weeds were doing besides making seeding difficult. In 1997 a group of Kellerberrin farmers formed the Kellerberrin Demonstration Group to look at on-farm solutions to existing and developing problems. This group was guided by Geoff Fosbery, Angie Roe and Ryan Pearce, of ConsultAg at Northam.

The Group ran Yield Prophet® calibration trials for local conditions and found that while it accurately predicted yields on uniform profile soils with no subsoil constraints, it was less accurate in duplex soils and those with hard pans or acidic subsoils.

What Yield Prophet® and fallow trials did show was the value of storing moisture during summer when growing season rain was limited. In wetter growing seasons there was no benefit from storing moisture during summer.

The trials showed a significant benefit of fallow to the following wheat or canola crop of 0.6 to 0.8 t/ha extra. Canola after fallow gave a greater economic return when compared to wheat after fallow. After fallow in 2011 Scott grew 1.5 t/ha wheat @ $320/tonne and 1.3 t/ha canola @ $580/tonne. The canola gave a gross income of $377/ha/year compared to $240/ha/year for the wheat (no income in the fallow year).

Scott found that 70 mm received in December 2011 contributed to his 2012 yields with a 10 to 15 percent yield increase due to the relatively low growing season rainfall of 130 mm. The stored moisture also allowed Scott to seed canola on the recommended date with an excellent plant density despite the dry autumn.

In the 2012 harvest, farmers in the Narembeen-Bruce Rock area achieved yields of 1.2 t/ha with less than 100 mm of growing season rain. If relying on growing season rain alone, the yields would be more like 0.5 t/ha. However in the summer of 2011-12 they received 200 mm of rain. A soil profile at capacity allowed farmers to seed on less rainfall and the crops to establish well despite a dry autumn-early winter.

Dealing with summer weeds now

Scott uses the services of ConsultAg and is involved with the Kellerberrin Demonstration Group (http://kellerberrin.gga.org.au/). The GRDC and Department of Agriculture & Food WA are also strong sources of weed management information.

While vine weeds can cause problems with seeding every season if not controlled, the benefits of killing weeds for moisture and nitrogen will depend on the amount of growing season rainfall.

The biggest change to weed management Scott has seen is the improved application technology. He now runs a 36m Miller Nitro 4000 self-propelled boom which allows him to spray the whole operation in 10 days.

The booms have twin nozzle selectors at 25 cm spacing and have 110-02 Agrotop TurboDrop® and Teejet AIXR-02 nozzles aiming for coarse and medium droplets. Scott also runs 110-02 Flat Fans for insecticides.

The Miller booms cut down on dust problems, giving more reliable summer weed control than his previous towed booms. "Now the dust is behind me" he says. To minimise the problem even further there are two nozzles mounted behind each wheel.

Dust was always a big problem with summer spraying, however Scott found 2012 particularly bad, possibly due to the hot conditions leading up to harvest.

The big advances Scott has seen in order of adoption are:

1. GPS to allow accurate night spraying
2. Auto-steer with stored A-B transit lines – Scott doesn't tram-line, but runs up and back
3. Auto boom on-off
4. Auto boom height adjustment
5. R2K (2 cm accuracy) auto-steer
6. Higher water rates – have given more reliable control of summer weeds
7. Double knockdown of glyphosate followed by paraquat has given high levels of weed control and minimised the risk of developing glyphosate resistant weed populations.

The spraying operation - making it work

The biggest constraint for Scott's spray operation is suitable spray conditions. High temperatures and low humidity lead to rapid loss of droplet mass decreasing the amount of herbicide reaching the target and increasing the potential for drift.

The main time for summer spraying is between midnight and 8 am. Depending on the conditions Scott might not start spraying till 3 am but always tries to stop when the temperature reaches 28 to 30 degrees. The daily spray target is 300 ha, conditions permitting.

Application volume is adjusted depending on temperature and humidity but aims to apply 70 to 90 L/hectare.

For summer weed control Scott uses robust rates of glyphosate + 2,4-D LV ester + triclopyr with an anti-evaporant adjuvant. Sometimes he has to come back with a Group B herbicide to control caltrop if further summer rain is forecast.

PHOTOS: Ann Dixon

Scott Dixon, Kellerberrin, WA, sees summer weed control as essential to minimising cropping risks from variable breaks to the season.

Afghan melon (*Citrullus lanatus*) and caltrop (*Tribulus terrestris*) are major summer weeds in the WA cropping zone.

Scott Dixon's Miller spray rig is essential equipment for successful farming in increasingly uncertain climatic conditions.

9.6 Grower Case Study – Esperance WA

Owners: Ron and Kerrie Longbottom
Farm name: Cape Lagoon Farm
Location: Grass Patch, via Esperance
Farm size: 6,200 ha arable; 2,000 ha wheat; 1,600 ha barley; 1,200 ha peas/canola
Rainfall: 350 mm annual; 145 mm growing season; 75 mm Jan to March
Enterprises: wheat, barley, peas, canola
Typical rotation: Peas/wheat/barley or canola/wheat/barley/canola/wheat is profitable, however he gets a better cereal crop (500 kg/ha) after peas
Soil types: Grey calcareous clay loam
Summer weeds: afghan melon (*Citrullus lanatus*), prickly paddymelon (*Cucumis myriocarpus*), caltrop (*Tribulus terrestris*), small flowered mallow (*Malva parviflora*), flaxleaf fleabane (*Conyza bonariensis*), common heliotrope (*Heliotropium europaeum*), volunteer crops
Herbicide resistance status and details: Group A fop resistance in annual ryegrass. Haven't used sulfonyl-ureas since early 1990s due to herbicide residues. Have been using Group B imi's such as imazethapyr due to lower persistence of soil residues.
Comments: Yields have been lifted by spraying summer weeds and spraying of zinc and manganese on crops. Have used approximately 15 tonnes of Zn and Mn across the farm to date.

Controlling summer weeds has added extra income to Ron Longbottom's Cape Lagoon Farm in Western Australia. Ron runs a 6,200 ha property with his wife Kerrie in Grass Patch near Esperance, and says that the extra income comes mainly from soil moisture conservation, however soil nitrogen and disease also play a role.

Ron first became convinced that controlling weeds in summer was a good practice in the early 1990s. He noticed that areas of crop where summer weeds had not been controlled due to spray misses always yielded worse than where summer weeds were controlled. He believed the summer weeds used up the soil water but he was also concerned about the weeds hosting diseases and pests between crops.

His biggest summer weed problems are melons and volunteer crop (wheat, barley, peas and canola) however small flowered mallow has been getting worse for the last 10 - 15 years. Fleabane is a problem in pea stubbles but Ron uses a late spray in cereal crops that controls the fleabane seedlings.

Ron will spray if weeds are present in his stubbles, which sometimes delays his Christmas break. He doesn't have a threshold number to trigger spraying, as any weeds are seen as a threat to next year's crop. He is also willing to cultivate if necessary and has occasionally used a 'summer tickle' to stimulate weed germination.

Ron's crop rooting depth is limited to about 50 cm due to salinity and boron toxicity below this depth. This increases the importance of soil moisture and nitrogen conservation.

Summer weed trial

In 2004, Ron conducted a trial with DAFWA agronomist Jeremy Lemon which showed that he wasn't wasting his time or money. The trial consisted of unsprayed strips (two boom sprayer runs wide) at the first summer weed spray in February.

PHOTO: Evan Collis

Ron Longbottom of Grasspatch, contemplates summer weed control to come.

A later spray was applied in April. This provided strips of early and late weed control for comparison. The strips were measured for soil moisture and nitrogen prior to sowing, with grain yield and quality measured at harvest.

The soil moisture and nitrogen levels were substantially higher where the weeds had been controlled early, equating to an extra 17 kg/ha of mineral nitrogen in the surface layers and an extra 40 mm of soil moisture. This related to an increase of 800 kg/ha of yield and 0.5% grain protein.

Spray gear

Ron uses two Sonic® 120 foot booms with 10,000 L and 5,000 L tanks. One is towed behind a Ford F250 and the other behind a tractor. Each unit carries enough herbicide for three tank loads. Water tanks are strategically located around the farm to minimise refill times.

Tramlines are used to guide the spraying and with reasonable weather, the whole farm can be sprayed in 7 to 10 days. In summer, spraying normally commences at 4 am and continues to 7 am or when the air temperature reaches 28 degrees. If it looks like the conditions are going to deteriorate spraying will start at 2 am. Dust becomes a big problem as the temperature increases and poor weed control along the wheel tracks occurs if there is too much dust. The problem is exacerbated if the same tracks are followed for each spray.

Ron is weighing up the benefits of a detect sprayer, however thinks it would need to be shared with a couple of neighbours due to the capital cost.

Measuring soil moisture and nitrogen

Ron has a moisture probe situated in a representative paddock which measures soil moisture down to 95 mm. The site was selected as it represents soils typical of a major portion of his farm. Many trials have been conducted in this paddock providing a large database to draw information and comparisons from.

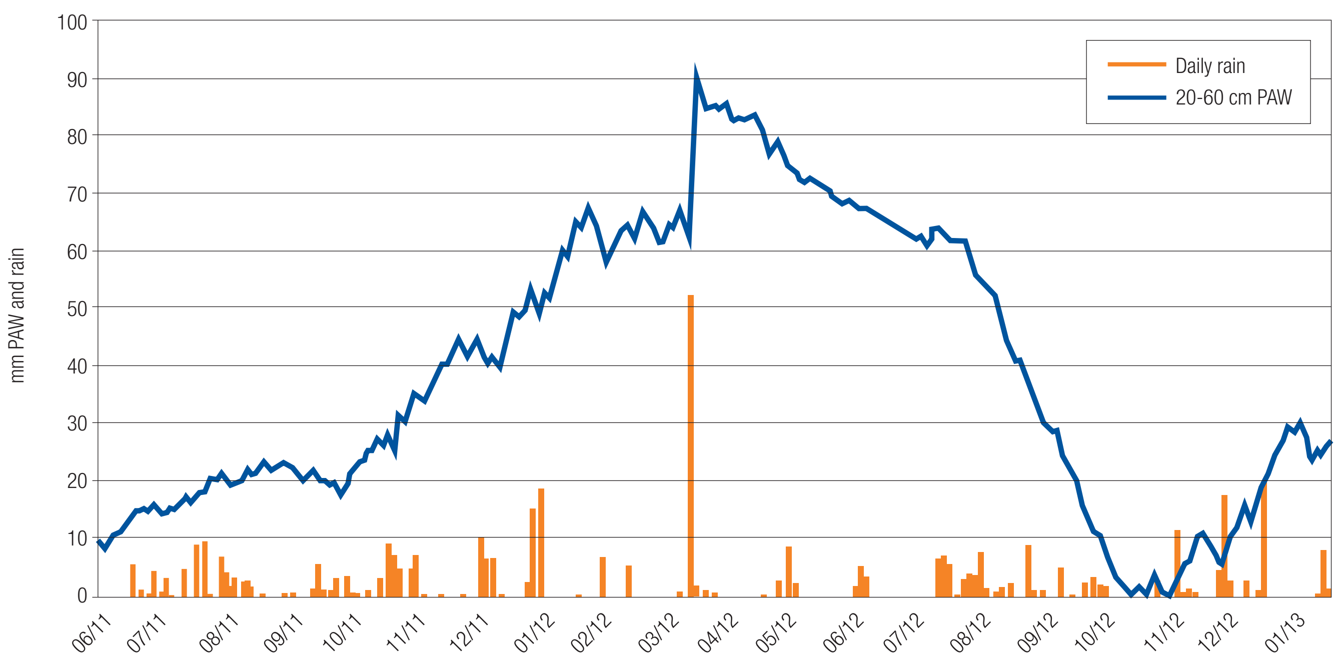
He gets the data from Jeremy Lemon. Figure 16 shows probe readings for 25, 35, 45, 55 65, 75 and 85 cm depth. 2011 was a wet year and the crop made little impact on drying the profile at different depths. It was mid-August 2012 when the crop started to use water from 25 cm to 55 cm. This site had salinity and high levels of boron below 55 cm preventing the crop from accessing water below this depth. Significant rain in November and December 2013 started to refill the top 60 cm of the profile. The paddock was sprayed in early January 2013 to control melons and common heliotrope.

The readings are used to determine nitrogen fertiliser strategy for the coming year. The more stored moisture - the more early nitrogen.

More soil moisture in autumn also gives Ron a broader seeding window. Canola is dry sown on 20 April, followed by barley, wheat then peas. He normally sows the same area of crop each year.

2005 was Ron's highest yielding year to date. There was no rain in the summer of 2004-05 and all the rain fell during the growing season.

Figure 16: Probe readings (20-60 cm) and rainfall since installation mid 2011.



9.7 Research data SA

In research conducted in 2000 and 2001 in SA's Mallee and Upper Yorke Peninsula, four sites were managed over two seasons with and without fallow weed control.

In 2000, treatment effects on stored soil water were largely negated by a 56 mm rainfall event in late February. In 2002, extra stored soil moisture was the main reason for the increased yield where fallow weeds were controlled. In 2003, the extra stored water from controlling fallow weeds led to a yield increase, but damage caused by trifluralin used in the crop did not permit this to be reflected in yield.

At Site 18, (see Table 36, page 60) in both 2001 and 2003, where fallow weeds were controlled there was extra stored moisture to increase yield and protein. In these two trials, there was no difference in the amount of stored soil nitrogen at the beginning of the growing season where summer weeds have been controlled/not controlled. (Fromm and Grieger 2004)

Table 34: Results from the 2000 and 2001 seasons in SA's Mallee and Upper Yorke Peninsula. Summer weeds were controlled/not controlled with herbicides. Data includes soil type, yield, (% change from untreated yield) and protein levels.

Site and soil	2000 data			2001 data		
	Water # (mm)	Yield t/ha (% change)	Potein (%)	Water # (mm)	Yield t/ha (% change)	Protein (%)
1: Sandy clay loam over lime rubble	+19	Pasture Pasture	Na Na	+11	1.88 (WH) (+47%) 1.28 (WH)	13.6 14.4
2: Calcareous sandy loam over lime rubble	+21	1.88 (LU) (+7%) 1.76 (LU)	30.8 31	+9	5.89 (WH) (+13%) 5.21 (WH)	11.4 10.8
3: Sand over sandy clay loam	+11	1.76 (WH) (0%) 1.70 (WH)	10.3 9.7		Pasture Pasture	
4: Shallow loamy sand over lime rubble & calcrete	+6	2.26 (WH) (+30%) 1.74 (WH)	11.3 10.7	+17	1.38 (BA) (+17%) 1.18 (BA)	11.3 10.4

# Measured at sowing relative to site with no weed control applied
LU=lupins, WH=wheat, BA=barley

SOURCE: (Fromm and Grieger 2002).

Table 35: Results from the 2000, 2001, 2002 and 2003 seasons in SA's Mallee and Upper Yorke Peninsula. Summer weeds were controlled/not controlled with herbicides. Data includes soil type, yield, (% change from untreated yield), protein levels fallow rainfall and growing season rainfall at each site.

Site and soil	Site 07 Yellow-brown sand grading to a loam sand and a clay sand		
	Yield (kg/ha)	Yield (% change from untreated +/- trifluralin)	Protein (%)
2000 data	**Rain mm: Fallow 153, growing season rainfall 247**		
Untreated	744		7.8
Fallow weeds controlled	772	+4%	8.7
Untreated +trifluralin in-crop	865		8.0
Fallow weeds controlled +trifluralin	1195	+38%	8.6
2002 data	**Rain mm: Fallow 58, growing season rainfall 86**		
Untreated	41		13.4
Fallow weeds controlled	311	+758%	12.4
Untreated +trifluralin in-crop	35		13.6
Fallow weeds controlled +trifluralin	249	+711%	12.5
2003 data	**Rain mm: Fallow 121, growing season rainfall 212**		
Untreated	1682		9.0
Fallow weeds controlled	2024	+20%	9.8
Untreated +trifluralin in-crop	1753		10.1
Fallow weeds controlled +trifluralin	1797	+2%	10.2

SOURCE: (Fromm & Grieger 2004).

Table 36: Results from the 2000, 2001, 2002 and 2003 seasons in SA's Mallee and Upper Yorke Peninsula where summer weeds were controlled/uncontrolled. Data includes soil type, yield, (% change from untreated yield), protein levels fallow rainfall and growing season rainfall at each site.

Site and soil	Site 18: Deep yellowish-brown sand over a yellowish-red sandy clay loam		
	Yield (kg/ha)	Yield (% change from untreated +/- trifluralin)	Protein (%)
2001 data	**Rain mm: Fallow 46, growing season rainfall 260**		
Untreated	312		9.9
Fallow weeds controlled	578	+85%	9.9
2003 data	**Rain mm: Fallow 106, growing season rainfall 229**		
Untreated	512		9.6
Fallow weeds controlled	651	+27%	10.6

SOURCE: (Fromm & Grieger 2004).

9.8 Assessment questions

1. **Using the data relating to Research Case Study SNSW1- which statement is correct?**
   a. Missing the first spray had a large detrimental effect on soil moisture, particularly at the deeper levels compared to full weed control
   b. Missing the first spray and delaying the timing of sprays were not significant factors on soil moisture
   c. Delaying spraying was only a significant factor in reducing soil moisture at shallow depths
   d. Complete weed control was only useful in maintaining surface water in the soil

2. **Using the data relating to Research Case Study SNSW2 - which statement is incorrect?**
   a. Stubble treatments such as stubble standing/slashed/ cultivation or deep ripping had no significant impact on moisture or nutrient retention at the Gunningbland or Tottenham sites in 2010
   b. At the Gunningbland site, an extra 49 mm of PAW was retained when weeds were controlled, while at Tottenham only an extra 22 mm was stored. This was under excessively wet summer conditions
   c. At all sites in the wet conditions in 2010 there was no significant differences in either fallow efficiency or nutrient retention due to the fact that there was always optimal amounts of water available to the crops
   d. The high fallow efficiencies of 2010 are felt due to much of the rainfall occurring in the latter half of the fallow period (Feb/Mar/Apr) when soil evaporation losses were much lower than in the peak of summer

3. **Using the data relating to Research Case Study SNSW2 - which statement is incorrect?**
   a. Zero tolerance of summer weeds gave the greatest response to both grain yield and profit with the yield at the Gunningbland site in 2010 increased by 65% over the nil weed control treatment
   b. Stubble treatments (stubble slashed, removed or cultivated) had a significant negative impact on yield across all sites
   c. Controlling summer weeds at the Tottenham site in 2010 also gave the greatest response to both grain yield (by up to 237%) and profitability

4. **"Good summer fallow management often enables crops to be planted earlier and on more marginal rainfall events with lower risk of crop failure." This statement is best supported by:**
   a. Storing soil water through better fallow management and early sowing complement each other and increase yield and WUE more than when either is practised alone
   b. Crop failure is more related to disease and conditions at harvest than practices during the fallow
   c. Farm average wheat yields across all sowing dates and varieties show that variety plays a more important role than water storage
   d. This statement is not supported by any data

5. **Which of the following statements is not true regarding research in WA summer fallow situations?**
   a. Fallow efficiencies averaged approximately 75%
   b. Evaporation was the main loss of soil water, although loss due to transpiration can also be important
   c. Once water moved below 0.3 m it was less accessible to losses via evaporation and transpiration unless weed growth was present
   d. Soil water accumulation in the fallow increased drainage under wheat in the following growing season

10 Assessment answers (Correct answers are bold)

10.1 Assessment answers Chapters 2 & 3

1. Fallow efficiency is measured by
   - **a. The % of fallow rainfall that is captured and stored for use by the next crop**
   - b. The amount (mm) of plant available water stored at the end of the fallow period (i.e. at sowing)
   - c. The cost of managing weeds vs. the amount of water conserved
   - d. The time taken for the crop to use the stored water in the soil

2. Which of the following statements about fallow water efficiency is correct?
   - a. Soils with a heavy clay content in the topsoil tend to have higher fallow efficiency than soil with a lighter topsoil and clay subsoil
   - b. Heavy clay soils are always more fallow efficient than lighter structured soils
   - **c. Soils with a lighter structured topsoil and clay subsoil tend to have higher fallow efficiency than soils with a heavier clay topsoil**
   - d. There is no evidence of difference in fallow efficiency of soils based on soil type

3. Summer fallow efficiency is likely to be higher in seasons when
   - a. There are a few smaller rainfall events
   - b. Fallow efficiency does not vary much between seasons for a particular soil type and region
   - c. There are drought conditions
   - **d. There are several larger rainfall events that occur within a period of several weeks**

4. Which of the following statements about return on investment (ROI) is **incorrect?**
   - a. The likely ROI from fallow weed management in a high growing season rainfall zone can sometimes be due more to nitrogen benefits than from extra stored soil water
   - b. The ROI from summer fallow weed management is likely to be highest when there is good fallow rainfall and low growing season rainfall
   - **c. The ROI from summer fallow weed management is likely to be highest when there is low fallow rainfall and high growing season rainfall**
   - d. The ROI from summer fallow weed management is usually higher when there is significant existing soil moisture to protect

5. Which of the following statements about Water Use Efficiency (WUE) is **correct?** (There may be more than one correct response)
   - **a. Water stored deep in the soil profile is very valuable due to its contribution later in the season when yield is being determined and set. WUE's of up to 60 kg grain/mm for water that is stored deep in the profile have been recorded**
   - b. Surface moisture is just as important as deep stored water to grain fill and has a similar WUE to deeper stored water - typically up to but rarely exceeding 20 kg grain/mm stored water
   - **c. If after a 25 mm summer rainfall event on a heavy clay soil there is no follow-up rainfall for 8 weeks, it is likely that most if not all the rainfall will have evaporated – even if weeds are controlled**
   - d. Water stored deep in the soil profile is most likely to be used early in the cropping season

6. True or false?
   - **a. A heavy cracking clay holds approximately 175 mm PAWC/metre of depth. Soil that is wet to a depth of 1.2 metres will have a PAW of 210 mm. With a growing season rainfall of 150 mm, total water supply is 360 mm. At an <u>average</u> WUE of 20 kg/mm, the crop yield potential is calculated at approximately 7.2 t/ha**
   - **b. A red loam soil holds approximately 100 mm PAWC/metre of depth. Soil that is wet to a depth of 0.8 metres will have a PAW of 80 mm. With a growing season rainfall of 150 mm, total water supply is 230 mm. At an <u>average</u> WUE of 20 kg/mm, the crop yield potential is calculated at approximately 4.6 t/ha**
   - **c. A heavy cracking clay soil holds approximately 175 mm PAWC/metre of depth. Soil that is wet to a depth of 0.3 metres will have a PAW of 52 mm. With a growing season rainfall of 200 mm, total water supply is 252 mm. At an average WUE of 20 kg/mm, the crop yield potential is calculated at approximately 5 t/ha**
   - **d. A red loam soil holds approximately 100 mm PAWC/metre of depth. Soil that is wet to a depth of 0.3 metres will have a PAW of 30 mm. With a growing season rainfall of 150 mm, total water supply is 180 mm. At an average WUE of 20 kg/mm, the crop yield potential is calculated at approximately 3.6 t/ha**
   - **e. An extra 30 mm of deep stored water at sowing could in a lower rainfall growing season have a WUE of 60 kg grain/mm and equate to extra yield of 1.8 t/ha**

7. A red loam soil is wet to 1 metre a cereal crop is sown. The grower has based yield expectations and nitrogen resourcing on growing season rainfall of 150 mm and stored soil water of 100 mm (PAWC of 100 mm/metre soil) = 250 mm. At an average WUE of 20, a yield potential of 5 t/ha is forecast. This does not eventuate and crop yield is only in the order of 3 t/ha. Measurement of soil water at harvest showed water levers below a depth of 50 cm to be similar to levels recorded at sowing, while the top 50 cm is bone dry. What is likely to have happened?

a. Root growth was limited by dry conditions and never reached into the subsoil zone
b. Crop nutrition was sub standard
c. A subsoil constraint at approximately 50 cm appears likely to have limited root growth and access to water deeper in the soil profile

10.2 Assessment answers Chapter 4

1. Both yield and protein can be affected by controlling weeds in summer fallow. This is explained by: (There may be more than one correct response)
   a. Weeds in the summer fallow use both water and nutrients such as nitrogen
   b. More nitrogen is available to the crop if weeds are controlled
   c. Water availability influences both the yield and protein of the grain
   d. Nitrogen is more likely to stay in the top part of the soil if weeds are present in the fallow

2. If controlling summer fallow weeds leads to more stored water at sowing – which statements are likely to be consistently true
   a. The higher levels of soil water in the fallow are likely to have led to more nitrogen being mineralised than would have been the case if weeds were not controlled
   b. The higher levels of water at sowing raise crop yield expectations which then need to be balanced by an increased supply of nitrogen
   c. As weeds have been controlled during the fallow period, its is unlikely that extra nitrogen would be needed to optimise yield
   d. Having more water at sowing can often mean a higher response to applied nitrogen

10.3 Assessment answers Chapter 5

4. Which statement **best** describes the relationship between weed density during summer fallow and yield in the subsequent crop?
   a. At low weed densities there is no significant effect on crop yield
   b. There is a similar positive effect on yield across all weed densities measured
   c. There is a similar negative effect on yield across all weed densities measured
   d. There is an effect on crop yield at low weed densities and this negative effect increases as the weed density increases

5. Which statement is most correct?
   a. The amount of water used by weeds is directly related to weed height
   b. The amount of water used by weeds is directly related to weed biomass (kg/ha)
   c. Weeds in a biodynamic system don't use soil water– they make if from the atmosphere using magic

6. Which statement about weed type and moisture depleting effect is the most correct?
   a. All weeds have a similar moisture depleting effect during the summer fallow
   b. C3 plants use more soil water than C4 plants at similar densities
   c. C4 plants use around twice as much soil water as a similar density of C3 plants
   d. Windmill grass has little moisture depleting effect during the fallow as its windmill effect acts to pump water into the soil

10.4 Assessment answers Chapter 6

1. What is **the most** critical period for weeds and crop volunteers to be killed to prevent survival of diseases and pests in the 'green bridge' between crops?
   a. The entire summer fallow
   b. 4-6 weeks before sowing of the new crop
   c. 4-6 weeks after sowing of the new crop
   d. 1 week before and after sowing of the new crop

2. Cereal rust is a biotrophic pathogen. This means that:
   a. It needs a live host to survive
   b. It consumes other pests to survive
   c. It can survive for long periods without a live host
   d. It makes its own food using photosynthesis

3. Wheat streak mosaic virus and its vector, wheat curl mite, can survive between crops using which of the following as hosts. (There may be more than one correct response).
   a. Barley grass
   b. Annual ryegrass
   c. Small burr grass
   d. Witch grass

4. Other diseases that can affect crops following fallow with green bridge conditions include: (There may be more than one correct response).
   a. Barley yellow dwarf virus
   b. Diamondback moth
   c. Dengue fever
   d. Bean leaf roll virus

5. Which of the following mites are generally more difficult to control?
   a. Balaustium and Bryobia mites
   b. Redlegged earth mites
   c. Pink spotted pond mites
   d. Queensland green striped vampire mites

6. Which of the following is **true** for canola in relation to its water use compared to wheat?
   a. Canola is more shallow rooted and does not use the soil water at depth
   b. Canola is harvested later than wheat usually thus making the following fallow shorter and less productive
   c. Canola is harvested earlier than wheat, so the summer fallow starts earlier but canola often leaves the soil very dry as it accesses and uses water at a greater depth than wheat
   d. Canola and wheat are essentially identical in water use and harvest timing

7. Which of the following is **true** of perennial pasture species such as lucerne in relation to crop rotation and fallow requirements?
   a. They leave large amounts of stubble to protect the soil surface from evaporation
   b. They often lead to crop yield increases in the following year especially if the growing season rainfall is low in the following year
   c. They leave larger amounts of soil moisture than corresponding wheat crops
   d. They are known to dry out the soil profile, be difficult to kill and leave only modest levels of stubble cover
8. In the Northern Region, grain sorghum crops are often sprayed with glyphosate once they reach physiological maturity. Reasons for this are (There may be more than one correct response).
   a. This stops late tiller development
   b. This evens up crop maturity for a more efficient harvest
   c. This helps conservation of water that the crop is still extracting from deep in the soil for use in the next crop
   d. This stops crop plants from continuing their growth in the fallow
9. Gaining most advantage from extra stored water depends on which of the following factors (There may be more than one correct response)?
   a. Adapting nutrition adequately to allow for the extra soil water
   b. Planning crop sequencing to provide a soil environment where issues such as nematodes, crown-rot or other soil diseases will not limit crop yield.
   c. Good crop agronomy and management of insects, foliar diseases and weeds.
   d. Optimising crop root growth using techniques such as controlled traffic and minimum tillage.
   e. Adapting the sowing date and variety to a system with higher amounts of PAW
11. Which of the following are economic reasons to control weeds during the summer fallow? (There may be more than one correct response)
   a. Controlling weeds may lead to higher water storage and greater yields in the subsequent crop
   b. Fewer weeds means nitrogen is not used and tied up in weed carcasses before the sowing of the next crop
   c. Controlling weeds during the fallow may assist in stopping the spread of diseases and pests through 'green bridges'
   d. The return on investment from killing weeds in summer fallow is usually very high in a wide range of environments
   e. Controlling weeds and storing more soil water, provides greater options for earlier sowing using longer season varieties as well as capitalising on a greater likelihood of a return from applied nitrogen fertiliser

10.5 Assessment answers Chapter 7

1. The 'wait and see' approach to spraying during summer fallow after rainfall is a high risk strategy because (select the one most correct answer)
   a. All rainfall events add significant moisture to the soil profile
   b. All rainfall events lead to weed germination and seed set
   c. Uncontrolled weeds will deplete moisture, may become difficult to control if not controlled when young and may set seed causing a worse weed problem for future years
   d. Weeds grow more quickly after isolated rainfall events and are most likely to set seed
2. Costs of the 'wait and see' approach can be higher due to (There may be more than one correct response)
   a. Higher rates of fertiliser may be required as weeds that are allowed to grow larger tie up greater amounts of nitrate
   b. Higher rates of herbicide are needed to kill larger and potentially more stressed weeds
   c. More than one herbicide spray may be required to kill larger weeds
   d. Weed escapes could interfere with sowing operations
3. There has been resistance demonstrated in fallow weeds to which of the following herbicide groups?
   a. Group M (glyphosate)
   b. Group I (e.g. phenoxies)
   c. Group B (sulfonylureas and imidazolinones)
   d. Group L (e.g. paraquat)
   e. All of the above
4. Due to widespread use of glyphosate since the late 1970s, which of the following is true?
   (There may be more than one correct response)
   a. Since the first population of glyphosate resistant annual ryegrass was found in 1996, the frequency of glyphosate resistant weed populations has risen significantly
   b. There has been species shift to weeds such as feathertop Rhodes grass due to high levels of natural tolerance to glyphosate
   c. Levels of resistance to glyphosate of weeds has remained unchanged – species shift to less susceptible species is all that has occurred
   d. Fence lines, roadsides and long term no-till paddocks where there has been extensive use of glyphosate over a prolonged number of years are key areas where glyphosate resistant weeds are likely to be first seen
5. In applying glyphosate herbicide, it is important to (select one answer)
   a. Use coarse droplets in accordance with the label requirements to reduce drift
   b. Use a fine mist to ensure complete coverage
   c. Use any droplet size as there are no issues related to droplet size
   d. Use as much water as possible to ensure maximum coverage

6. Which of the following statements are true in relation to spraying glyphosate? (There may be more than one correct response)
   - **a. Highly translocated and not overly sensitive to application coverage. Issues can arise with small targets (1-2 leaf upright and narrow leaved grasses) when using low carrier volumes and large droplets**
   - **b. High levels of clay binding makes it unavailable to roots with no effective soil residual**
   - **c. Requires good quality water as it is inactivated by divalent and trivalent cations and clay dispersed in water**
   - d. There are no restrictions or considerations in the use of glyphosate

7. Which of the following statements are **correct** regarding the application of bipyridyl herbicides during fallow spraying?
   - **a. Contact activity makes it sensitive to application coverage**
   - **b. Medium/coarse droplets are recommended, with high carrier volumes to maintain the level of coverage needed**
   - c. Does not require good quality water
   - **d. There is no effective soil residual**

8. Which of the following statements are **correct** regarding the application of phenoxies during fallow spraying?
   - **a. Must be applied with coarse droplets (Label requirement)**
   - b. Contact activity makes it sensitive to application coverage
   - **c. Plant back restrictions apply to most products.**
   - **d. Activity at very low dose rates makes droplet drift to non-target crops a significant issue**

9. A Double Knock is where two weed control tactics, with different modes of action are applied to a single germination of weeds to stop weed survivors from setting seed. Which of the following would represent a Double Knock situation? (There may be more than one correct response)
   - a. Two sprays of glyphosate a week apart to control difficult weeds
   - **b. Spray of glyphosate followed by a spray of paraquat one week later**
   - **c. Spray using a Group A herbicide followed by a bipyridyl**
   - **d. Spray using a Group M herbicide followed by tillage before any weed survivors have set seed**

10. The reasons for adopting a Double Knock approach can include which of the following? (There may be more than one correct response)
   - **a. Very high levels of weed control which drive down weed seed banks**
   - **b. If implemented well before resistance is apparent, double knock can delay the onset of herbicide resistance**
   - **c. Improved control of difficult to control weeds such as feathertop Rhodes grass, fleabane and sowthistle**

11. Which of the following is **NOT** a factor in determining the interval between the successive treatments in a Double Knock tactic for weed control?
   - a. The type of herbicide being used for each application
   - b. The species being targeted
   - **c. The yield of the last crop grown**
   - d. The climatic conditions

12. Which of the following statements are correct concerning night time spraying?
   - **a. Under conditions of marginal weed stress, kill rates from sprays applied in the cooler night time temperatures can sometimes be slightly better than when applied during the heat of the day**
   - b. The risk of drift from night time spraying is generally lower than spraying in the heat of the day
   - **c. The risk of drift from night time spraying is generally much higher than spraying in the heat of the day, as temperature inversions that can lead to widespread drift are far more likely at night time**

10.6 Assessment answers Chapter 8

1. Accurate night spraying is now far easier with the advent of GPS and self-steer technologies. What are the **risks** of spraying at night? (There may be more than one correct response)
   - a. Off target drift issues in cotton and vineyards
   - **b. Increased chance of inversion conditions**
   - c. Reduced heat stress on weeds
   - d. All of the above

2. The double-knock strategy can cause logistical stresses to growers. Which statement is NOT appropriate for increasing spray capacity?
   - **a. Increase boom speed above 20-25 km/h**
   - b. More multiples of 24 metre linkage booms
   - c. Employ a contractor
   - d. Purchase a self-propelled spray rig

3. When there are only a small number of weeds in a fallow, spraying the whole paddock is expensive. What technology is available to reduce the amount of chemical applied whilst spraying all survivors? (There may be more than one correct response)
   - **a. WeedSeeker**
   - **b. WEEDIt**
   - c. Aerial application
   - d. Self-propelled spray rig

4. Growers already in a full no-till system may need to consider increasing their capacity to cultivate. Which statement(s) below demonstrates the benefit of cultivation to control hard to kill summer weeds?
   - a. Potential to spread weed seed throughout the paddock as well as prolonging seedbank dormancy
   - **b. Stimulates a more uniform germination of the seed bank**

c. Provide a bed for pre-emergent herbicides
d. Bury short lived surface germinating weed seeds to manage the seed bank (fleabane, windmill grass & feather top Rhodes grass)

5. Which of the following statements are correct concerning night time spraying?
   a. Under conditions of marginal weed stress, kill rates from sprays applied in the cooler night time temperatures can sometimes be slightly better than when applied during the heat of the day
   b. The risk of drift from night time spraying is generally lower than spraying in the heat of the day
   c. The risk of drift from night time spraying is generally much higher than spraying in the heat of the day, as temperature inversions that can lead to widespread drift are far more likely at night time

10.7 Assessment answers Chapter 9

1. Using the data relating to Research Case Study SNSW1- which statement is correct?
   a. Missing the first spray had a large detrimental effect on soil moisture, particularly at the deeper levels compared to full weed control
   b. Missing the first spray and delaying the timing of sprays were not significant factors on soil moisture
   c. Delaying spraying was only a significant factor in reducing soil moisture at shallow depths
   d. Complete weed control was only useful in maintaining surface water in the soil

2. Using the data relating to Research Case Study SNSW2 - which statement is **incorrect**?
   a. Stubble treatments such as stubble standing/slashed/cultivation or deep ripping had no significant impact on moisture or nutrient retention at the Gunningbland or Tottenham sites in 2010
   b. At the Gunningbland site, an extra 49 mm of PAW was retained when weeds were controlled, while at Tottenham only an extra 22 mm was stored. This was under excessively wet summer conditions
   c. At all sites in the wet conditions in 2010 there was no significant differences in either fallow efficiency or nutrient retention due to the fact that there was always optimal amounts of water available to the crops
   d. The high fallow efficiencies of 2010 are felt due to much of the rainfall occurring in the latter half of the fallow period (Feb/Mar/Apr) when soil evaporation losses were much lower than in the peak of summer

3. Using the data relating to Research Case Study SNSW2 - which statement is **incorrect**?
   a. Zero tolerance of summer weeds gave the greatest response to both grain yield and profit with the yield at the Gunningbland site in 2010 increased by 65% over the nil weed control treatment.
   b. Stubble treatments (stubble slashed, removed or cultivated) had a significant negative impact on yield across all sites
   c. Controlling summer weeds at the Tottenham site in 2010 also gave the greatest response to both grain yield (by up to 237%) and profitability

4. "Good summer fallow management often enables crops to be planted earlier and on more marginal rainfall events with lower risk of crop failure." This statement is best supported by:
   a. Storing soil water through better fallow management and early sowing complement each other and increase yield and WUE more than when either is practised alone
   b. Crop failure is more related to disease and conditions at harvest than practices during the fallow
   c. Farm average wheat yields across all sowing dates and varieties show that variety plays a more important role than water storage
   d. This statement is not supported by any data

5. Which of the following statements is **not true** regarding research in WA summer fallow situations?
   a. Fallow efficiencies averaged approximately 75%
   b. Evaporation was the main loss of soil water, although loss due to transpiration can also be important
   c. Once water moved below 0.3 m it was less accessible to losses via evaporation and transpiration unless weed growth was present
   d. Soil water accumulation in the fallow increased drainage under wheat in the following growing season

11 Glossary – weed Latin and common names

Weed name	Scientific name
GRASSES	
annual prairie grass	*Bromus catharticus*
annual ryegrass	*Lolium rigidum*
Australian millet/native millet	*Panicum decompositum*
barley grass	*Hordeum leporinum/H. glaucum*
barnyard grass/barnyard millet	*Echinochloa crus-galli/E. colona*
black grass/stinkgrass	*Eragrostis cilianensis*
black oats/wild oats	*Avena fatua/A. ludoviciana*
blown grass	*Lachnagrostis filiformis*
brome grass	*Bromus diandrus/B. rigidus*
burr grass, Small	*Tragus australianus*
button grass	*Dactyloctenium radulans*
canary grass	*Phalaris canariensis/P. minor/P. paradoxa*
common barbgrass	*Hainardia cylindrica*
couch grass	*Cynodon dactylon*
crab grass	*Digitaria sanguinalis*
feathertop Rhodes grass	*Chloris virgata*
foxtail millet	*Setaria italica*
Innocent grass/Mossman river grass/gentle Annie	*Cenchrus longispinus/C. echinatus*
Japanese millet	*Echinochloa utilis*
Johnson grass (seedlings)	*Sorghum halepense*
Kikuyu grass	*Pennisetum clandestinum*
native millet/Australian millet	*Panicum decompositum*
paradoxa grass	*Phalaris paradoxa*
paspalum	*Paspalum dilatatum*
phalaris, annual	*Phalaris paradoxa/P. minor;*
phalaris, perennial	*Phalaris aquatica*
pigeon grass, pale	*Setaria pumila*
Rhodes grass	*Chloris gayana*
silver grass	*Vulpia bromoides/V. myuros/V. muralis*
spiny burrgrass/sand burr/bohena beauty	*Cenchrus longispinus/C. echinatus*
stinkgrass/black grass	*Eragrostis cilianensis*
summer grass/crab grass	*Digitaria sanguinalis/D. ciliaris*
volunteer – barley	*Hordeum vulgare*
volunteer – maize	*Zea mays*
volunteer – oats	*Avena sativa*
volunteer – sorghum	*Sorghum bicolour*
volunteer – triticale	*Tritiosecale spp.*
volunteer – wheat	*Triticum aestivum*
vulpia	*Vulpia bromoides/V. myuros/V. muralis*
weeping lovegrass	*Eragrostis parviflora*
wild oat; black oat	*Avena fatua/Avena ludoviciana*
Wimmera ryegrass	*Lolium rigidum*
windmill grass	*Chloris truncata*
winter grass/annual poa	*Poa annua*
GRASS-LIKE WEEDS	
cape tulip	*Moraea miniata/M. flaccida*
chincherinchee	*Ornithogalum thyrsoides*
Guildford grass/onion grass	*Romulea rosea*
nut grass/nutsedge - purple	*Cyperus rotundus*
Star-of-Bethlehem	*Ornithogalum umbellatum*
toad rush	*Juncus bufonius*

Weed name	Scientific name
BROADLEAF WEEDS	
amaranth	*Amaranthus spp.*
amsinckia	*Amsinckia spp.*
bedstraw	*Galium tricornutum*
bifora	*Bifora testiculata*
bindweed, Australian	*Convolvulus erubescens*
bindweed, perennial	*Convolvulus arvensis*
black bindweed/climbing buckwheat	*Fallopia convolvulus*
blackberry nightshade	*Solanum nigrum*
burr, Bathurst	*Xanthium spinosum*
burr, noogoora	*Xanthium occidentale*
caltrop/cat-head	*Tribulus terrestris*
capeweed	*Arctotheca calendula*
castor oil, false	*Datura spp.*
charlock	*Sinapis arvensis*
chickweed	*Stellaria media*
cleavers	*Galium aparine*
clovers	*Trifolium spp.*
cobbler's peg/farmers' friend	*Bidens pilosa*
common heliotrope	*Heliotropium europaeum*
common verbena/purpletop	*Verbena spp.*
corn gromwell/sheep weed/white iron weed	*Buglossoides arvensis*
crassula/stonecrop	*Crassula spp.*
crested goosefoot	*Dysphania cristata*
crumbweed, small/goosefoot/mintweed	*Dysphania pumilio*
cudweed	*Gamochaeta calviceps*
cudweed, Jersey	*Pseudognaphalium luteoalbum*
datura (thornapple)	*Datura spp.*
deadnettle	*Lamium amplexicaule*
docks	*Rumex spp.*
doublegee/spiny emex/three cornered jack	*Emex australis*
fat hen	*Chenopodium album*
fleabane	*Conyza spp.*
fumitory	*Fumaria spp.*
heliotrope (white)	*Heliotropium europaeum*
Hexham scent/yellow sweetclover	*Melilotus indicus*
hoary cress	*Lepidium draba*
hogweed	*Polygonum aviculare/P. arenastrum*
hogweed, tree	*Polygonum bellardii*
horehound	*Marrubium vulgare*
kidney weed	*Dichondra repens*
knotweed	*Persicaria spp.*
lesser swine cress	*Lepidium didymum*
Lincoln weed	*Diplotaxis tenuifolia*
lucerne	*Medicago sativa*
mallow, small flowered/marshmallow	*Malva parviflora*
melon, camel/afghan	*Citrullus lanatus*
melon, paddy/prickly	*Cucumis myriocarpus*
milk thistle/sowthistle	*Sonchus oleraceus*
mintweed/small crumbweed/goosefoot	*Dysphania pumilio*
mintweed	*Salvia reflexa*
mustard, Indian hedge	*Sisymbrium orientale*
mustard	*Sisymbrium spp.*
New Zealand spinach	*Tetragonia tetragonoides*
Paterson's curse	*Echium plantagineum*
peppercress, African	*Lepidium africanum*
pigweed	*Portulaca oleracea*

Weed name	Scientific name
BROADLEAF WEEDS continued	
pimpernel/scarlet pimpernel	*Lysimachia arvensis*
plantain	*Plantago lanceolata*
plantain, buckshorn	*Plantago coronopus*
poppy, rough	*Papaver hybridum*
prickly lettuce/wild lettuce	*Lactuca serriola*
rhynchosia	*Rhynchosia minima*
rolypoly, soft	*Salsola tragus/S. kali*
scarlet pimpernel; Pimpernel	*Anagallis arvensis*
shepherd's purse	*Capsella bursa-pastoris*
Silverleaf Nightshade	*Solanum Elaeagnifolium*
skeleton weed	*Chondrilla juncea*
sorrel	*Acetosella vulgaris*
soursob	*Oxalis pes-caprae*
sowthistle/milk thistle	*Sonchus oleraceus*
speedwell, ivy-leaf	*Veronica hederifolia*
spiny emex/doublegee/three cornered jack	*Emex australis*
sticky ground cherry	*Physalis spp.*
stinging nettle, dwarf	*Urtica urens*
stinking goosefoot	*Chenopodium vulvaria*
storksbill	*Erodium spp.*
thistle, saffron	*Carthamus lanatus*
thistle, slender	*Carduus tenuifloris*
thistle, stemless	*Onopordum acaulon*
thistle, variegated	*Silybum marianum*
thornapple – Common	*Datura stramonium*
thornapple – Fierce	*Datura ferox*
thornapple/False castor oil	*Datura spp.*
three cornered jack/doublegee/spiny emex	*Emex australis*
threehorn bedstraw	*Galium tricornutum*
turnip weed	*Rapistrum rugosum*
turnip, wild	*Brassica tournefortii*
vetch	*Vicia spp.*
volunteer – cotton	*Gossypium hirsutum*
volunteer – lupins	*Lupinus spp.*
white clover	*Trifolium repens*
wild lettuce/willow lettuce	*Lactuca saligna/Lactuca serriola*
wild radish	*Raphanus raphanistrum*
wireweed	*Polygonum aviculare/P. arenastrum*

12 Bibliography and references

GRDC Green Bridge Fact Sheet (2009) www.grdc.com.au/greenbridge_factsheet

Bell, LW, Kirkegaard, JA, Swan, A, Hunt, JR, Huth, NI, Fettell, NA 2011, 'Impacts of soil damage by grazing livestock on crop productivity', *Soil & Tillage Research* vol 113, pp 19–29.

Brown, C, Hunt, J, Craig, S, Whitbread, A & Mowat, Damian 2010, 'Improving winter crop productivity through increased capture and storage of summer fallow rain'. "*Food Security from Sustainable Agriculture*" Edited by H. Dove and R. A. Culvenor Proceedings of 15th Agronomy Conference 2010, 15-18 November 2010, Lincoln, New Zealand. Accessed 2013 from http://www.regional.org.au/au/asa/2010/crop-production/soil-water/7005_brownec.htm

Borger, CPD, Riethmuller, G & Hashem, A 2010, 'Control of windmill grass over the summer fallow increases wheat yield' 17th Australasian Weeds Conference (2010): New Frontiers in New Zealand: Together we can beat the weeds, Christchurch Convention Centre, Christchurch, New Zealand, 26-30 September 2010, SM Zydenbos, SM (ed), pp 48-51, viewed in 2013 at http://www.caws.org.au/awc/2010/awc201010481.pdf

Brown, C, & Jones, B 2008, How important is straw for yield of no-till crops on heavy soils in the low-rainfall southern Mallee? "Global Issues. Paddock Action." Edited by M. Unkovich. Proceedings of 14th Agronomy Conference 2008, 21-25 September 2008, Adelaide, South Australia. Accessed 2013 from . http://www.regional.org.au/au/asa/2008/concurrent/crop-agronomy/5832_brownec.htm

Dolling, PJ, et al. 2006, 'Consequences of rainfall during summer–autumn fallow on available soil water and subsequent drainage in annual-based cropping systems'. *Australian Journal of Agricultural Research,* vol 57, pp 281–296.

Farre, I, Robertson, M, Foster, I, & Pasqual, G 2010, 'Our Changing Climate - Merredin at a glance'. Department of Agriculture and Food Western Australia, Perth, Australia.

Felton, W, et al. 1987, 'Crop residue management', *Tillage*, Cornish PS, Pratley JE eds, Inkata Press: Melbourne pp. 171-193.

Fischer, RA & Armstrong, JS 1990, 'Simulation of soil water storage and sowing day probabilities with fallow and no-fallow in southern New South Wales: II. Stochasticity and management tactics', *Agricultural Systems*, vol 33, pp. 241–255.

Freebairn, DM & Boughton, WC 1981, 'Surface runoff experiments on the eastern Darling Downs'. *Australian Journal of Soil Research*, vol 19, pp. 133-146.

French, RJ, and Schultz, JE, 1984, 'Water use efficiency of wheat in a Mediterranean-type environment: 1. The relationship between yield water use and climate'. *Australian Journal of Agricultural Research* vol 35, pp 743-764

Fromm, G & Grieger, V 2002, 'The effect of summer weed management on subsequent grain yield and quality'. *Weeds: Threats Now and Forever? - Proceedings from the 13th Australian Weeds Conference*. (8-13 September 2002) Perth. (H Spafford-Jacob, H, Dodd, J, Moore, JH (eds)) Plant Protection Society of WA: Perth, pp 63–66.

Fromm, G & Grieger, V 2003, 'Weed program boosts following yields'. *GRDC Ground Cover Article* Issue 47 Nov 2003, Research code: DAS293.

Fromm, G & Grieger, V 2004, 'The effect of summer weed management on grain yield and quality'. *Weed Management: Balancing People, Planet, Profit*, Proceedings from the14th Australian Weeds Conference. Charles Sturt University, Wagga Wagga, New South Wales, Australia, 6-9 September 2004, B.M. Sindel and S.B. Johnson. (eds), Published by Weed Society of New South Wales129-132

Haskins, BJ & McMaster, CL, 2012, 'Summer fallow management in 2010 across Central West NSW. In. (Australian Society of Agronomy. Available at http://www.regional.org.au/au/asa/2012/soil-water-management/8114_haskinsbj.htm

Hunt, JR & Kirkegaard JA 2011, 'Re-evaluating the contribution of summer fallow rain to wheat yield in southern Australia'. *Crop & Pasture Science*, vol 62, pp. 915–929.

Hunt, JRet al. 2011, 'Summer fallow management'. GRDC Grains Research Updates 2011, viewed 2013 at http://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2011/02/Summer-fallow-management

Hunt, JR et al. 2012, 'Improving WUE in southern NSW - summer fallow management and sowing early', *GRDC Grains Research Updates* 2012.

Kirkegaard, JA, 1995, 'A review of trends in wheat yield responses to conservation cropping in Australia'. *Aust. J. Exp. Agric.*vol 35, pp 835-848.

Kirkegaard J A, Hunt JR 2010, Increasing productivity by matching farming system management and genotype in water-limited environments, *Journal of Experimental Botany*

Kirkegaard, JA, Lilley, JM, Howe, GN, Graham, JM 2007, 'Impact of subsoil water use on wheat yield'. *Australian Journal of Agricultural Research* vol 58, pp 303-315

Krause, M 2008, 'Planning for low risk farming 2008 GRDC Publication'. http://www.grdc.com.au/uploads/documents/2008%20GRDC%20Planning%20Guide%20for%20Low%20Risk%20Farming.pdf GRDC Project Codes: CSP00111, UNF00001, CWF00013, DAS00089, BWD00012, FLR00005, AWRC08-86

McDonald, G, Hayman, P, Alexander, B 2009, 'Managing time of sowing' GRDC Advisor Update Southern Region 2009

McMaster, C & Graham, N (2013), Summer weeds reduce moisture and nitrogen – Forbes (2011 & 2012 results), Central Western Farming Systems Factsheet

McMaster, C et al. 2011,. 'Summer weeds rob moisture and nutrients – 2011', NSWDPI Factsheet

McMaster, C, Motley, K 2009, 'Evaluation of summer fallow efficiencies during the 2007/08 summer fallow period in the Parkes and Forbes districts'. *Central West Farming Systems Compendium 2010*.

Mudge, B & Whitbread, A 2010, 'Making better decisions about crop rotations in low-rainfall environments: should stored moisture and the timing of the seeding opportunity influence this decision?' *Food Security from Sustainable Agriculture*: Proceedings 15th Australian Agronomy Conference, Lincoln, New Zealand, November 2010, viewed 2013 at http://www.regional.org.au/au/asa/2010/crop-production/sequence/6994_mudgeb.htm.

Matthews, P, McCaffery, D & Jenkins, L 2013, Winter Crop Variety Sowing Guide 2013, NSW Department of Primary Industries

Norris, R 1996, 'Water use efficiency as a method for predicting water use by weeds'. *Weeds Technology* vol 10, pp. 153-155Osten, V, Hashem, A, Kotez, E, Lemerle, D, Pathan, S & Wright, G 2006, 'Impacts of summer fallow weeds on soil nitrogen and wheat in the southern, western and northern Australian grain regions' Managing Weeds in a Changing Climate: Proceedings from the 15th Australian Weeds Conference, Adelaide, South Australia,

24-28 September 2006, C. Preston, C, Watts, JH and Crossman, ND (eds),

Published by Weed Management Society of South Australia Inc. 395-398 viewed 2013 at http://www.caws.org.au/awc/2006/awc200613951.pdf

Poile G., etal 2012 Canola and subsoil constraints. Technical Report EH Graham Centre http://www.farmlink.com.au/past-projects

Preston, C 2003, The Australian Glyphosate Sustainability Working Group. Online. Internet. March 2013 . http://www.glyphosateresistance.org.au/

Sadras, V, Lawson, C, Hooper, P, McDonald, G, 2012, 'Contribution of summer rainfall and nitrogen to the yield and water use efficiency of wheat in Mediterranean-type environments of South Australia', *Europ. J. Agronomy* vol 36, pp. 41– 54.

Scott BJ, Eberbach PL, Evans J and Wade LJ, 2010, EH Graham Centre Monograph No. 1: Stubble Retention in Cropping Systems in Southern Australia: Benefits and Challenges. Ed by EH Clayton and HM Burns. Industry & Investment NSW, Orange. Available at: http://www.csu.edu.au/research/grahamcentre/ Verburg, K, Bond, W & Smith, C 2004, 'Fallow management affects the risks of deep water loss', in Fischer T et al. (eds.), New directions for a diverse planet: Proceedings for the 4th International Crop Science Congress, Brisbane, Australia, 26 September – 1 October 2004.., viewed 2013, http://www.cropscience.org.au/icsc2004/symposia/6/2/1187_verburgk.htm

Verburg, K, et al. 2007, 'Managing the fallow period for optimum water use and nitrogen availability', *GRDC Final Report*, Project: CSO232.

GRDC
Grains Research & Development Corporation
Your GRDC working with you
GRDC, PO Box 5367, Kingston ACT 2604 T 02 6166 4500 F 02 6166 4599