

Investigating options for herbicide resistance management and lime incorporation in Western Australia's northern wheatbelt



A KWINANA EAST
PORT ZONE PROJECT



Grower case studies from the Geraldton Port Zone

An initiative of the Kwinana East Port Zone
Regional Cropping Solutions Network

Prepared by the Grain Industry Association of
Western Australia (GIWA)

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Rod and Andrew Messina's farm-built chaff carts in action at Tenindewa.
Photo courtesy Rod and Andrew Messina

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Thank you to the Kwinana East Port Zone Regional Cropping Solutions Network (RCSN) who initiated the project, helped identify potential case study participants and provided valuable feedback during its development.

The RCSN identified lime and herbicides as the inputs with the most impact on profitability and sought to explore the options growers in the Geraldton Port Zone were using to incorporate lime to ameliorate soil acidity in the shortest possible time and to prevent or manage herbicide resistance. The Kwinana East Port Zone RCSN identified investigating options for herbicide resistance management and lime incorporation as a priority for investment of Grains Research and Development Corporation's (GRDC) Research Development and Extension (RD&E) funds.

Thank you to Bob Nixon of the Kwinana East RCSN for his involvement in identifying case study participants and for his significant contribution to the development of the bus tour itinerary.

Thank you to Chris Gazey and Gaus Azam from the Department of Agriculture and Food, Western Australia (DAFWA), who travelled with participants for the duration of the three-day bus tour and shared their considerable expertise in soil acidity management.

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Finally, GIWA would also like to acknowledge its team members and contractors; in particular, Peter Nash, who coordinated and led the bus tour, and prepared the grower case studies for inclusion in this booklet.



Bus tour participants

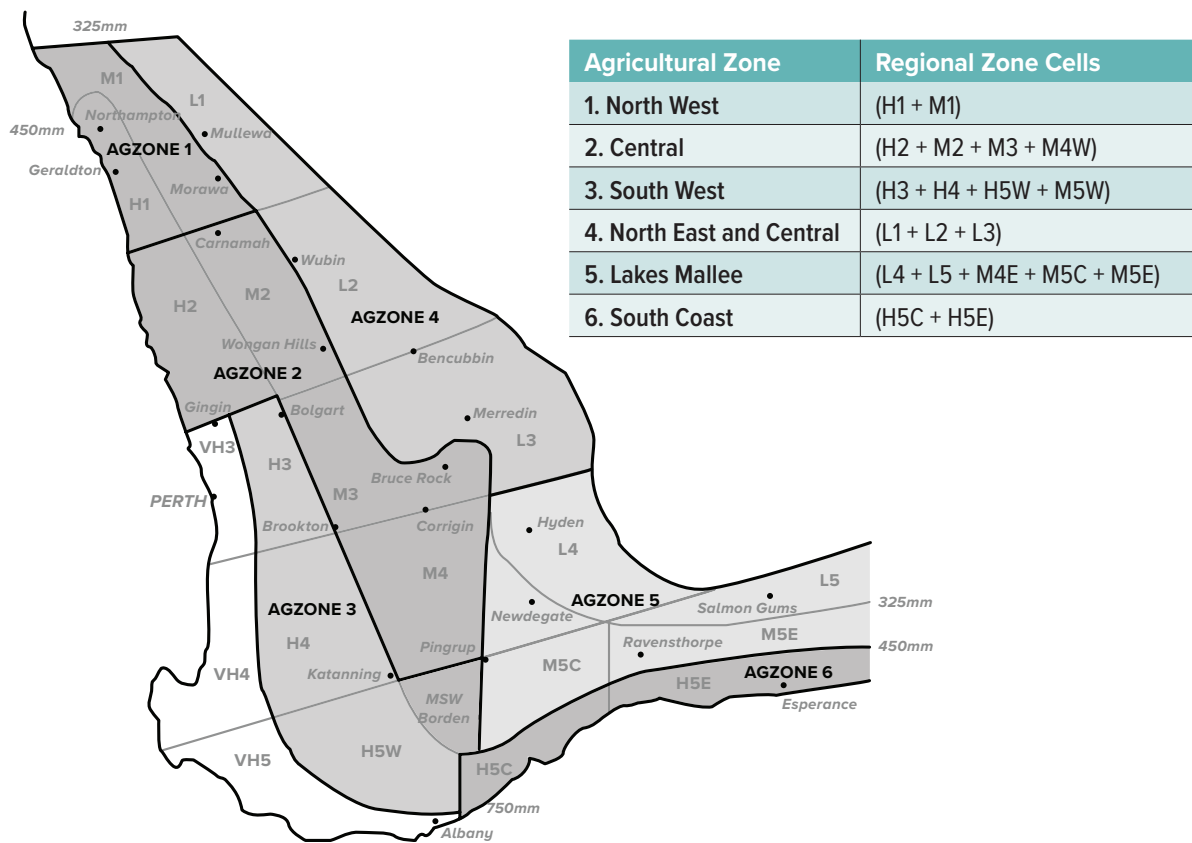


Figure 1. Western Australian Agricultural Zone

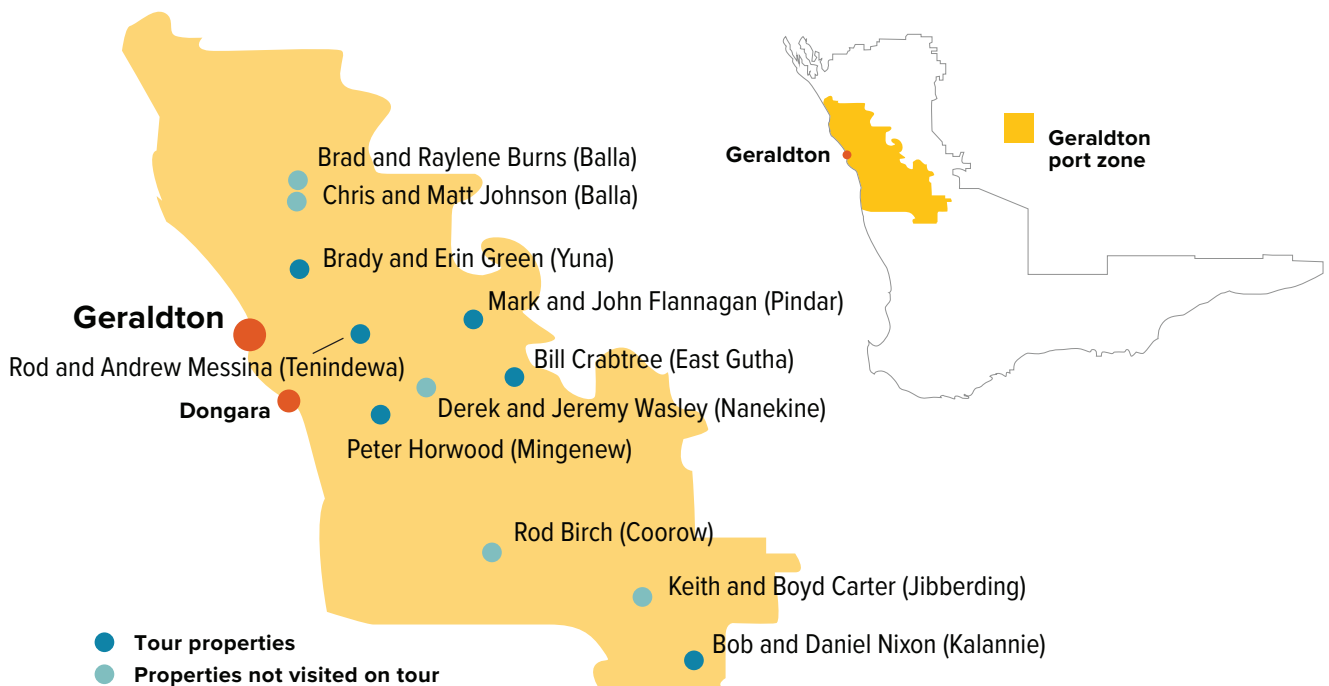


Figure 2. Kwinana Zone RCSN northern wheatbelt bus tour properties

Background

During 2015, the Kwinana East Port Zone Regional Cropping Solutions Network (RCSN) identified input costs and weeds as two of their highest priorities.

They further identified that in their eastern wheatbelt environment where yields are relatively low and the seasons highly variable, growers are very conscious of the need to carefully manage inputs to maintain profitability. Lime and herbicides were identified as the inputs with most impact on their profitability.

Research undertaken by Liz Petersen of the Department of Agriculture and Food, Western Australia (DAFWA) estimates that subsoil constraints (acidity, compaction, sodicity and transient salinity) cost WA growers approximately \$3.19 billion per annum in lost production potential by reducing rooting depth and function to the extent that water and nutrient levels are insufficient to sustain production at or near the rainfall limited yield potential (Petersen, 2016).

Of these four subsoil constraints, soil acidity is the most severe and widespread and is the highest risk to production. It is estimated to cost WA growers an average \$141 per hectare per year (/ha/yr) which equates to \$1.6 billion/yr in lost production potential. This is followed by compaction (\$54/ha/yr or \$0.9 billion/yr), sodicity (\$52/ha/yr or \$0.6 billion/yr) and transient salinity (\$19/ha/yr or \$92 million/yr).

Of the strategies considered by Petersen (2016) to manage these subsoil constraints, it is estimated that liming has the most potential to increase profitability (by approximately \$63/ha/yr), followed by deep ripping and deep working with controlled traffic farming (CTF) to manage compaction (estimated to increase average profits by \$35/ha/yr) and gypsum for the amelioration of sodic soils (estimated to increase average profits by \$9/ha/yr).

It is worth noting that although there are practices which can reduce the rate of acidification such as using non-acidifying or less acidifying fertiliser, minimising leaching of applied nitrogen (N) and returning stubble to the paddock, acidification is on-going and is part and parcel of a productive system which exports food or fibre. Typically, a wheatbelt farming system operating a winter crop/pasture rotation in WA has an acidification rate equivalent to 25–345kg/ha/yr of pure calcium carbonate (*National Land and Water Resources Audit 2001*). The more productive and higher the leaching environment the greater the acidification rate.

DAFWA estimates about 14.25 million hectares (ha) of the State's wheatbelt soils are acidic, or at risk of becoming acidic, to the point of restricting crop yields (Gazey *et al*, 2014). During 2013, DAFWA estimated that WA growers applied about 1 million tonnes (mt) of lime annually. However, DAFWA believes this level needs to increase to 2.5mt annually to address acidification and to recover pH to levels where cereal yields are not constrained.

The Australian Herbicide Resistance Initiative (AHRI, a GRDC-funded initiative UWA00171) surveys conducted during 2003 and then again during 2010 for the L3 Zone (low rainfall) show that incidence of herbicide resistance in annual ryegrass (*Lolium rigidum*) for a range of chemicals in the Kwinana East zone has remained relatively stable compared to other port zones in WA. This however is not the case for wild radish (*Raphanus raphanistrum*). Of the eight wild radish populations sampled in the L3 Zone during 2003, 13 per cent showed resistance (>20% survival) to atrazine. None were detected as being resistant to chlorsulfuron, 2,4-D amine or diflufenican. However, by 2010 this had greatly changed. 60% of wild radish populations sampled during 2010 in the L3 Zone were resistant to 2,4-D amine, 100% were resistant to chlorsulfuron and 70% to an imazamox (33g/L) plus imazapyr (15g/L) formulation. For more information, visit www.ahri.uwa.edu.au/research/surveys/survey-zones/zone-l3/l3-wild-radish/

Geraldton Port Zone growers have been very proactive in using strategies to address herbicide resistance issues due to the research and extension efforts of the AHRI team. With this in mind, the Kwinana East Port Zone RCSN prioritised a bus trip to the northern wheatbelt to visit growers who had been active in:

- applying and incorporating lime to treat subsoil acidity;
- seeking to manage sodicity; and
- managing herbicide resistance.

The intention was to determine how Kwinana East Port Zone growers may apply this knowledge on their own properties.

Kwinana East Port Zone RCSN, private consultants, industry agronomists and DAFWA researchers were consulted to identify growers in the Geraldton Port Zone who had been experimenting with, or who had adopted, soil acidity and herbicide resistance management practices that could be applied to the low rainfall, eastern wheatbelt environment. Growers who had been trialling such things as mouldboard ploughing or rotary spading to incorporate lime, or using high rates of lime to hasten pH



Lime sand being loaded for transport to farm. *Photo courtesy of Chris Gazey*

change, or who had been managing herbicide resistance by using chaff carts, windrow burning, mouldboard ploughing, chemical fallow, tactical grazing and other methods were identified.

Eleven growers were selected from more than 20 identified, as being of particular relevance to the interests of the growers participating in the bus tour. Six of these 11 growers were selected to be visited on the bus tour which took place from 12–14 September 2016, commencing and ending in Merredin.

Some of the growers included in this booklet are featured for their soil acidity management practices or their herbicide resistance management practices while some are featured for both.

Chris Gazey (DAFWA) and Gaus Azam (DAFWA) travelled on the bus for the duration of the three-day tour and shared their considerable expertise in soil acidity management. Peter Newman (Planfarm/AHRI), Abul Hashem (DAFWA) and other experts in the management of herbicide resistance were also invited to accompany the bus tour, however the tour coincided with the 20th Australasian Weeds Conference being held in Perth and those invited were unable to attend the tour.



Photo courtesy of Meg Hele



KEY TAKE-HOME MESSAGES

The following summarises the key messages derived from the experiences and observations of the growers featured in this booklet and reflect the prominent topics of discussion amongst those growers who undertook the bus tour.

MANAGING SOIL ACIDITY:

- The need to effectively manage soil acidity, especially sub-soil acidity, is widely accepted as being essential to farming profitably in a drying climate.
- There is a trend towards higher rates of lime and more frequent applications in order to reduce the time taken to increase soil pH at depth.
- There is strong interest in incorporation techniques capable of reducing the time taken for applied lime to increase pH at depth.
- There is a conflict between the need to incorporate lime to maximise its affect at depth and the desire to retain the soil structure benefits obtained through many years of minimum or zero-tillage practices.
- 'Top-soil slotting' shows promise as a technique to move higher pH topsoil down the profile, but more research is required to refine the system.
- The use of alternatives to lime sand, such as 'Morell lime', become increasingly viable as distance from the coast increases and as high grade lime sand becomes scarcer.
- Managing soil acidity is a key component of effective weed management.
- Regular soil testing of both topsoil and subsoil is essential to manage pH and nutrients.
- Acidification is on-going and is part and parcel of a productive system which exports food or fibre. The more productive and higher the leaching environment the greater the acidification rate.

MANAGING HERBICIDE RESISTANCE:

- Effectively managing weeds at the lowest cost possible is a very high priority for growers.
- Integrated weed management incorporating harvest weed seed management, effective in-crop weed management and the elimination of point-sources of weeds is essential for the management of herbicide resistance.
- There is an increasing trend towards a 'no escapees' approach to managing weeds, particularly those susceptible to the development of herbicide resistance such as annual ryegrass and wild radish. This includes removing isolated trees, rock piles, contour banks, fence lines and other point-sources of weeds.
- Summer weeds are becoming increasingly expensive and time consuming to control, with some such as button grass (*Dactyloctenium radulans*) and tar vine (*Boerhavia coccinea*, *Boerhavia dominii* and *Boerhavia schomburgkiana*) becoming more prevalent.
- When coupled with spot-spray technology, chemical fallow is becoming increasingly accepted in the low rainfall areas where moisture capture and the ability to sow early is critical, but has less acceptance in higher rainfall zones.
- There is significant interest in the research being undertaken into residual herbicides for chemical fallow.
- Sheep are seen by many growers as incompatible with effective weed management, while in contrast, some growers see sheep as an essential tool for managing weeds that are difficult or expensive to control with herbicides.
- There is increasing interest in hand weeding wild radish once numbers are low. Global Positioning System (GPS) technology makes this more viable by allowing the accurate mapping of isolated plants and residual populations.
- Overcoming soil acidity is a key component of effective weed management.
- Using mouldboard ploughs to bury weed seeds can be an effective way to manage herbicide resistant weeds, but can introduce significant issues with seed depth control, surface crusting and trafficability.
- Harvest weed seed management practices vary considerably between growers and it is common for growers to use different practices from season to season in response to crop biomass levels.

CASE STUDY

BOB AND DANIEL NIXON, KALANNIE

SNAPSHOT

GROWERS: Bob and Daniel Nixon

PROPERTY NAME AND LOCATION: 'Dalmeny East', Kalannie

AREA: 16,000ha arable

RAINFALL: 260–300mm (220mm average growing season rainfall)

SOIL TYPES: 50% red loam to heavy red clay and Morrel clay; 20% Wodjil sand; 15% good yellow sand; 15% Tammar sand

LIVESTOCK: 1100 merino ewes, but moving out of sheep

CROPPING (2016): 7300ha wheat (55%); 3800ha canola (29%); 2100ha barley (16%); plus 3000ha of fallow and pasture. Canola area is up from the usual average of 2000ha in response to early break during 2016.



Bob Nixon on his Kalannie property demonstrating lime quality

The Nixon family took up new land in Kalannie during 1922 and sowed their first crop during 1927. Four generations later, Bob and his brothers Daniel and Matthew, together with wives Amanda and Melanie and parents Robert and Helen, have added to the family's original holdings of predominantly heavy red valley soils by purchasing additional, lighter soil types nearby. This has been a tactical move to manage risk in the drying climate, as these lighter soils are much more forgiving in dry years.

The Nixons have steadily moved the pasture phase to chemical fallow and with that has come a commensurate reduction in their sheep enterprise.

"Sheep are not compatible with our system anymore," said Bob Nixon. "They compromise it. They damage the soil friability we work so hard to achieve through no-till and stubble retention and this hampers our dry seeding where we need cover and soft friable soil to get good seed coverage and good pre-emergent herbicide efficacy.

"Sheep also aren't compatible with the bigger paddock sizes we need to drive our machinery efficiency and to implement controlled traffic farming, which is one of our goals. Plus, fence lines along with contour banks, rock piles and trees host weeds so their removal helps with weed hygiene and combatting herbicide resistance."

The Nixon's 1100 remaining merino ewes were scheduled to be sold during 2015, but with prices comparatively weak, are being held over until prices improve. Their days are numbered.

The Nixons have worked hard to achieve a low cost structure and economies of scale.

"We are all about managing risk," said Bob. "Seasonal variability is one of our biggest challenges. More so even than declining annual rainfall."

"Our farming system involves carefully managing our inputs and getting maximum efficiency out of our machinery and labour units. By understanding our costs and keeping them as low as possible, we keep our breakeven yields low. That enables us to make a profit most years, even in the decile two and three rainfall years which are our new norm."

Figure 1 page 11, illustrates the variability in the Nixon's wheat yield over time. Bob believes decreasing autumn rainfall and greater seasonal variability are the principal causes of their average wheat yield dropping by about 300kg/ha despite improving genetics and technology since the 1990s.

The Nixon's five-year rolling average yield for wheat is presently 1.75 tonnes per hectare (t/ha) and approximately 1.0t/ha for canola.

To match their inputs to the needs of the crop, Bob and brother Daniel rely heavily on soil and tissue testing and apply a significant amount of lime and gypsum to manage soil constraints. This is discussed in more detail in the *Managing Soil Acidity* section page 12.

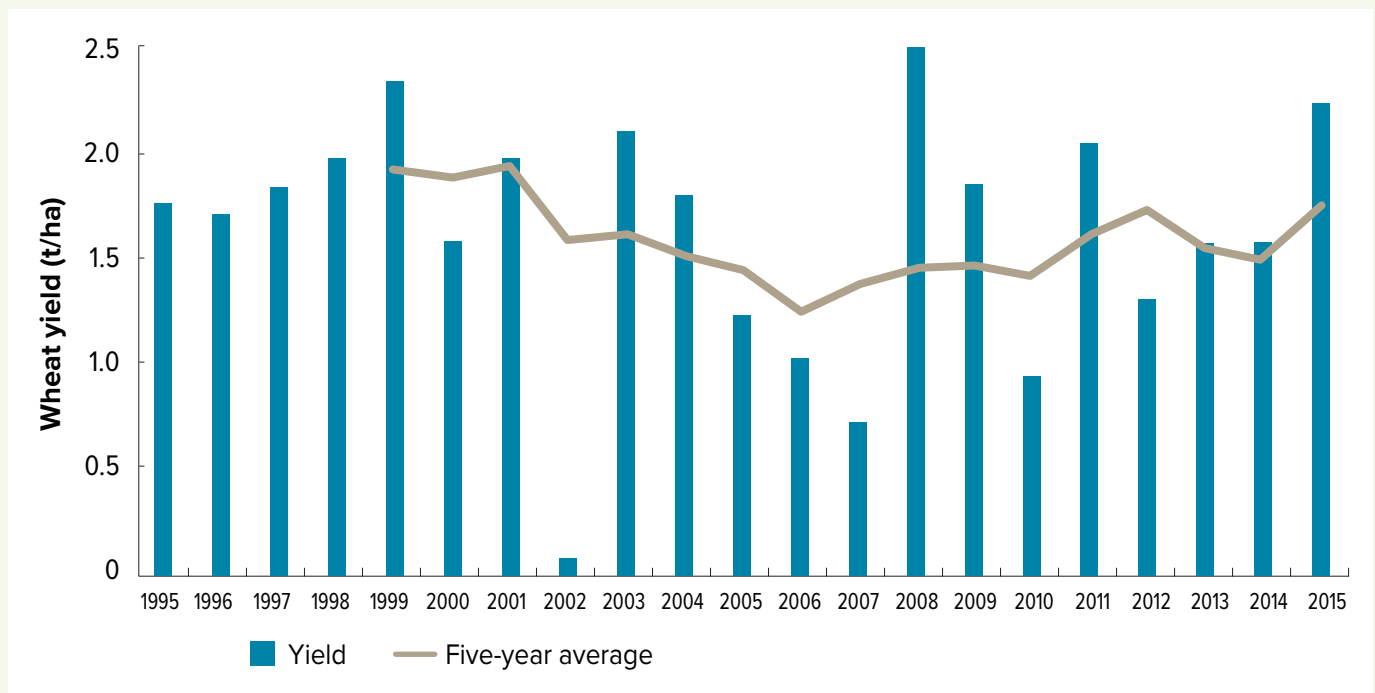


Figure 1. The Nixon’s historic wheat yield and five-year rolling average over time (graph data courtesy of Bob Nixon)

They have also matched their machinery size and labour to their crop program, running two seeding units (DBS bars on 12 inch tyne spacing), two spray rigs and two headers to capacity. To keep these operating efficiently, the Nixons have two permanent, full-time workmen and employ four casuals at seeding and two at harvest.

Dry seeding is an integral part of the Nixon’s system. With their target to complete seeding being 25 May, the Nixon’s seeding program usually commences on 25 April, wet or dry. The seeders will be kept working round the clock to finish on time.

Because of the great start to the 2016 season and larger canola program, the Nixon’s seeding program began on 12 April.

Crop rotation decisions are made on a paddock-by-paddock basis, guided by soil type, pH and nutrient status, weed burden and past rotation history. On the heavy valley floor soils that make up about a third of their farms, the Nixons use either a fallow/wheat/wheat/barley rotation or continuous barley. On their light to medium soils that make up the other two thirds of their farms, the usual rotation is canola/wheat/wheat/wheat or if weeds are an issue the double break is utilised with fallow/canola/wheat/wheat.

“We are big fans of the double break,” said Bob. “Two successive years not growing cereals allows us to achieve two years of 100% weed and disease control leading into a low cost cereal phase. This has been very useful in bringing weed issues under control on our recently purchased property.

“We are introducing about 3000ha of chemical fallow to replace what has traditionally been pasture. The fallow is often followed by canola to give a double break and improve the reliability of the canola and this then leads into the low cost cereal phase.

“Due to poor returns, we stopped growing legumes (lupins, field peas, chickpeas) five years ago. Their poor performance in dry years, their susceptibility to soil constraints like salinity and the poor weed control compared to what we could achieve in canola were the main reasons. We have found canola to be a superior break crop on our farm and have experimented successfully with canola after canola, which is something we may occasionally do again as sclerotinia is not a high risk in our area.”

The Nixons have also been removing banks, fences, rock piles and trees, including oil mallee plantations, to further improve machinery efficiency and importantly weed hygiene.

“Tree removal at first was a hard thing to do as I pushed the planting of many in the wetter period of the 1990s,” said Bob. “However tree plantings on the contour no longer fit our up-and-back system. We still plant trees, but in blocks on our poorly performing soil types. If the seasons continue to become less favourable to cropping in the future, taking poor performing soil types like high heavy clay high in the landscape out of production will become important.”

MANAGING SOIL ACIDITY

The Nixons began applying lime on their lighter soil types during 1994, initially applying at a rate of 2t/ha then reducing that to 1.5t/ha.

The Nixon's strategy of complementing their predominantly heavy red valley soils by purchasing more, lighter land higher in the landscape has meant they have had to become better at managing soil acidity.

"The naturally acidic Wodjil soils on the new country purchased had a pH_{Ca} at the surface of around 4.0–4.3," said Bob. "As did the better quality sands that had produced better crops over the years and had become very acidic. By 2012/13, we were spreading 4000t of lime sand per year and we had to look for a more economical way to raise pH as freight was a major cost."

Bob and Daniel began to look to their alkaline (pH 8) Morrel soils as a possible replacement for lime sand. The Nixon's Morrel soils are poor performers in dry years and they had virtually stopped cropping these soils unless it was shaping up to be a wet year. The brothers did some intensive sampling and testing which determined they had an extensive resource of alkaline calcium-magnesium carbonate, which they term Morrel lime, available to them.

With an average neutralising value of around 50%, it meant the Nixons would have to apply around 2t of Morrel lime to have the same effect on pH as 1t of high quality lime sand.

"We calculated the cost of harvesting and spreading the Morrel lime at full contract rates to see how it stacked up against contract carting and spreading of lime sand," said Bob. "Even though having half the neutralising value of lime sand means having to spread twice as much for the same effect, the economics were in favour of using the on-farm Morrel lime. As an added bonus, we found it contains useful amounts of potassium (> 600 parts per million (ppm) Colwell in surface tests) plus around 14% calcium and 4% magnesium."

"The Morrel lime has a much higher specific gravity than lime sand, which means that a tonne of Morrel lime occupies less volume than a tonne of lime sand. We can actually get more Morrel lime in our spreader than lime sand, measured by weight.

"Because it has half the neutralising value of lime sand, we need to apply twice as much Morrel lime by weight to get the same effect. We had therefore assumed that it would take us twice as long to spread, but because it has a higher bulk density, we found we don't have to fill up so often. This helps swing the economics further in favour of the Morrel lime."

With two years of mining and spreading the Morrel lime now behind them, Bob and Daniel are confident they have made the right decision.

"Our best investment is in soil pH," said Bob. "Because we are trying to bring the pH up to an optimal level as quickly as possible, we have been putting out a lot of Morrel lime.

We spread 12,000t of Morrel lime in both 2015 and 2016, which is much higher than we would expect to be applying in the future when we will just be putting out maintenance rates."

"We are finding the Morrel lime easier to spread than lime sand. We have had difficulties in the past getting lime sand to spread evenly, especially if it is windy. The Morrel lime spreads more like crushed limestone; nice and evenly."

The Nixons incorporate the Morrel lime using offset discs on some paddocks, ploughing to 150mm ahead of seeding. Ploughing is done as close to seeding as possible following wheat with stubble cut high to limit the wind erosion risk. Having been no-till farming for 20 years, the Nixons are very careful about how they plough and how often they plough as they don't want to undo the benefits of their years of no-till.



Stockpiling Morrel lime for the Nixon's 2016 liming program
(Photo courtesy of Bob Nixon)



Screening the Morrel lime (Photo courtesy of Bob Nixon)



Bob Nixon (with shovel) discussing with the tour group how he and brother Daniel harvest and use the Morrel lime (12 September 2016)

“We have been getting an increase in hard-to-kill perennials like bluebush (*Maireana brevifolia*) as a result of years of no-till. Offset ploughing solves this at the same time as incorporating the lime; however, you need to have good ryegrass control before ploughing or you risk stimulating a large ryegrass germination and swamping the following crop undoing the good work. After ploughing, we use both trifluralin and pyroxasulfone in crop so ryegrass does not proliferate and negate the benefit of ploughing. The double break is also very important to ensure you have low ryegrass numbers in the system.”

Using the above system, the Nixons have been able to raise the pH of their acidic soils from the low 4s up to the desirable 5.8 to 6.0 pH.

“To keep our soils at these target pH levels, we think a maintenance application of 4t/ha of Morrel lime (equivalent to 2t/ha of lime sand) will be required about every 10 years,” said Bob.

In addition to 4t/ha of Morrel lime, the Nixons have been applying 1.5t/ha of gypsum to their Wodjil soils to try and ameliorate aluminium problems at depth as quickly as possible. So Bob is keenly looking forward to seeing what results flow from the GRDC State acidity project trial to be established on Wodjil soils during 2017 and which will quantify pH responses on these soils to treatments including lime sand, gypsum*, alternative lime sources (e.g. Morrel lime), deep ripping with inclusion plates and ploughing.

“Its objective trials like these that will further our knowledge about how best to treat soil acidity at depth in the shortest possible time and for least cost.”

The Nixons soil test all paddocks every five years, which Bob feels is still not frequent enough. Problem areas are tested to depth and tissue testing is performed tactically every year in poorer performing paddocks.

* Gypsum does not increase soil pH



Chris Gazey (DAFWA) spraying the Morrel lime with Universal indicator. The dark purple colour indicates a pH of approximately 8 (in water) throughout the profile (NB: the shallow topsoil had been scalped from this area)



Using Universal indicator to measure the pH (in water) of the Morrel lime

“With our strong liming regime, we are starting to see some nutrient deficiencies on our light soils that we have never seen before,” said Bob. “Tissue testing has shown low zinc and manganese in wheat, even though this doesn’t seem to be resulting in any yield penalty as yet. Trace element levels are something we will need to watch more closely and I expect we will need to increase our tissue testing program.”

“Next year we will begin applying zinc seed dressing to wheat going on lighter soils. This was previously only ever needed on our alkaline Morrel soils, but conversely, because we have raised the pH on our lighter soils, we don’t need to apply molybdenum anymore.”

The Nixons are now also starting to look to their heavy soils where they are seeing pH_{Ca} levels drop below 5.0 for the first time. They have begun selectively treating known problem areas within paddocks by applying 4t/ha of Morrel lime, and they know they have a Morrel lime resource which will satisfy their needs for many years to come.

“So far we have harvested around 3ha of our available Morrel soil to utilise for lime,” said Bob. “We know we have about 40ha of similar quality material still available.”

Bob believes other farmers, particularly those furthest from high grade lime sand supplies, should look closely at the economics of using local, lower neutralising value lime alternatives.

“As the cost of cartage becomes higher, the economic argument for using lower neutralising value lime alternatives increases. It could be that even a 25% neutralising value lime alternative could be more economical than trucking lime sand over significant distances, but you would need to have a good understanding of the quality of the available local resource, then do your sums carefully.”

MANAGING WEEDS

Like many other growers, by the late 1990s the Nixons were experiencing widespread resistance in annual ryegrass to the sulfonylurea and ‘fop’ herbicide groups. Their use of break crops, paddock hygiene and rotating herbicide groups has since dealt with the resistant ryegrass and today they maintain a zero tolerance approach to weeds.

“The only number that works when it comes to weeds is zero,” said Bob. “We work very hard to get good weed control before we enter a cereal phase. On our farm we’ve had success growing canola after pasture or fallow over the past 10 or so years. This gives us two years of 100% weed and disease control, what we call the ‘double break’, before heading into an extended low cost cereal phase.”

“The double break has been a particularly valuable tool for us to clean up our most recently purchased farms which had large weed burdens. We have been very successful in getting high weed burden paddocks clean within five years using the double break and paying attention to detail with paddock hygiene.”

Windrow burning is one weed control strategy used sparingly and not favoured by the Nixons.

“Harvest residue is the cheapest and most valuable source of organic matter and nutrients. We can’t afford to remove those from the system, so we prefer to control our weeds with rotation and break crops and retain all harvest residues.”

As mentioned, the Nixons are very particular on paddock hygiene.

“Fence lines, rock heaps, banks and so on host, breed up and reinfest paddocks with weeds,” said Bob. “When fence lines and banks are sprayed it puts pressure on weed resistance as there is no crop competition and the fallow effect of stored moisture means weeds continue to germinate.”

“For example, ryegrass on a contour bank gets picked up by the end of the header front and spread across 45 feet, undoing the in-crop weed control. We are big on paddock hygiene because each paddock is effectively only as clean as the dirtiest patch.

“Our biggest win in controlling costs in the last 10 years has been the reduction in costs of off-patent herbicides. That’s why we are so keen to manage their effectiveness carefully and protect herbicides like trifluralin and clethodim. On our Kirwan property, we are using Roundup Ready® genetically modified (GM) canola in the rotation to clean up ryegrass while maintaining clethodim so we can return lupins to the rotation in the future.”

To maximise the effectiveness of pre-emergent herbicides like trifluralin, Bob and Daniel are using snake chains which they trail behind the seeder. These knock the shoulders off the square furrows left by the press wheels. The Nixons had commonly observed ryegrass germinating from the vertical faces of the press wheel furrows which had not received good coverage of trifluralin. The snake chains help distribute the trifluralin more evenly.

“Snake chains drag loose soil back on top of the seed helping to stop capillary rise, slowing drying of the seed zone and helping to prevent crusting,” said Bob. “They help maintain seed depth with the DBS because the square press wheel furrows collapse when dry and stay square when wet. We have noticed a deep square press wheel furrow can shade light from the base of the plant effecting tillering.”

A chemical fallow has also been introduced into their system in the last few years as a means to carry moisture over into the following crop year and help manage dry seasons. Significant amounts of mineralised nitrogen also accumulate reducing the cost of growing the following crop. The Nixons prefer to spray later to build up some cover first to reduce the erosion risk. The extra cover will then help to stop evaporation and cuts the number of sprays needed to keep fallow bare all winter.

ADDITIONAL READING



‘Soil acidity management strategies throughout Western Australia’ (2015), Liebe Group and GRDC, page 23.

CASE STUDY

BILL AND MONIQUE CRABTREE, EAST GUTHA

SNAPSHOT

GROWERS: Bill and Monique Crabtree

PROPERTY NAME AND LOCATION: 'Shalom Valley',
East Gutha

AREA: 3200ha, 85% arable

RAINFALL: 305mm (last four years of April–September
rainfall has been 206, 164, 182, 160mm)

SOIL TYPES: 15% sandy loam (Wodjil); 75% red loam; 10%
loamy clay (eroded plough layer)

LIVESTOCK: None

CROPPING (2016): 100% crop (80ha fallow in 2014) – wheat
(94%); lupins (2%); canola (4%); have tried triticale and barley
also five-year average yields: 1.2 t/ha wheat, 0.6 t/ha lupins,
canola 0.6 t/ha

ROTATION: Wheat on wheat for nine years on most of the farm



Bill Crabtree on his East Gutha property standing in his April 15 sown crop of Nuseed GT41 Roundup Ready® canola photographed on 23 July 2016. (Photo courtesy of Bill Crabtree)

Bill Crabtree is well known in WA and beyond for his passion for no-till farming; so much so that he is widely known as 'No-Till Bill'.

Bill is a graduate of Agricultural Science from the University of Western Australia, he has a Masters in Science on water repellence and is currently studying a PhD on no-tillage. He is a champion for biotechnology promotion and won the 2009 McKell medal. He is renowned for thinking and acting outside the square.

Bill and Monique purchased their Morawa farm in late 2007. It is located on the eastern fringe of the agricultural zone in 305mm annual average rainfall (100-year average).

MANAGING SOIL ACIDITY

The soils on Bill's farm are naturally slightly acidic. After purchasing the farm in late 2007, soil samples taken from 12 sites during March 2008 showed an average pH_{Ca} of 5.3 at the surface with only three sites having a pH below the DAFWA minimum target of 5.5 at the surface. Bill's three below-target sites showed readings of 4.6, 4.8 and 4.9.

"At this time, I did not think subsoil acidity was limiting farm productivity," said Bill.

2008 and 2009 were reasonable rainfall years on Bill's farm, with 2010 rainfall very low (decile 1) and then 2011 was a very wet year (decile 9 year) for the area.

Bill noticed that some areas, especially on the lighter soils, were performing very poorly and so he conducted some targeted soil sampling which confirmed these areas had low pH. He then applied lime sourced from Dongara to these areas in two applications during 2009 and 2010 which totalled 3t/ha.

"2011 was a very wet year," said Bill. "We received 470mm, yet there were patches of poor, yellow crop in most paddocks during June, so I top-dressed 100kg/ha of ammonium sulphate during July in an attempt to mitigate the yellowing. Despite good rainfall after the ammonium sulphate was applied, these areas remained yellow until crop maturity."

Investigating further, Bill began to suspect that subsoil acidity and aluminium toxicity were the most likely reasons for the severely reduced root growth he observed in these poor performing areas.

"As rainfall in the region is typically low during August and September, being able to fully exploit water and nutrients in the subsoil is very important for grain filling and optimising crop yield potential," said Bill. "I was keen to explore the subsoil pH further, and address it as economically as possible if a problem was found."

Bill discussed the situation with Chris Gazey at DAFWA and subsequently took part in a Caring for our Country funded project which offered cost-shared soil testing. During February 2012, Precision SoilTech sampled 34



Bredal spreader on a truck with the famous R1250 Chamberlain loader. (Photo courtesy of Bill Crabtree)



Seed Hawk® seeder in action after 2t/ha of applied lime during 2013. (Photo courtesy of Bill Crabtree)

geo-located sites at three depths: 0–10, 10–20 and 20–30cm. The subsoil tests were replicated three times at each site, bulked, sub-sampled and tested for pH. The results revealed widespread subsoil acidity. 83% of sites had a pH in the 20–30cm soil layer of less than 4.8 and many of these were in the areas that had exhibited yellowing and yielded poorly in the wet year of 2011, despite the supplementary nitrogen applied.

“These low pH results prompted me to apply 2t/ha of lime on half of the farm,” said Bill. “From March until May 2012, we spread a total of 2650t. After the 2012, 2013 and 2014 harvests, we spread a further 2t/ha on the most acidic areas. My intention was to apply high rates of lime to increase the surface pH to above 5.7 in order to maximise the movement of mineralised lime into the subsoil from 10–30cm deep.”

The area experienced low rainfall during 2012–14 (deciles 1–3) and then during late January 2015, Bill’s farm received the first of three intense 60mm rainfall events which fell three weeks apart. Most of the rainfall received in these intense one-day events penetrated the soil due to Bill’s previous eight-years of continuous no-till with 100% residue retention. Only some of the heaviest soils, which had low residue levels, allowed some water from the third rain event to run off. Bill believes that these heavy rain events helped the lime he had applied move to depth.

“However, given I had applied up to 6t/ha of lime to some areas of the farm from 2012–14 to try and correct the low yielding patches, I was disappointed crop yields were still relatively poor in some areas. I concluded that much of the applied lime probably remained undissolved in the surface soil and given that cultivation does increase the ability of the soil to react with the lime making more dissolved lime available to be leached into the subsoil, I believed it was time for some strategic cultivation,” said Bill.

“During April 2015 I purchased a couple of single disc ploughs and removed every second disc to ensure deep mixing of the limed topsoil and put a back-packer on the tractor. However, with the back-packer leaving the paddock very rough behind the plough, ploughing was stopped after just a week and abandoned for that year. I decided to repeat some soil tests before continuing with any more tillage.”

Pleasingly for Bill, his 2015 harvest saw improved wheat yields on some areas that had previously yielded poorly, giving him confidence that the lime he had applied was taking effect. This was despite a dry spring (only 17mm of rain fell during August and 1.5mm during September) which followed 72mm during July.



Bill kneeling in a paddock of Magenta wheat sown on 25 April at his Gutha property. This paddock has received 10t/ha of lime since 2008. Photographed on 13 September 2016



Bill explaining his soil acidity management strategy to the tour group on 13 September 2016

With a 1.3t/ha average wheat crop for 2015 allowing investment in more soil testing, Bill repeated the sampling done at the 34 sites during 2012. After harvest during November 2015, the 34 geo-located sites were resampled, plus 20 new sites including an additional depth of 50cm at each site. Bill reported the results from the above lime program and sampling in a paper submitted to the 2016 Grains Research Update titled '*Applying high rates of lime lifts sub-soil pH on Morawa loams*' (Bill Crabtree, Crabtree Agricultural Consulting and Farmer, Geoff Anderson, DAFWA, Northam). The article on page 18 is extracted from that paper.

While discussing his soil acidity management strategy with the tour group, Bill was questioned about whether it may have been more economic to leave the problem portions of his paddocks out of production, rather than apply the 8–10t/ha of lime that he had to these areas.

"Yes it may have been, but I only have a small farm and I want every arable hectare to be productive, so being relatively close to a lime source (about 140km by road from Dongara) I was prepared to invest in these high rates of lime on these small areas, about 15% of the farm, to bring their productivity in line with the rest of the paddock," said Bill. "I am hoping that from now on, they will only require the same maintenance levels of lime that the rest of the farm will receive to counter acidification caused by crop removal."

ADDITIONAL READING



Flower KC, Crabtree WL (2011). Soil pH change after surface application of lime related to the levels of soil disturbance caused by no-tillage seeding machinery Field Crops Research Volume 121, Issue 1, 28, Pages 75–87.

Gazey C, Andrew J, Griffin E (2013). 'Soil acidity'. In: Report card on sustainable natural resource use in agriculture, Department of Agriculture and Food, Western Australia. <https://www.agric.wa.gov.au/sites/gateway/files/2.1%20Soil%20acidity.pdf>

APPLYING HIGH RATES OF LIME LIFTS SUB-SOIL PH ON MORAWA LOAMS

Bill Crabtree, Crabtree Agricultural Consulting and Farmer, Geoff Anderson, DAFWA, Northam. 2016 Grains Research Updates proceedings

www.giwa.org.au/2016researchupdates

Accessed: 18 August 2016

APPLIED LIME – AMOUNT, QUALITY AND COST

The amount of lime–sand applied to these 34 sites varies from 5–8t/ha over a 5 year period. The quality of the lime is excellent, coming from the Aglime pit in Dongara. A typical neutralising value of this lime is 94 to 95%.

The purchase cost of the lime is about \$7/t and \$17/t cartage to the farm. Application cost is perhaps \$6/t, with farm labour (often myself) using a truck-mounted 9 tonne Bredal spreader, usually covering 10m width. The spread cost of applied lime therefore totals about \$30/t.

Soil pH in the 20–30cm soil test results revealed a large increase with 67% of sites having soil pH greater than 4.5 (Figure 2). Although 10 sites still have soil pH < 4.2. The average increase in soil pH for the depths 0–10 cm, 10–20cm and 20–30cm is; 0.9, 1.2 and 0.6 (Figure 3).

This is a very pleasing result. The low critical pH level of 4.8 has been achieved at all depths, on average over the farm.

The blue line in the graph in Figure 3 clearly shows the improved subsoil pH on the limed soils. While the topsoil and subsoil (10–30cm) has been strongly improved, further deep subsoil tests in December 2015 show that 39% of all the sites (21 of 54) have a soil pH of 3.8–4.2 in the 40–50cm soil layer. Deeper soil sampling, below 30cm appears to be important for identifying these areas of deep sub-soil acidity.

While lime movement has been successful on most areas, over a 5–6 year period, it has not been successful on paddock 10 (Figure 4) where crop growth has also been limited by low soil P and organic matter. These areas are likely destined for deep Grizzly ploughing in 2016, but certainly at least another 2t/ha of lime.

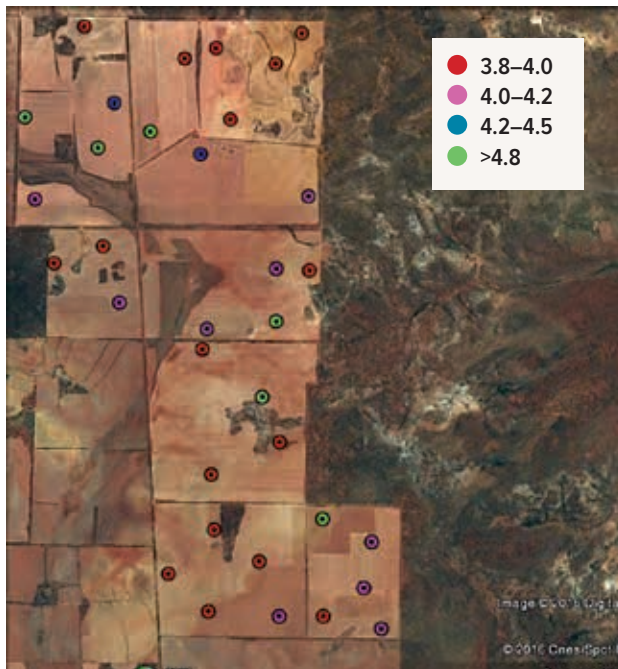


Figure 1. Soil pH ranges for the 20–30cm soil layer in January 2012

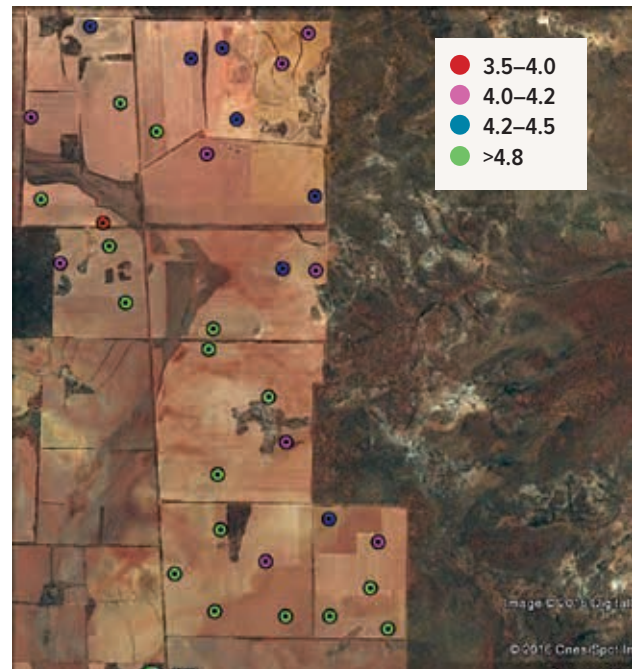


Figure 2. Soil pH ranges for the 20–30cm soil layer in December 2015

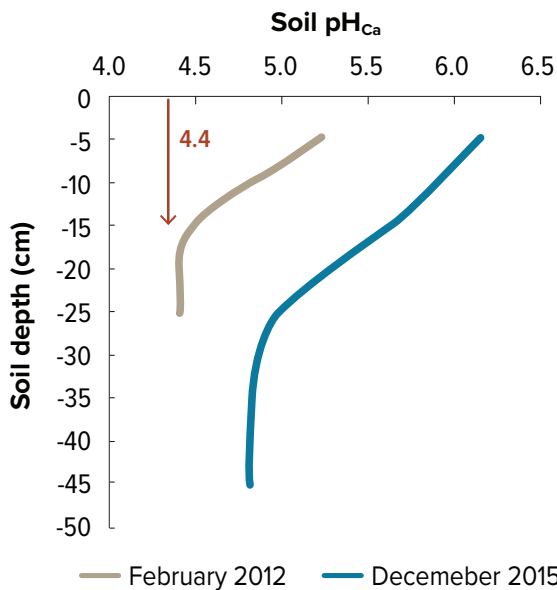


Figure 3. Soil pH change with depth and time (four years) at the Crabtree Morawa farm (average 34 sites)

CONCLUSION

This work gives encouragement for farmers to test for subsoil acidity in loamy soils; it may well be a sleeping giant causing poor crop yields.

This data shows that farmers can overcome severely acidic subsoils by applying large amounts of lime and allowing rainfall to move the lime to depth in a no-till and 100% stubble retention system. This data is consistent with that of Flower and Crabtree (2011) who found that on sandier Tammar soils at Meckering that 2–4t/ha of applied lime was able to significantly lift subsoil pH without the use of tillage.

It is acknowledged that the cost of applied lime is significant and will vary for farmers based on their distance to quality lime. There is also a cost associated with tillage to incorporate lime if that strategy is employed. If more financial strength existed on the Crabtree Morawa farm then perhaps a more aggressive tillage strategy may have been employed several years ago and would likely have returned immediate good lime responses.

Some 45% of the WA wheatbelt soils has subsoil pH (10–30cm) of less than 4.8 prior to 2012 (Gazey et al; 2013). Despite this result most farmers are not testing their subsoils. Indeed, it is estimated that less than 30%

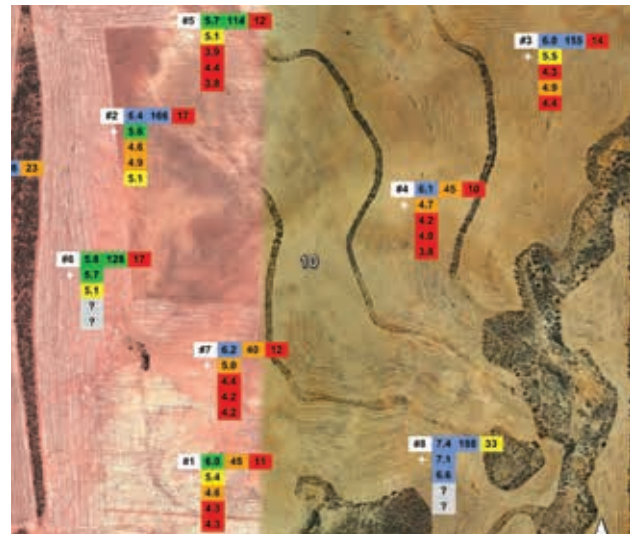


Figure 4. Soil fertility in Dec 2015 in the problem paddock #10 at 8 sites, showing pH values at 10cm depth increments (vertical numbers) and K and P ppm levels horizontal (CSBP soil test results).



Bill's 'problem paddock 10' that has never performed before. Shown during August 2016, sown with Corack wheat after portions of the paddock had received 10 t/ha of lime applied over eight years. (Photo courtesy of Bill Crabtree)

of farmers that conduct soil tests are testing for subsoil pH in WA (Wes Lefroy, pers com). It also shows that severe subsoil acidity can be rectified in loams through time without tillage provided high levels of lime are applied and given several years of even modest rainfall.

CASE STUDY

FLANNAGAN FAMILY, PINDAR AND TARDUN

SNAPSHOT

GROWERS: Alf Flannagan, Mark and Sarat Flannagan, John Flannagan and partner Michelle

PROPERTY NAME AND LOCATION: Properties at Pindar and Tardun include 'Windsong', 'Challymenda', 'St Theresa' and 'Christian Brothers Ag School'

AREA: 24,000ha arable, including 8000ha of leased land

RAINFALL: 285–300mm, about 200mm during the growing season

SOIL TYPES: 50% yellow sand over gravel; 25% sandy loam; 25% red sandy loam

LIVESTOCK: None

CROPPING (2016): Wheat (85%); lupins (15%)

ROTATION: Fallow/wheat/wheat



Mark Flannagan answering questions during the bus tour on their property

The Flannagan family have a long history of farming the Pindar and Tardun areas, east and south east of Mullewa respectively. After attending the Christian Brothers Agricultural School as a child, Alf Flannagan took up and cleared new land between Tardun and Pindar. Alf's wife's family, the Smalls, also developed new land at Pindar. Since then, Alf with sons Mark and John and their partners, have expanded significantly to now be farming 24,000ha of arable land, including 8000ha of leased land they took up during 2016.

Rainfall in the Pindar area is low and very variable, with almost a third of the annual rainfall falling outside the growing season.

They have recently leased another 8000ha on which they anticipate their operating costs to be higher because of the many unknowns they will encounter. The Flannagans calculate their break even wheat yield to be between 1–1.3t/ha. They are sure they can bring this down as they develop a better understanding of their leased land. As their wheat yield averaging 1.51t/ha over the past five or so years on the balance of their land, growing crops in this environment is inherently risky.

The Flannagans want to take the peaks and troughs out of the seasonally variable yields as much as they can. As such, they have sought to refine their system to minimise inputs and maximise stored soil moisture. They are also attempting to overcome soil constraints in order to maximise the crops ability to access nutrients and moisture, as well as seeding as early as possible to maximise growing season length.

"If we are to be profitable in our low rainfall area, we have to make careful, calculated, tactical management decisions based on our experience, seasonal conditions, our pH and nutrient testing and the advice we receive from our consultants," said Mark.

Management of soil acidity and weeds, increasingly summer weeds, are two of the highest priorities for the Flannagans. They utilise a variety of advice sources to inform both their long-term and their tactical decision making, including Craig Topham (Agrarian Management), Peter Norris (Synergy), Wes Lefroy (Precision SoilTech) and DAFWA researchers.

Of the Flannagan's 24,000ha arable land, 12,850ha was cropped to wheat during 2016, 2200ha to lupins and the remaining 8950ha was in fallow. Their preferred rotation is fallow/wheat/wheat. The Flannagans have tried and discarded canola because it proved to be uneconomical on their soils types (see *Managing soil acidity* section page 21) and they believed it took too much out of the following wheat crop.

Fallow has become an increasingly important part of their system on all but their very light soils where the risk of wind erosion is too high and is now integral to their risk management.

"We could not continue to grow wheat on 140mm of rainfall and we can't afford to make losses too often," said Mark. "We are trying to make each year more reliable by cramming two years' rainfall into one wheat crop by using a full year of fallow to store moisture for that crop. In our



A typical paddock on the Flannagan's 'Christian Brothers Ag School' property at Tardun; characterised by soils with highly variable pH depending on their position in the landscape. The Flannagans preferred rotation on these soils is fallow/wheat/wheat.

experience, if we have 30–60mm of stored moisture as we go into the cropped year, we know we can grow a profitable crop. Without that stored moisture it is a huge risk.”

“With well-managed fallow, we can dictate when we seed and can target the moisture with our DBS seeding bars. We can get going during April while others are still waiting for rain or are dry seeding. Luckily, most of our land is quite high in the landscape so frost is not a big risk. We want a short seeding window too. We won't seed into June unless it either looks like being an exceptional season or there has been summer rain and we need to get some sort of a crop in.”

The Flannagans use of fallow is also a critical component of their weed management strategy and fits nicely into their liming strategy. These are both discussed further below.

MANAGING SOIL ACIDITY

The Flannagans first began to suspect they had a soil acidity problem when they observed patchy crops during the late 1990s. They also noticed weeds like radish and Afghan/paddy melons (*Citrullus lanatus/Cucumis myriocarpus*) kept growing for months after harvest as they had been utilising the moisture the wheat hadn't been able to access.

“Around that time, we started trialling some small plots of lime including burnt lime,” said Mark. “As this was so reactive, showing immediate responses, it confirmed our suspicions that acidity was a problem for us. That was also about the time the Time to Lime campaign was being promoted by the Department of Agriculture, which influenced us further; so we began to spread lime at 1t/ha

and increased our application rate to 2t/ha in subsequent years.”

They have continued to spread lime as their budget allows, which has meant spreading about 10,000t per year for the past 4-5 years; some of the Flannagan's paddocks have now received up to 6–8t/ha of lime in total. The Flannagans generally cart and spread all their lime themselves. Because they want to raise pH as quickly as possible, they source the majority of their lime from Dongara which has a higher neutralising value and finer particle size than the closer Geraldton supply.

Mark confirmed they have a strong interest in gaining a better understanding of the soil constraints on their farms and have implemented a regime of intensively soil testing some of their paddocks going into crop each year.

“We currently spend \$15,000–\$20,000 a year on soil testing. Rather than taking a shotgun approach, I recommend intensively soil testing a small number of paddocks then using your own experience and the advice of your advisors to extrapolate those results to similar paddocks until their turn comes around to be tested. We sow using a John Deere RTK system and our soil testing results are a key factor in determining the prescription maps for our variable rate fertiliser system.”

The Flannagans have also been working with their consultant agronomist Craig Topham (Agrarian Management) to do some EM38 mapping on the their 'Challymenda' property and with Wayne Parker (DAFWA Geraldton) to trial lime incorporation methods at their 'Christian Brothers Ag School' property at Tardun.

“Surprisingly for us, the soil coring and EM38 mapping that Wayne and Craig have done on our loamy and valley floor soils showed that the topsoil is highly acidic, around pHCa 4.5, but the subsoil pH is much higher, around pH 6.0–6.5 at 30–35cm. This raised the possibility that if we could overcome the acidity problem at the surface, we could increase our yield potential by increasing the depth of the 'bucket' on those soils,” said Mark.

On the Flannagan's 'Christian Brothers Ag School' property, Wayne Parker (DAFWA Geraldton) has a trial testing subsoil pH response to lime comparing no incorporation with two different incorporation techniques on the areas variable soil types. This property, acquired by the Flannagans during 2012, had previously had a long history of low inputs and little use of lime.

The results from the trial are on the following pages:

COMPARISON OF TILLAGE METHODS FOR LIME INCORPORATION, TARDUN 2015 TRIAL REPORT

Wayne Parker, Department of Agriculture and Food WA, Geraldton

www.agric.wa.gov.au/soil-acidity/comparison-tillage-methods-lime-incorporation-tardun-2015-trial-report?page=0%2C0

Accessed: 5 September 2016

The effect of mechanical incorporation of different lime rates on crop yield and sub-surface pH was observed three years after application.

Lime application increased yield for all incorporation treatments.

Mechanical incorporation with Grizzly small offset disc and TopDown plough increased the sub surface pH more quickly than no incorporation.

BACKGROUND

Until recently the most common rate of agricultural lime application is one tonne per hectare as a blanket application across the surface of the whole paddock (*Taking soil acidity seriously – results of grower surveys 2012*, page 118).

This amount is often insufficient to recover and maintain soils above recommended targets of pH 5.5 and 4.8 in topsoil and subsoil, respectively.

As a result of Caring for Country project SP11-01226, growers in Western Australia are increasingly testing pH of soils below 10cm.

Growers understand the importance of lime in restoring soil pH, as seen by the increase in sales of lime in the northern wheatbelt (Liebe group technical audit results 2012).

However, according to Gazey and Andrew, lime sales of 1.1 million tonnes in 2012 (Effective management of soil acidity requires knowledge at the farm, state and national scale) are still less than half that of the 2.5 million tonnes required per year, indicating low adoption of the recommended practice.

Preliminary work by Davies, 2012 (DAW00244 *Developing and assessing agronomic strategies for water repellent soils*, page 71) has shown the applicability of a number of innovative techniques, including mouldboard ploughing and rotary spading, for incorporation of lime to depth.

Lime on the topsoil can be incorporated to a depth of 30cm enabling management of pH at this depth.

This trial is one of six similar trials throughout the

northern wheatbelt. It will help establish best practice methods and promote the effectiveness of these techniques throughout the rainfall zones of the NAR.

AIM

To showcase to growers different innovative practices for deep incorporation of lime to ameliorate sub surface acidity and improve soil health.

Tardun trial details

Property	Tardun Agricultural School
Soil type	North: Shallow acid gravel Mid: Loamy sand over gravel South: Red sandy loam with clay content increasing with depth
Crop /variety	Wheat, mace
Paddock rotation	2013 wheat, 2014 wheat, 2015 wheat
Treatments	2013 lime: 0, 2, 4t/ha 2013 incorporation: Nil, small offset disc (Grizzly), TopDown® plough
Replicates	Three
Growing season rainfall (Clontarf Farm patched point weather station)	January–March 129mm April–September 171mm

RESULTS AND DISCUSSION

Note; pH discussed as pH (1:5 CaCl₂)

This trial covers three distinct soil types throughout the paddock. The northern section of the paddock is a shallow acid gravel, the middle section a brown sand over gravel of varying depths, the southern section red sandy loam. The results are reported from each of these soil types as each differ in their response to lime and incorporation.

The inclusion of lime, irrespective of incorporation treatment, has given the greatest benefit to yield. The greater the amount of lime the higher the yield response.

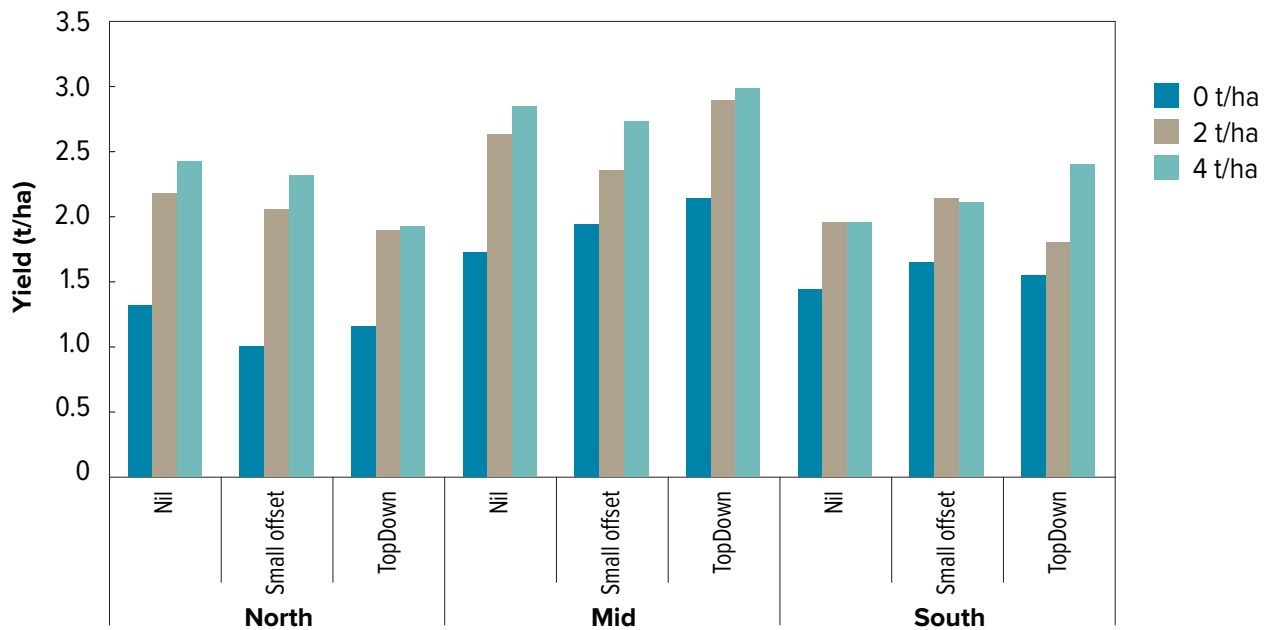


Figure 1. Yield results of lime incorporation trial, ‘Tardun Agricultural School’, Tardun 2015. LSD (5%); Lime 0.2, Incorporation NS, Lime x Incorporation NS

In the loamy soil (south) where pH is inherently higher than other parts of the paddock yield response to lime is still positive but not as great as the more acidic parts of the paddock.

The TopDown plough has trended slightly higher yield response across many treatments though not significantly.

TABLE 1 Percent (%) screenings of lime incorporation trial 2015, Tardun Agricultural School				
Location	Incorporation method	Lime 0t/ha	Lime 2t/ha	Lime 4t/ha
North	Nil	3.69	2.90	2.54
North	Small offset disc	3.44	3.60	2.48
North	TopDown	4.55	2.57	2.17
Mid	Nil	1.85	1.03	0.88
Mid	Small offset disc	1.12	0.99	0.99
Mid	TopDown	1.41	1.06	1.65
South	Nil	0.63	1.24	0.88
South	Small offset disc	0.97	0.80	1.17
South	TopDown	1.56	0.89	1.68

Yield response of the acid gravel soils has been greatest of the three soil types. The different treatment plots visible in the crop throughout the growing season to harvest. The reason for this is apparent when looking at the pH results. With the addition of lime, 2t/ha or 4t/ha, the surface pH has shifted from below target of pH 5.5 to above. In this soil the TopDown plough has created a greater shift in pH in the 20–30cm zone than the Grizzly offset.

The incorporation story on the red loamy sand is not as clear because of the inherently high pH.

All sub-surface soils are above the target of pH 4.8. Mixing by the Grizzly doesn’t seem to have influenced the sub-surface pH.

COMMENTS

Incorporation, irrespective of machine, has sped the increase in sub-surface pH.

It is necessary to consider the speed of the operation and hectares covered, (ha/hr), along with implementation cost (\$/ha) when incorporating lime.

If we compare the TopDown with the small offset disc on area per day and the impact this has on the whole business, in terms of lime incorporation only:

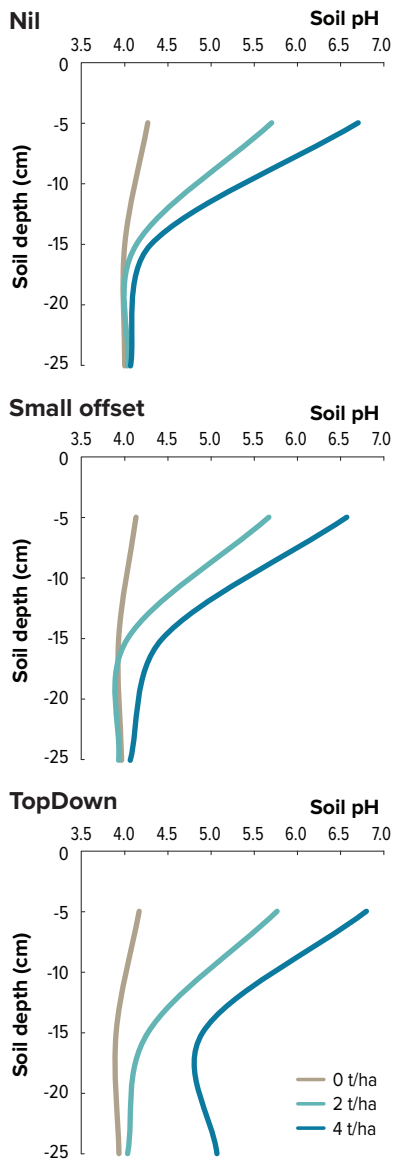


Figure 2. Soil pH of north section (acid gravel soil) after harvest 2015, three seasons after lime application and incorporation in 2013

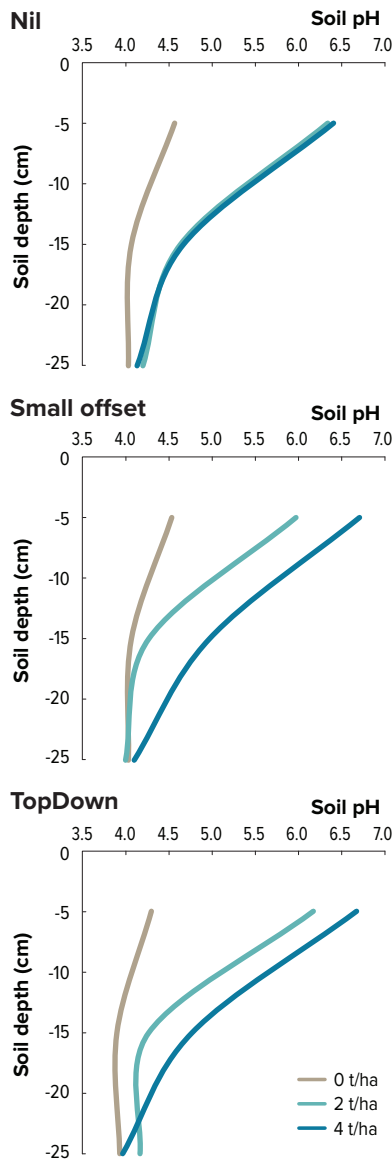


Figure 3. Soil pH of mid-section (brown loamy sand over gravel soil) after harvest 2015, three seasons after lime application and incorporation in 2013

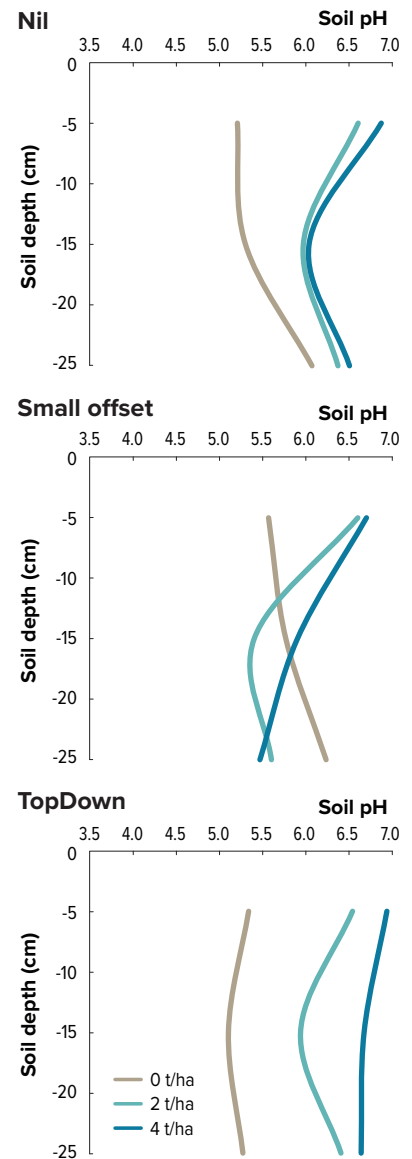


Figure 4. Soil pH of south section (red loamy sand) after harvest 2015, three seasons after lime application and incorporation in 2013

TopDown 6m wide x 6km/hr = 3.6ha/hr. After 100hr, 360ha have been covered at a cost of \$45,000 assuming \$125/ha cost for the implement and process.

Small offset 12m wide x 8km/hr = 9.75ha/hr. After 100hr, 975ha have been covered at a cost of \$39,000, assuming \$45/ha cost for the implement and process.

More than twice as much area is covered by the small offset, at a lower cost.

It may be that the cheaper option has smaller yield benefit though greater return given the larger area

incorporated. This would allow for increased investment in lime for years following.

ACKNOWLEDGEMENTS

Thanks to Mark and John Flannagan for managing the trial; also to DAFWA technical services staff for their assistance and SoilTech for soil sampling.

This project is supported by the Northern Agricultural Catchments Council, through funding from the Australian Government's National Landcare Programme.



The tour group inspecting the above lime trial with Craig Topham from Agrarian Management and Dr Geoff Anderson from DAFWA who is irrigating sub-plots on this site to study lime response in the absence of the variability created by natural rainfall



A Kelly Diamond Harrow similar to that used by the Flannagans (Photo courtesy of Kelly Engineering)

Alf, Mark and John Flannagan have opted to use a combination of Kelly chain (diamond harrow), Grizzly plough (offset discs) and seeding with the DBS bar to incorporate lime on their farms.

“We now spread our lime in our fallow phase,” said Mark. “By spreading it in winter, we get that extra opportunity for it to mineralise and leach before the wheat crop goes in the following season. It puts us one year ahead of those liming during March. It also means we are not sitting on a spreader for weeks over summer when it is hot and dusty and when it also competes for time with our summer weed control. Carting and spreading our lime in winter also allows us to negotiate better freight rates when we do use contract carting, as there are more trucks sitting idle.”

On their fallow paddocks, the Flannagans use a Kelly chain where woody weeds such as bluebush are a problem.

They aim to get their lime on ahead of the Kelly chain so it can start the incorporation process but a Grizzly plough is their primary lime incorporation tool.

“The majority of our weed control is through herbicides, but we find we need to use a Grizzly plough about once every five-years to deal with troublesome weeds, especially where we suspect resistance, and to improve infiltration,” said Mark. “Once the lime is spread, we are likely to go over the paddock with the Kelly chain to control any woody weeds, then wait until we have adequate soil moisture and another weed kill is needed and go over it with the Grizzly.”

MANAGING WEEDS

The Flannagan’s property is recognised as being the first in WA to experience glyphosate resistant ryegrass. The first find was during the early 2000s and then during 2009, they located patches of glyphosate resistant ryegrass on a second, different property. In both cases, the resistant ryegrass was spotted as green patches in a chemically fallowed paddock. The paddock in which the resistant ryegrass was found during the early 2000s had a history of chemical fallow, but the paddock in 2009 was new to chemical fallow.

As reported recently in the *GRDC News*, John Flannagan said the family’s approach to controlling the resistance has been to hit it hard and early. The following is extracted from the *GRDC News* article:

EXTRACT FROM: GROWER EXPERIENCE SHOWS RESISTANCE CAN BE MANAGED

GRDC News (West), April 2016

www.grdc.com.au/Media-Centre/Media-News/West/2016/04/Grower-experience-shows-resistance-can-be-managed

“We smashed the weed seedbank by using paraquat; crop rotation; some cultivation at times (for the first paddock); narrow windrow burning; robust pre-emergent herbicide mixes in our crops; and never letting ryegrass set seed,” John said.

“Resistance is not a problem where there are no weeds.

“On heavy country that won’t blow, we have used a Grizzly plough to incorporate lime. Herbicide followed by the Grizzly gives us the ultimate ‘double knock’.”

Mr Flannagan said that where glyphosate resistant ryegrass was found in 2009, they initially hit the

survivors with high rates of Spray.Seed® (paraquat and diquat) sprayed at night.

“The paddock went to triazine tolerant canola in 2010 and the combination of atrazine prior to sowing and clethodim post-emergence did a good job, as not much clethodim had ever been used on this block,” he said.

“It was sown to wheat for three consecutive years from 2011, with good pre-emergent herbicide application, paraquat knockdown and narrow windrow burning at harvest.

“The paddock went back to fallow in 2015 and there was no ryegrass in this fallow.”

The Flannagans crop approximately 15–16,000ha of their 24,000ha of arable land each year, with the remaining 8000ha being in chemical fallow for the year prior to cropping. Farming such a large area in a low rainfall zone where approximately one third of that rain falls outside the growing season, the Flannagans spend a lot of time controlling weeds and need their system to be both effective and as low-cost as possible. Good harvest weed seed management and chemical fallow are key components of their system.

“We have burnt about 13,000ha of narrow windrows every harvest since we first discovered glyphosate resistant ryegrass during the early 2000s,” said Mark. “Our aim is to have no ryegrass set seed and that begins with controlling seeds at harvest. With harvest weed seed management and chemical fallow, we have successfully managed to reduce ryegrass densities from thousands of plants per square metre (/m²) down to around two plants/m².”

“We used to have sheep in our system. There were a few reasons why we got out of them, but one of the big ones was that they made it harder for us to control weeds. They would selectively graze, so that when we came to apply a knockdown, we had some weeds with little leaf area but huge root systems and they were extremely difficult and costly to kill. In our environment, chemical fallow is a better option. For sheep you need feed, which equals weeds. Weeds and cropping are not compatible.”

The Flannagans start the management of their chemically fallowed paddocks by controlling any summer weeds that emerge after the previous wheat crop with their two WEEDit® detection sprayers, then straight after their next year’s seeding operation is completed, usually around June, a glyphosate based knockdown (typically 2.5L glyphosate 540 plus 600ml ester 680 + 5g metsulfuron-methyl plus sulphate of ammonia) is applied to the fallow paddocks. This operation is delayed if there is a danger of wind erosion to allow more cover to establish before killing it with the knockdown.

Following the knockdown, the Flannagan’s two WEEDits® are again put into operation, spraying a mix containing high rates of glyphosate, 2,4-D ester 800 and metsulfuron-methyl.

“Between the first knockdown and seeding of our fallow paddocks, we will typically do 3–4 passes over every fallow paddock with a WEEDit®,” says Mark. “The WEEDits® can cover 10 times the area for the same tank load as a full knockdown spray through our conventional booms. We like to get a spray in during early August or September if conditions are right so that we hit the early melons.”

“Where we get a partial weed kill or have patches of survivors we suspect might be resistant, we will use one pass of a Kelly chain or the Grizzly to replace one pass with the WEEDit®. Whenever we need to bring the plough out, we try to leave a cloddy surface to reduce the risk of wind erosion.”

“The fallow phase is also really good for spotting weed problems such as resistant ryegrass or radish,” said Mark. “In crop, you can’t see weeds as easily as you can on a brown fallow paddock where anything green really stands out and we can investigate and take appropriate action with either chemical or mechanical control means.”

Summer weeds are becoming an ever increasing problem for the Flannagans.

“Summer grasses are our biggest problem, more so than mintweed (*Salvia reflexa*) or melons for example,” said Mark. “Button grass which we started to see appearing around 2008 is a particular problem. It germinates quickly, grows quickly, sucks up valuable nutrients and moisture and has proven hard to kill. When it first started to show up, we didn’t pay any special attention and it carried over summer into the crop. Our wheat crop was a sea of yellow and it halved the yield. That particular crop followed a chemical fallow year and we had upped our fertiliser to benefit from the stored moisture we thought we had captured during the fallow, so not only was the yield of that wheat crop reduced by the competition from the button grass during the growing season, we also lost the benefit the fallow year should have supplied to that wheat crop.”

However, Mark says their current strategies are keeping button grass under control at present. “Our WEEDits® are effective at controlling it because it grows flat and makes a good target for the WEEDits® detection system. In our fallow paddocks, we also have the option of hitting it with the Kelly chain or Grizzly if it becomes too prolific.”

ADDITIONAL READING



www.grdc.com.au/Media-Centre/Media-News/West/2016/04/Grower-experience-shows-resistance-can-be-managed

www.liebegrup.org.au/wp-content/uploads/2016/01/Soil-acidity-management-strategies-throughout-Western-Australia.pdf

CASE STUDY

CHARLIE, ANDREW AND ROD MESSINA,
MULLEWA AND TENINDEWA

SNAPSHOT

GROWERS: Charlie, Andrew and Rod Messina

PROPERTY NAME AND LOCATION: 'Spring Park Farms',
Mullewa and Tenindewa

AREA: 10,000–12,000ha cropped annually

RAINFALL: 260–350mm, about 250mm during the growing
season

SOIL TYPES: 85% sandplain; 15% sandy loam

LIVESTOCK: None

CROPPING (2016): Wheat (60%); lupins (20%); canola (20%)

ROTATION: Prefer wheat/wheat/canola/wheat/lupins



Andrew Messina who farms with his father Charlie and brother Rod in the north-eastern wheatbelt

The Messina family began farming in the Mullewa area during the 1960s in an environment of low and variable rainfall. Charlie, and sons Rod and Andrew, have expanded their operation over the years and now crop 10,000–12,000ha annually on their properties at Mullewa, Tenindewa and Eradu.

The Messinas recognise that along with the low and highly variable rainfall, weeds, soil acidity, soil compaction and non-wetting are the other major factors limiting their potential yields. Consequently, they have been experimenting with different techniques to minimise or overcome these limitations for many years. They have adopted controlled-traffic farming, deep ripping and mouldboard ploughing and utilise soil-water probes and Yield Prophet® to aid their decision making.

MANAGING SOIL ACIDITY

Rod and Andrew have seen the rainfall pattern in their area gradually change since they began farming; saying 3–4 week dry spells between rain events are now common and the rainfall pattern is now more influenced by tropical factors. They believe maximising the depth of soil that plant roots can access to chase moisture and nutrients is critical on their farms and the brothers have invested heavily in overcoming soil constraints.

The Messina's belief that overcoming key soil constraints such as soil acidity, non-wetting and compaction is important to maximising profitability in their dry environment was strengthened during 2008. That year they observed on their Westwithy property, 35km west of Mullewa, that although their crop yields were okay, soil pits

they dug showed there was unused moisture in the profile. While some roots were visible down to 1–1.5m in places in the pits, the bulk of root growth was restricted to the top 30cm.

This prompted them to undertake soil testing across the whole farm to 30cm to determine if soil acidity, aluminium toxicity or nutrient deficiencies were limiting the yields. The surface samples were given a full analysis, with the sub-soil samples being analysed for pH and aluminium. The results returned no obvious nutrient deficiencies and pHs of around 5.3–5.5 at the surface and 4.4–4.6 at depth, with only moderate aluminium readings. A compacted layer at 30–40cm was also present, with this layer being slightly more acidic than the soil above and below it.

The Messinas could see that soil acidity at depth, non-wetting and compaction were all issues that they needed to overcome to increase the ability of their crops roots to chase moisture and nutrients.

Charlie and sons Rod and Andrew began applying lime on their original home farm at 1t/ha around 1990 and have carried on the practice on their new farms. Since taking on a new property at Eradu during 2007 where lime had never been applied, the Messinas have been applying about 5000–7000t of lime every year across their farms; all carted and spread by themselves.

Some of the Eradu properties have now received 7t/ha of lime over the last seven years. Sourcing lime out of both Dongara and Geraldton, this operation typically takes four people 6–7 weeks to complete, running two trucks and two spreaders.



Another load of lime sand arrives for spreading.
(Photos courtesy of Rod and Andrew Messina)



One of the Messina's two spreaders which are soon to be replaced with a single, 20–25t capacity unit

The Messinas originally began spreading lime at 1t/ha ahead of seeding when they were still using mechanical weed control methods. They then increased this to 1.5t/ha and then further to 2t/ha, with the 2t/ha rate being the maximum which works with the capacity of their two spreaders.

“In hindsight, we should have bought a 20–25t spreader earlier rather than persevere with our two smaller units,” said Andrew. “In 2017 we will upgrade to a bigger spreader that can spread lime to 12.2m and urea to 36.4m. With our paddock sizes, that will suit our controlled traffic system which uses tramlines 36.4m apart and allow us more flexibility with lime rates.”

The Messinas have been using a controlled traffic farming system since 2007, with all machinery being based on multiples of 36.4m widths. Their sprayers and air spreader booms are 36.4m wide; their seeders are 18.2m and 12.13m; their headers and deep rippers are 12.13m; their current lime spreader is 9.1m; and their deep Heliripper is 6.06m.

Until 2011, all crops were put in using a no-till system, but during 2011 the Messinas began experimenting with mouldboard ploughing to manage weeds and non-wetting and to incorporate lime (their experiences with mouldboard ploughing to control weeds is discussed in more detail in the *Managing weeds* section page 30).

After working with Peter Newman (DAFWA, now Planfarm/AHRI) who during 2010 was comparing mouldboard ploughing and spaders to bury weed seeds, the Messinas saw a place for mouldboard ploughing in their system. During 2011 they acquired a 14-board, 6.2m wide Grégoire Besson mouldboard plough to control troublesome weeds, ameliorate non-wetting and incorporate lime to depth. That year, they treated 1460ha with the mouldboard plough, mostly paddocks containing non-wetting soils and high ryegrass numbers. Good weed control and a 50% increase in plant establishment above those in untreated areas gave Rod and Andrew confidence that mouldboard ploughing was a useful tool. Over and above its weed



The Messina's 14-board, 6.2m wide Grégoire Besson mouldboard plough in action

control benefits, it clearly improved establishment on non-wetting soils and could incorporate lime to depth.

“Based on our 2011 results, and rainfall permitting, we decided to treat 1000ha/year with the mouldboard plough until we had treated all our lighter soils,” said Rod. “We managed to exceed that and have now mouldboarded approximately 9000ha, which is pretty much all our lighter soils.”

Mouldboard ploughing has not been without its problems however and the Messinas have experienced problems with surface crusting and also with managing seeding depth after mouldboard ploughing.

To overcome seed depth control issues in the soft and fluffy soil left by the mouldboard plough, the brothers modified a 12m Concord bar, removing the points and leaving the boots to drop the seed at approximately 20mm deep ahead of tyre packers. They now use an 1830 John Deere Air Hoe Drill, but are still refining their system as the press wheel gangs on the air hoe bulldoze a lot of soil in the soft paddocks, especially on those paddocks that have also now been deep ripped to 70–80cm.



The mouldboard plough leaves the soil loose and ridged. This can cause problems with seeding depth and the Messinas are still refining their seeding system to ensure consistent depth control. (Photos courtesy of Rod and Andrew Messina)

The Messinas have been deep ripping to 30–40cm with an Ausplow deep ripper on their sandplain soils since 1989. Their usual practice has been to deep rip every four years in front of a wheat crop, but they began to suspect they needed to rip to even greater depth to improve root penetration and assist their applied lime to have an impact further down in the profile. During 2015 they invested in a 6m wide Grégoire Besson Heliripper capable of ripping to 80cm.

As reported in GRDC's *Ground Cover* during May 2015, Andrew says in 12m-wide and 200m-long paddock strip trials on an area that had been ripped during 2014, the Heliripper produced wheat yields of 2.7t/ha, compared with 2t/ha from the nil-treated area and 2.3–2.4t/ha from conventional deep ripping to a depth of 30cm.

"This highlighted that we are still getting a yield response from conventional ripping to 30cm in the ripped area, three



The Messina's 6m wide Grégoire Besson Heliripper capable of ripping to 800mm

years down the track, but we got double the response by ripping down to 60 to 80cm," said Andrew.

Deep ripping can only be undertaken in those seasons when sub-soil moisture in summer or autumn is adequate, but Rod and Andrew's preferred practice is to deep rip to 60–80cm with the Heliripper between 1–3 years after mouldboard ploughing. They find the loosened surface created by the mouldboard plough assists the Heliripper to better shatter the compacted layer. However, the combination of mouldboard ploughing and deep ripping to 70–80cm has increased the seed depth control issues as the press wheel gangs on the air hoe drill bulldoze a lot of soil. To aid this, they began seeding at a slight angle of 10 degrees to the direction of the tramlines.

They have also found with their controlled traffic system, the tramlines in the paddocks that have been both deep ripped and mouldboarded develop ridges on both the inside and outside of the tractor wheels. These ridges cause blockages as they are bulldozed by the press wheel gangs of the air hoe, especially when chasing moisture at depth. Typically, their controlled traffic lines are yielding 0.2t/ha less than the rest of the paddock. To overcome this, during 2016 the Messinas used a tyre roller behind their Heliripper. This will now be standard practice in the future. They also plan to modify the press wheels on the air hoe and replace the standard press wheels with car tyres to give better floatation. This follows testing of a range of seeding bars during 2016, none of which was able to deal any better with depth control. The Messinas also plan to trial some sort of tramline renovating during 2017, but at present have not determined exactly what this will be.

Crusting and surface sealing has also been experienced when the mouldboard plough has brought clay to the surface, leading to poor emergence and delayed development. This has been exacerbated by the low levels of organic matter in the soil that is a function of poor seasons and windrow burning.

"We need to think of our mouldboarded sands as loams rather than sands and when it rains, park the seeder to avoid crusting," said Andrew. "Because wind erosion has also been a problem on some paddocks in some years after mouldboard ploughing, we now leave it until as late as possible to do any mouldboard ploughing and seeding to minimise this risk."

Mouldboard ploughing is gaining popularity in the Mullewa area and is being used by a number of the Messina's neighbours.

"We are not yet sure how often we will need to bring out the mouldboard plough in the future," said Andrew. "We think having now ploughed each suitable paddock once, we may only need to repeat the mouldboard ploughing every ten years or so. The GRDC-funded project 'DAW00243, Minimising the impact of soil compaction on crop yield' being conducted by Wayne Parker (DAFWA) will help determine the actual required frequency."

Based on their experiences with liming, mouldboard ploughing and deep ripping, Rod and Andrew will be continuing to evaluate and refine the following system on their sandplain soils (Table 1):

Year	Treatment	Crop
1	2t/ha lime, then mouldboard plough	Wheat
2	2t/ha lime ahead of seeding	Wheat
3	No lime	Lupins
4	2t/ha lime, then deep ripping to 70–80cm	Wheat
5	No lime	Canola
6	2t/ha lime, then deep ripping to 70–80cm*	Wheat

* Rod and Andrew will be trialling deep ripping in Year 6 in the sequence described above in the hope that they will then only need to deep rip every four years or so thereafter.

MANAGING WEEDS

The Messinas recognise weeds as their number one issue and have long been monitoring new developments in weed management through research trials and farmer innovations, trialling the most promising of these on their farms and then continuing to refine those that work for them.

As they have expanded their business, they have had to learn to manage sandplain soils that have had 40 years of wheat/lupins rotations with high weed burdens. Their management system has to cope with herbicide resistance in both ryegrass and radish.

To control weed seeds before germination, the Messinas began windrow burning during 1997, then modified their chaff spreaders to drop a narrower windrow and began narrow windrow burning.

Their experiences with window burning are described on the Weed Smart (UWA00172) website from which the following is taken:

WINDROW BURNING BEATS WILD RADISH

WeedSmart website

www.weedsmart.org.au/case-studies/rod-messina-wa/

Accessed: 14 August 2016

Rod Messina, whose family farming business ‘Spring Park Farms’ has hosted windrow trials for more than a decade, says the practice has underpinned their property expansion.

“We find that when we buy a new property it always has a lot of weeds but after two or three years of integrated weed management (IWM) practices including burning windrows, it’s amazing how quickly weed numbers come down,” Rod said. “Weeds dictate what we do here, they’re our number one issue. So if a paddock’s dirty, rotation becomes vital and ultimately allows us to continuously crop.

“It is quite expensive to leave paddocks out of production so with the rotation and windrow burning it allows our operation to be more profitable in the long run.”

Rod farms 12,500 hectares with his father Charlie and brother Andrew on the Eradu sandplain east of Geraldton. They employ a wheat/lupin/wheat/canola rotation and strategically use herbicides to control radish in the cereal phase while windrowing canola and lupin crops to collect and destroy hard-to-kill wild radish seed.

“Wild radish is one our most problematic weeds. We do have ryegrass but radish is our biggest concern because the seed is viable for so long,” Rod said. “In our lupin and canola phases we try to make sure we control all the seed set either through windrow burning or crop-topping.

“We try to get a germination of wild radish before we sow but in this environment that is not always possible.

“There is no doubt through our long-term IWM strategy, including windrow burning, autumn tickles, crop-topping, a double knock and now the mouldboard plough, that our weed numbers are decreasing.”

The Messinas aim to stop seed set at every stage of the crop production and weed life cycle.

“We deep rip to stimulate a germination of weeds that we can treat with a knockdown herbicide or double knock, then we’ll use one, maybe two post-emergent sprays followed by crop-topping lupins and windrow burning.”

The Messinas have trialled a mouldboard plough and spading but chose to go with the mouldboard plough for its weed and non-wetting soil management benefits. Rod says the practice of windrowing as demonstrated by the GRDC-supported work by DAFWA weed researcher Peter Newman (now Planfarm/AHRI) has been proven over more than a decade.

“The numbers are declining quite rapidly and one of the greatest benefits of windrowing is that it doesn’t slow harvest at all,” he said. “The hotter the fire the better it is and through the GRDC focus paddocks we’ve learnt that you do need a much hotter fire to control wild radish than for ryegrass.



“We have to try and get the fire as hot as possible. It’s easy in lupins and canola because there is less chance of the fire spreading than in wheat so you can light the windrows up during the day and make sure you get a really hot burn.

“In an ideal world you wouldn’t windrow your wheat because there is a chance you’ll lose the paddock but in a lighter year like this year we’ve windrowed all the paddocks in order to use that tool.”

Rod says a cereal crop of more than two and a half tonne per hectare is too dense for windrowing due to the risk of burning the whole paddock and losing valuable soil cover.

“If you’ve got a really dense windrow the fire will run across the top and won’t penetrate the windrow and research shows some of the seed falls to the bottom within about 24 hours.”

He advocates burning late in the day rather than at night as the intensity of the fire drops as the temperature falls.

“Five to seven years ago we windrowed every acre but now that we’ve got our numbers down we can just do the lupins and canola phases,” he said. “There is more opportunity to control wild radish during the wheat phase using herbicides and other tools and can manage the ryegrass during the non-cereal phases.”

Rod and Andrew say windrow burning typically takes them 5-6 weeks to complete and can leave little residue behind. Conscious of the need to maximise retained organic matter, the brothers have now moved to using chaff carts which they say typically allows them to leave around 50% of the stubble behind and still get good weed seed control through burning the piles.

As described in the *Managing soil acidity* section page 27, Rod and Andrew worked with Peter Newman (DAFWA, now Planfarm/AHRI) during 2010 to put in a trial comparing mouldboard ploughing and spaders to bury weed seeds.

When the weed population was checked during March 2010 after a wet summer, Andrew says the results showed mouldboard ploughing had outperformed spading. Weed suppression rates were 98% for the mouldboard plough and 46% for the spader, and by 25 April 2010, no additional weeds had germinated.

This prompted the Messinas to acquire a 14-board, 6.2-metre-wide Grégoire Besson mouldboard plough during 2011 to control troublesome weeds, ameliorate non-wetting and incorporate lime to depth. That year, they treated 1460ha with the mouldboard plough, mostly



Andrew Messina (foreground) talks to the tour group. In the background can be seen one of two 21m³ chaff carts built on-farm by the Messinas for harvest weed seed management

paddocks containing non-wetting soils and high ryegrass numbers. Good weed control and a 50% increase in plant establishment above those in untreated areas gave Rod and Andrew confidence that mouldboard ploughing was a useful tool.

HOW MOULDBOARD PLOUGHING WORKS

GRDC website

www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-97-March-April-2012/Mouldboard-tactic-pays-its-way

Accessed: 14 August 2016

Mouldboard ploughing to 300 millimetres inverts the soil to move weed seeds from the surface to the bottom of a furrow, from where they are less likely to emerge.

Andrew says success hinges on soil moisture levels. As a result, the paddocks nominated for mouldboard ploughing are scheduled for the end of the sowing program, the delay allowing time for the opening rains to have thoroughly wet the soil down to 300mm. They can plough 6ha per hour at a speed of about 8.5km/h.

Andrew says the importance of having sufficient soil moisture was a costly lesson learnt when the plough was first put to work. On 28 April 2011, Andrew and Rod ploughed a paddock that was dry on the

surface, but wet underneath, which brought wet soil to the surface. The paddock was subsequently sown, but Andrew says the soil quickly dried out, forming a crust under the topsoil that hampered crop emergence. The crop had to be re-sown.

“So it is important to only use the mouldboard plough on completely wet soil,” he says. “In partially wet soil, weed seeds don’t flow to the bottom of the furrow and are more likely to germinate.”

Now, the Messinas wait for more than 25mm of rain before ploughing paddocks and Andrew says it was difficult to find weeds after using this approach in 2011.

Reducing the risk of wind erosion is another reason for delaying mouldboard ploughing until the end of sowing. This risk is further lowered by immediately sowing crops into the area that has been mouldboard ploughed.

The Messinas believe that while harvest weed seed control is key, the mouldboard plough is an important tactical weed control tool well suited to their Eradu sandplain soils. However, as described in the *Managing soil acidity* section above, mouldboard ploughing also requires modifications to be made to seeding machinery to cope with the tendency for seeders and their press wheel gangs to sink into the soft soil left by the plough.

Rod and Andrew think they may only have to mouldboard plough each paddock every 10 years or so, but when the time comes to mouldboard a second time, they are contemplating working across the paddock at 90 degrees to the initial ploughing to try and even out the surface ridges left by the first ploughing.

The Messinas typical rotation on their sandplain soils is wheat/wheat/canola/wheat/lupins and to maximise the number of herbicide groups available to them for radish control, the Messinas use Triazine Tolerant canola varieties.

“We need to be able to grow a 0.7t/ha canola crop for us to keep canola in the rotation and we accept that Roundup Ready varieties will out yield the Triazine Tolerant varieties, but the ability to use triazines to clean up any radish that escape our harvest weed seed control and mouldboard ploughing strategies outweighs the yield penalty,” said Rod.

Their weed management strategies are paying off to the extent that the Messinas have not sprayed for wild radish in any of their lupin crops for the past four years, which is a tremendous achievement. Wild radish densities are now so low that Rod and Andrew have begun hand-weeding paddocks to control isolated plants.

The brothers’ goal is to preserve their herbicide options, particularly the use of diflufenican, so during 2015 they hand weeded 400ha of lupins, concentrating on the tramlines where radish tends to be more prevalent. This

took a week to complete during 2015, with two people in a ute driving down each tramline and hand pulling any radish spotted.

The Messinas hand weed their lupins during early August when early germinated radish is large enough to be seen above the lupins, but has not yet set seed. Any seed set by later germinated plants is captured by their chaff carts used at harvest and if there are any major late germinations, these patches are crop-topped.

“We see hand weeding as an important part of our management system to maintain the effectiveness of our chemicals,” said Andrew. “We are looking at setting up some sort of tow-along trailer that will enable our farm workers to spot radish plants, hop off and pull them, then get back on-board all in a safe manner. Something similar to that used to search for skeleton weed (*Chondrilla juncea*) maybe, but something our workers can get on and off safely.”

OTHER TECHNOLOGY BEING ADOPTED BY THE MESSINAS

Charlie, Rod and Andrew are constantly seeking to refine their farming system. Rod and Andrew are firm believers in the potential of the Harrington Weed Seed Destructor and have given up their time to tour the country with Peter Newman (Planfarm/AHRI) and Michael Walsh (AHRI) promoting its benefits.

They now have five soil moisture probes in place that they use in conjunction with Yield Prophet® to guide their decision making. They are also trialling the ‘Crop Manager’ data management software and are looking at putting in a 3G wireless network to enable them to monitor their moisture probes and rainfall gauges and to allow easily transfer data between machines so that all operators have the same information in front of them. It will also allow them to remotely control security cameras and pumps.

Now that they have started to eliminate their soil constraints, they will be investigating Variable Rate Technology on their properties in coming years.

ADDITIONAL READING



www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-116-May-June-2015/Deep-ripper-deals-with-compaction-at-Mullewa

www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-97-March-April-2012/Tactical-mouldboard-proves-a-weeds-control-option

www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-97-March-April-2012/Mouldboard-tactic-pays-its-way

www.weedsmart.org.au/case-studies/rod-messina-wa/



CASE STUDY

BRADY AND ERIN GREEN, YUNA

SNAPSHOT

GROWERS: Brady and Erin Green

PROPERTY NAME AND LOCATION: 'Carrawingee Farms', Yuna

AREA: 8650ha arable

RAINFALL: 350–375mm, 240mm average growing season rainfall

SOIL TYPES: 75% yellow sandplain; 25% red loam

LIVESTOCK: None

CROPPING (2016): 8000ha – wheat (48%); lupins (32%) barley (12%); canola (8%).



Erin and Brady Green of Yuna. (Photo courtesy of Brad Collis, GRDC Ground Cover, Issue 123)

Having already worked on the farm for 10 years, Brady together with wife Erin, moved onto and took over the management of their Yuna property from Brady's parents during 2006.

The couple chose a difficult year to make the move, with 2006 being a drought year resulting in no crop being sown – the first time that had ever occurred on the property. 2007 also proved to be a very dry year. These two drought years were a major driver behind Brady and Erin's move

away from more conventional crop establishment methods to no-till and controlled traffic farming (CTF).

"At that time, we had two main goals," said Brady. "We wanted a system that conserved as much soil moisture as possible and we wanted to rehabilitate our soils. We needed to address our soil compaction and soil acidity problems."

As reported in the extract from GRDC's *Ground Cover*, Issue 123, July–August 2016 (Author: Brad Collis):



Brady Green (with shovel) describes his experiences managing soil acidity to the tour group at a soil pit on the deep yellow sands of his Yuna property

DEEP RIPPING SETTING NEW PRODUCTIVITY BENCHMARKS

Brad Collis, GRDC *Ground Cover*, Issue 123, July–August 2016

www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-123-JulyAugust-2016/Deep-ripping-setting-new-productivity-benchmarks

The first thing the couple decided they needed was expert help (and outside their local comfort zone). They were put in touch with Victorian no-till pioneer Rob Ruwoldt. It has become an enduring friendship and working relationship that has changed, completely, the way the Greens manage their land and their cropping. And from those first two drought years has come a fascinating case study in adaptation to a drying climate – the implementation of system changes that have allowed the couple to steadily, and with growing confidence, expand their operations to almost 9000 hectares despite a measurably drying, warming climate.

Brady says that up to the time he and Erin took over the daily management from his father, Ray, the property comprised 75 per cent cropping (wheat, lupins and barley) and the balance was devoted to Merinos.

After 2007, the stock and fences went, they bought a disc seeder and began the transition to controlled-traffic farming (CTF).

They had two immediate objectives: to farm in a manner that preserved soil moisture, and to rehabilitate soils that had become compacted and acidic.

“Everything came down to retaining ground cover and making the most of the limited water available,” Brady says. “So inter-row sowing and stubble retention were our starting points.”

RISK REDUCTION

Erin adds that they decided the goal was not to build a system for capitalising on the good years, “which look after themselves”, but to have in place a system that lessened the impact of poor years.

“We also refocused on our production costs to increase profits by getting these down.”

This meant soil testing to determine what the crop actually needed rather than what was simply applied as standard district practice. After the drought, it was the soil tests on the mostly yellow sandplain that delivered the next rude shock.

“As soon as we started to dig below the surface we discovered compaction and really dire subsoil acidity, particularly at the 20 to 30-centimetre layer. It reinforced, again, the need for change. We had to make our soils a far less hostile environment for the plants,” Brady says.

The surface pH was 4 to 4.6 and worsened as they probed deeper.

Working with Rob Ruwoldt, the couple began, slowly, to transform their system – initially subject to the scepticism of friends and neighbours, given their advice was coming from the other side of the country where conditions are quite different, but, as Brady points out, not the principles.

“But we felt we needed to find someone who wasn’t local; someone who would take us out of our comfort zone, and that has proved really important.”

Their main divergence from district practice has been the introduction of full stubble retention, no windrow burning and integrated weed management. Summer weed control has become an absolute priority. They also widened their row spacings from the district norm of 250 to 381mm.

“People were, and are, obviously curious, but for us the slightly wider spacing helps us to better get through the prolonged dry spells we now experience. The wider row spacing reduces competition between plant roots, allowing them to search further for moisture; keeping in mind the ground between the rows is standing stubble, not bare ground,” Brady says.

“There is potentially a slight yield penalty from wider rows, but we feel this is negated by all the other processes and efficiencies now in place. At the end of the day we are now sowing with confidence, knowing we have the techniques in place to make the most from whatever rain we get.”

As part of this matrix, Brady and Erin also moved to smaller, lighter machinery. Most growers in the area, for example, use 18 or 24-metre seeders. The Greens went down to 12m.

“It was to allow us to use smaller, more versatile tractors which use less fuel and can do all the jobs on the farm,” Brady says. “They are working 1000 hours a year doing everything from towing boom sprays, chaser bins, seeders and the lime and urea spreaders, and get turned over every 5000 hours.”



At the end of a long day visiting growers, the tour group listens to Brady Green describe the Yuna Farm Improvement Group soil testing equipment (foreground) he used to test many hundreds of samples during 2012

MANAGING SOIL ACIDITY

During 2010, a trial to compare the effects of CTF, mouldboard ploughing and deep ripping on grain yields, subsurface compaction and acidity was established on the Green's property, funded through the 'Caring for Our Country' program and coordinated by the Yuna Farm Improvement Group. Positive results from the deep soil amelioration techniques prompted Brady and Erin to begin investigating their soils intensively. They began to use biomass imagery to identify poor yielding areas and installed soil moisture probes.

Brady and Erin then took a novel approach to implement an extensive soil testing program by partnering with their friend Nigel Metz, a South East Premium Wheat Growers Association project officer, who during 2012 helped them set up a soil testing laboratory in their garage. With backpacker labour they tested samples from 160 sites, each sampled to 50cm with the Yuna Farm Improvement Group's deep soil sampler. Despite a history of top-dressing 1–1.5t/ha of lime over the previous 15 years, the soil test results were alarming with pHCa at the surface of 4.0–4.6 and 4.4 at depth being common.



Steel 'inclusion plates' fitted to an Austil ripper on the Green's property. (Photo courtesy of Brad Collis, GRDC Ground Cover, Issue 123)



A 'v' of topsoil effectively incorporated into the subsoil by the DAFWA experimental ripper fitted with 'inclusion plates' pulled at 4kph. The soil has been sprayed with Universal indicator (photo taken at Liebe Group long term trial site, Nugadong).

Combining yield mapping, biomass imagery and the soil testing results, the Greens set about mapping production zones to guide their inputs. They planned to begin using variable rate technology (VRT) to manage their inputs, including lime to ameliorate the soil acidity problem. After creating a colour-coded soil pH map of their farm using Google Maps and their pH test results, they realised that variation within paddocks was not sufficient to justify VRT and a more general application of lime was needed across much of the farm. It was decided to delay the introduction of VRT for applying lime until the fine-tuning stage.

The Greens set about spreading around 8000t of lime per year at an average application rate of 2t/ha, sourcing their lime from Geraldton.

The lime was incorporated to a depth of around 20cm with an Austil deep ripper which created a slot behind the tyne into which topsoil fell. Brady and Erin have now deep ripped the bulk of their sandplain soils to 55cm to aid root penetration and the movement of mineralised lime through the profile.

Encouraged by the work of Dr Paul Blackwell and Bindu Isbister from DAFWA, Brady was keen to trial soil 'inclusion plates' behind his deep ripper tynes during 2016 to better capture and direct loosened topsoil and applied lime into the furrow created by the tyne. However, when it was time to start ripping, 30mm of rain during early April was not sufficient to soften the sandplain soils enough to pull the ripper with inclusion plates, so the inclusion plates were removed.



A soil pit dug at Brady and Erin Greens' to determine how effective the inclusion plates trialled had performed. As described in the text, conditions were not optimal when ripped and little of the topsoil has been incorporated in the ripped slot which is situated immediately above Chris Gazey's (DAFWA) hand. With the soil profile sprayed with Universal indicator, the dark purple at the surface indicates a pH of approximately 8 (in water) and suggests that the bulk of the applied lime remained in the top 10–15cm after ripping. The vertical purple bands above Chris' hand shows that some of the limed topsoil was deposited lower in the profile by the inclusion plates. The purple colouration below Chris' hand indicates that the pH at this site improves with depth. The desire to enable crop roots to penetrate through the low pH band (that area above Chris' hand that has not been dyed purple by the Universal indicator) to access this higher pH subsoil is what prompted Brady Green to trial inclusion plates.

With most paddocks on the farm now receiving an average of 4t/ha of lime since 2010, pH at the surface now averages 6.0–6.2 and 5.5 at 20–30cm. These are comfortably above the targets of pH 5.5 at the surface and 4.8 at depth recommended by DAFWA.

To maintain their pH around the levels they have now managed to achieve, the Greens anticipate they will need to apply around 2t/ha of lime every four years into the future.

Having treated their soil acidity problem, treated compaction through deep ripping, introduced controlled traffic farming and minimum-disturbance seeding and brought their weeds under control, the Greens are now averaging 2.2t/ha of wheat from around 250mm of growing season rainfall.

ADDITIONAL READING



www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-123-JulyAugust-2016/Drought-inspires-a-cropping-paradigm-shift

www.grdc.com.au/Media-Centre/Ground-Cover/Ground-Cover-Issue-123-JulyAugust-2016/WA-cropping-plumbs-new-depths



CASE STUDY

PETER AND BELINDA HORWOOD,
MINGENEW

SNAPSHOT

GROWERS: Peter and Belinda Horwood

PROPERTY NAME AND LOCATION: 'Lockier River Farm',
Mingenew

AREA: 5650ha, 85% arable

RAINFALL: 390mm, last five-years received 165–280mm
during the growing season

SOIL TYPES: 95% sandplain; 5% red loam

LIVESTOCK: Small merino flock, moving away from sheep

CROPPING (2016): Wheat (50%); lupins (40%); canola (10%)

ROTATION: Wheat/lupin or wheat/lupin/wheat/canola



Peter Horwood discusses his management strategies with the tour group

Peter and Belinda farm 10km west of Mingenev and have recently purchased more land south of Mingenev.

“Our rotations are typically wheat/lupin or wheat/lupin/wheat/canola, with some pasture/lupins/wheat on very light country,” said Peter. “Our average yields for the last five-years are 2.77t/ha for wheat and 1.78t/ha lupins. We are growing canola again during 2016 for the first time in some years, but in general our country is better suited to lupins than canola.”

Peter is the first to admit he is not an innovator. “I tend to watch and monitor new ideas and the performance of new

grain varieties for three or four years before making changes. My target is to continue to accumulate those 1% gains here and there, without taking any big backwards steps.”

MANAGING SOIL ACIDITY

Beginning in 2000, Peter applied lime for a couple of years then stopped for no particular reason. During 2010 he began again in earnest when as neighbours of Stuart Smart, he became aware of strong residual effects from a 20-year-old lime trial over the fence on the Smart's 'Eragulla Plains' property.

THE ERAGULLA PLAINS LONG-TERM LIME RESPONSE

'20 years of soil acidity RD and E in Western Australia—what have we learnt?' — GRDC Crop Updates 2014
Chris Gazey, Department of Agriculture and Food, Western Australia; Yvette Oliver, CSIRO; James Fisher, Desiree Futures; Joel Andrew, Precision SoilTech and Stephen Carr, Aglime of Australia.

www.giwa.org.au/pdfs/2014/Presented_Papers/Gazey%20Chris_20%20years%20of%20soil%20acidity%20RD%20and%20E%20in%20Western%20AustraliaWhat%20have%20we%20learnt_PAPER%20DR.pdf

In 1994 a DAFWA small-plot lime trial was established at Stuart Smart's "Eragulla Plains" property near Mingenev. Limesand was applied at 0, 0.5, 1, 2 and 4t/ha to plots 1.8m wide and 30m long. There were four replicates. The location of the trial was recorded and marked by burying large pieces of metal at a depth of 40cm at each of the four corners. The trial was relocated using a metal detector in 2013 in a farmer-sown paddock of wheat following aerial observation of significant growth response to the treatments applied 20 years previously.

Subsequent to the initial treatments, the farmer had applied 1t/ha of lime in 1998, 1999, 2003 and 2012 (total 4t/ha lime) to the whole trial as part of normal paddock operations. In 2013, the trial plot yields were measured using a small plot harvester and soil samples collected to a depth of 50cm.

The cumulative application of 4t/ha increased or maintained the topsoil (0–10cm) pH_{Ca} above 5.5–6 for all initial lime treatments. Only the plots that received the initial 4t/ha lime application and the subsequent farmer-

application of a further 4t/ha had subsurface pH that is close to target (\geq pH_{Ca} 4.8). The soil pH below 20cm has continued to acidify from the initial pH as measured in 1994 for all treatments that initially received 2t/ha lime or less. Not only has the soil continued to acidify but the depth to the lowest pH is deeper, meaning that it will now require more lime and take longer to recover.

Wheat grain yield was 10% higher in the treatment that had received a total of 8t/ha lime (initial trial 4t/ha plus 4t/ha in farmer applications) and 6% higher for the treatment that had received a total of 6t/ha lime (initial trial 2t/ha plus 4t/ha in farmer applications) over the treatment that had received a total of 4t/ha lime (nil in trial and 4t/ha in farmer applications).

The soil pH of the plots that received 8t/ha lime over a 20-year period almost meets the recommended targets. This amount of lime far exceeds most current and intended farming practices. Improvements in farming

TABLE 1 2013 grain yield response to 1994 lime treatments at a trial near Mingenew, WA. Subsequently each treatment received 4t/ha farmer-applied lime

1994 lime treatment (t/ha)	Wheat grain yield (t/ha)
0	4.43 a
1	4.56 ab
2	4.69 b
4	4.85 c
Lsd (p=0.05)	0.14

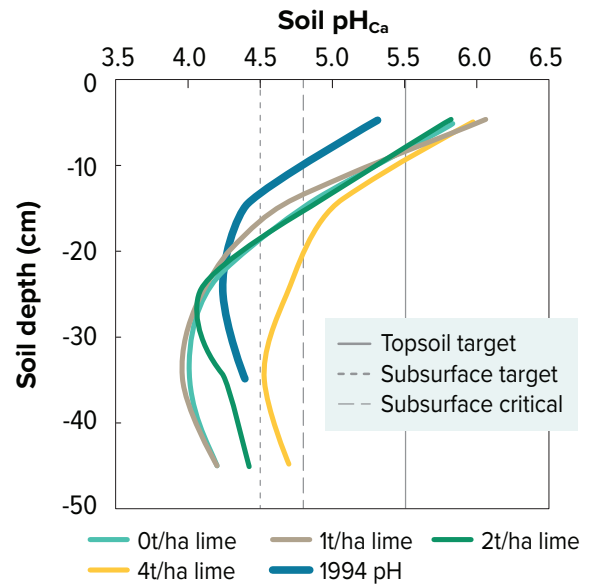


Figure 1. Soil pH profiles in 2013 for different lime treatments compared to the starting pH 20 years ago in a trial near Mingenew, WA

practices leading to greater productivity have also led to increased acidification and therefore an increased lime requirement. The treatments receiving lower rates of lime over this time are now so acidic at depth that they will require large amounts of lime and mechanical incorporation by ripping, ploughing or spading to recover the soil pH profile in a reasonable time frame (3–5 years).



The plots are still visible, 20 years after the initial treatments were applied. *Photo courtesy of Chris Gazey*

“This was an absolute eye-opener for me and made me realise soil acidity was very likely to be limiting yield on my farm,” said Peter.

After observing this response and noting the 400kg yield advantage to 8t/ha of lime sand, Peter embarked on a sizeable soil testing program sampling down to 500mm during 2011 with the assistance of Wes Lefroy from Precision SoilTech. A full nutrient analysis was undertaken at the surface and pH, phosphorus (P) and potassium (K) were measured at depth. The testing confirmed that the yellow sandplain soils were acidic at depth (pH's of 4.0–4.2 were common) but that there was substantial P and K at depth. Peter quickly came to the conclusion that he needed to invest in lime to allow his crops to access those nutrients at depth.

Armed with this soil testing information, Peter began spreading lime annually at 2t/ha in front of his wheat crops, but soon increased his application rate to 4t/ha.

“During 2014, having a source of high quality lime available only 50km away in Dongara, I decided to get our pH's back to optimal levels as quickly as possible,” said Peter. “I was a bit concerned that high rates of lime might induce nutrient deficiencies or toxicities, so to test this I applied 10t/ha of lime on one paddock on our Lockier River property and followed this with deep ripping to 30–40cm on part of the paddock and used a Grizzly on the remainder of the paddock.”

“The wheat crop was then tissue tested by CSBP and we found no adverse nutrient issues with either incorporation method. This gave me the confidence that on our soil types, I could safely crank up our liming program as much as our budget would allow.”

AGLIME AUSTRALIA, PRECISION SOILTECH AND CSBP LIME INCORPORATION TRIAL

Also during 2014, a long term trial to test how quickly subsoil acidity can be corrected by lime was established on Peter's property by AgLime Australia, Precision SoilTech and CSBP. In a paddock in which Peter applied 4t/ha of lime during 2013, the trial compares an additional 0, 3 and 6t/ha lime applied during 2014 then incorporated by nil, spade, deep ripping, Grizzly, offset discs and mouldboard plough.

The aims of this trial were:

- To determine the effectiveness of the different incorporation techniques in moving lime through the surface soil to the subsoil
- To see if high lime rates decreased the yield of lupins

The trial at Horwoods was sown to wheat during 2014, then lupins during 2015 and tissue tests from the 6t/ha lime plots (plus basal rate of 4t/ha applied by the farmer) indicated that manganese (Mn) levels were below the critical level of 20mg/kg in lupins stems, however no visual symptoms of Mn deficiency were evident in the seed at harvest and seed Mn levels were all well above 15mg/kg suggesting that Mn was not deficient.

Yield results from 2014 (wheat) and 2015 (lupins) follow in Table 2 below.

TABLE 2 Yield results from the AgLime Australia, Precision SoilTech, CSBP lime incorporation trial at Peter Horwood's, Mingenew

Type of cultivation	Farmer-applied lime in 2013 (t/ha)	Trial-applied lime in 2014 (t/ha)	Wheat yield 2014 (t/ha)	Lupin yield 2015 (t/ha)
Offset disc	4	0	1.56	1.38
	4	3	1.62	1.34
	4	6	1.54	1.25
Spade	4	0	1.87	1.63
	4	3	2.06	1.53
	4	6	2.08	1.52
Grizzly	4	0	1.46	1.28
	4	3	1.53	1.19
	4	6	1.20	1.21
Deep ripped	4	0	1.62	1.55
	4	3	1.30	1.45
	4	6	1.44	1.43
Mouldboard	4	0	2.42	1.10
	4	3	2.21	1.11
	4	6	2.39	1.08
Probablility			<0.001	0.03
		LSD	0.4	0.35

Those managing this trial cautioned that when comparing the yields of the different incorporation techniques during 2014, it should be noted the seeding system used was one specifically set up to sow mouldboarded country and so may not have seeded some of the other treatment plots as well as they should have been.

The trial has been sown to wheat again during 2016 and all plots will be soil sampled to depth during March 2016, to determine how effective the different lime rates and incorporation techniques.

The results from the AgLime, Precision SoilTech, CSBP trial coupled with his paddock scale experience with spreading 10t/ha, confirmed for Peter that on his country, he could apply up to 10t/ha of lime with little likelihood of inducing problems.

By the summer of 2015/16, Peter had spread 21,000t of lime across the entire farm with each paddock now having received between 6–12t/ha of lime in total since 2010.

“My aim is to apply an average of 8t/ha of lime in order to raise the pH to between 6.0–6.5 in the top 10cm and then to maintain this pH into the future,” said Peter. “I firmly believe optimising pH is an essential strategy to manage seasonal variability and climate change and it directly benefits factors such as nutrient availability and soil biological activity. We can’t afford not to put lime on. Historically, it’s the first thing that goes from the farm budget, but where soil pH is low, many farmers may be better off taking some money out of their fertiliser budget and spending it on lime.”

Peter is particularly keen to optimise conditions for the rhizobium which are critical for his lupin crops and he is also conscious that by optimising pH, he will be increasing the saleability and asset value of his farm, should he ever want to sell.



Peter Horwood (left) and Wes Lefroy (Precision SoilTech) discuss the results of the large-scale, AgLime Australia/Precision SoilTech/CSBP lime incorporation trial on Peter’s Mingenew property with the bus tour group



Peter’s ‘topsoil slotting’ system: ripper tynes with 75 x 75mm angle iron (left) or old scarifier points (right) welded behind the tyne

Peter is targeting a pH of 6.0–6.5 in the top 10cm across his whole farm, believing that at these levels his deep ripping program coupled with leaching will contribute to raising the pH at depth. Peter rips to 30–40cm before each wheat crop.

Peter has been deep ripping for 20 years and has been using homemade ‘topsoil slotting’ additions to his deep ripper for the past few years, trying to encourage topsoil to fall into the ripped slot.

“I noticed how couch grass would often wrap around the ripper tynes and keep the slot open longer before the soil subsided,” said Peter. “I began experimenting with welding old scarifier points or 75x75mm angle iron behind the ripper tyne to create a wider slot. I found that the angle iron works best and is remarkably resistant to wear. It doesn’t look flash but it is cheap and effective at helping the higher pH topsoil to drop into the slot.”

“I now apply as much lime as our annual budget allows to bring our surface pH up to the 6.0–6.5 I am chasing as quickly as possible. Being close to Dongara, we are fortunate to have a source of high neutralising value lime sand nearby and I want to take advantage of the current availability of high grade lime because lime will only become more expensive as the easily accessible high grade supplies are consumed.”

Looking beyond his own farm, Peter believes to reduce the costs of lime growers should look carefully at the economics of carting their grain to port and then back loading lime, or taking advantage of the current opportunity to negotiate cheaper freight rates while the transport industry continues to be impacted by the mining downturn.

Having also decided he did not want to spend the money required to increase the capacity of his spreading equipment or to spend six to eight weeks on a tractor over summer spreading lime, Peter uses contractors to cart and spread all of his lime.



Grant Thompson (Crop Circle) at left of picture, discusses the results of the GRDC funded trial examining the potential for residual herbicides in chemical fallow systems on the red river loam at Peter Horwood's property with the tour group

Peter and Belinda have recently purchased a new farm south of Mingenew and applied 2t/ha of lime ahead of the 2016 wheat and canola crops, and will double this to 4t/ha ahead of the 2017 wheat and canola sowings if the budget allows. Based on his experience and the results of the trials on his Lockier River property and on the Smart's neighbouring property, Peter's philosophy is now "if the pH is below 5.8 at the surface, I know I need to add lime".

Once they have raised their pH at the surface to 6.0–6.5, Peter thinks on his soil types he may need to apply around 4t/ha of lime every 10 years or so to maintain that pH.

"Wherever pH is still below the optimum, my standard practice will now be to apply 4t/ha of lime in two applications of 2t/ha, each applied before a wheat or canola crop. This will be followed by deep ripping if going into wheat and the crop sown with a John Deere 1830 air hoe with knife points. I believe two applications of 2t/ha is better as it should result in more uniform distribution than a single 4t/ha application," said Peter.

To guide his lime and fertiliser decisions, Peter also plans to keep soil testing every paddock extensively on a four-year cycle, undertaking a full nutrient and pH test at the surface and testing for pH, P and K at depth.

ADDITIONAL READING



20 years of soil acidity RD and E in Western Australia—what have we learnt? Chris Gazey, Department of Agriculture and Food, Western Australia; Yvette Oliver, CSIRO; James Fisher, Desiree Futures; Joel Andrew, Precision SoilTech and Stephen Carr, Aglime of Australia. GRDC Crop Updates 2014.

www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2014/05/20-years-of-soil-acidity-RD-and-E-in-WA

CASE STUDY

KEITH, ROSEMARY AND BOYD CARTER,
JIBBERDING

SNAPSHOT

GROWERS: Keith, Rosemary and Boyd Carter

PROPERTY NAME AND LOCATION: 'Glenfyne', Jibberding

AREA: 12,000ha owned and leased, 80% arable

RAINFALL: 260mm average annual, 180mm average growing season rainfall

SOIL TYPES: 60% good yellow sand and sand over gravel; 20% acidic (Wodjil) yellow sand; 20% red clay

LIVESTOCK: 2500–3000 merino and crossbred flock

CROPPING (2016): 9700ha cropped annually.

During 2016 — 5000ha wheat; 2000ha malting barley; 500ha feed barley; 1100ha canola; 250ha lupins; 220ha oats for hay

ROTATION: Red clay — pasture/barley/barley/wheat/wheat/pasture. Sands — pasture/lupins or canola/wheat/wheat or acid tolerant barley



Boyd Carter on his family's Jibberding property

The Carter family began farming in the Jibberding area during the early 1920s. Keith and his wife Rosemary now farm 12,000ha with their son Boyd, a fourth generation farmer.

Of the 12,000ha, 20% is leased and the Carters are currently seeking to bring underutilised areas into production to increase the arable area of their enterprise. To achieve this, they are removing unwanted fences and realigning others to better group soil types into like units. Crop rotation decisions are made on a paddock-by-paddock basis, guided by soil type, pH and nutrient status, weed burden and past rotation history. They commenced growing lupins again during 2016 for the first time in six years and the pasture phase that supports the merino/crossbred sheep flock is a key component of managing high weed burdens.

The Carters use a CTF system on all their soil types. Their two DBS seeding bars, one with 12 inch tyne spacing and one with 10 inch, are 60 feet wide and are pulled by a John Deere tracked machine. Their header currently has a 40 foot front, but it is planned to move to a 60 foot unit. Their boomsprays are 120 foot wide. Boyd and his father Keith are supported by one permanent workman and three casual workmen and the family uses contractors on a needs basis for lime spreading; any spraying and fertiliser spreading they are unable to manage themselves; and grain carting.

MANAGING SOIL ACIDITY

The Carter's yellow sand and sand over gravel are naturally acidic and readily develop hardpans. To maximise the depth of soil to which crop and pasture species can explore for nutrients and moisture, the Carters began liming around 30 years ago, typically applying 1.0t/ha across about a third of their sandplain country most years. As a result, their sandplain soils have received around 6t/ha of lime sand over the past 30 years.

In years where money is tight, the most acidic Wodjil soils receive what lime can be afforded. On their leased land, which is more acidic than the home farm because it has had less lime applied, the Carters use a variable rate approach to increase lime application rates on problem areas.

"Liming is a critical part of our farming system," said Boyd Carter. "Without lime, we would never have been able to increase our wheat yields on our Wodjil soils from the 0.8t/ha we used to get in a reasonable rainfall year, to the 2.4t/ha we regularly achieve with the same rainfall. In addition, lime has improved our ability to kill weeds. Herbicide uptake is better in healthy weeds. Even with the newer herbicides, we continue to see this difference. Weeds are easier to kill on our limed country than on our newly acquired, leased land which has lower pH."



The Carters also deep rip on a regular basis to incorporate lime and break up the hardpan. They first began deep ripping to 400–600mm back in 1996.

“We are concentrating on achieving access to the full bucket of soil moisture and nutrients, so ripping is also important on our sandplain” said Boyd. “We have explored other lime incorporation options, including the use of mouldboard ploughs, but are not convinced that mould boarding is something we need.”

The family’s lime incorporation and deep ripping strategy now involves two different configuration rippers used in rotation. The first, a Westlands ripper with 15 inch tyne spacing capable of ripping to 300mm, is used on their sandplain country every six to eight years. The second machine, a Primary Sales bar purchased during 2010 has 18 inch tyne spacing with a leading tyne setup which has been modified to allow the tynes to lift to keep the tramlines intact. This bar is capable of ripping to 400mm and is also used every 6–8 years.

“We use the two rippers in rotation and spread lime ahead of each ripping operation because we want to get as deep into the profile as quickly as possible” said Boyd. “We typically rip 400–800ha every year, spreading lime directly ahead. We use the Primary Sales ripper in rotation with the Westlands ripper so that if we ripped a paddock to 400mm with the Primary Sales bar this year, we would rip it to 300mm with the Westlands bar in three to four years’ time, then come back again three to four years later with another lime application and rip again to 400mm with the Primary Sales bar.”

The Carters are hoping that once they raise the pH of their subsoils sufficiently, they will be able to stop ripping to 400mm and just rip to 300mm every three to four years to manage compaction closer to the surface. With their sandplain country now having received a total of 10t/ha of lime over the past 30 years and their regime of deep ripping to incorporate that lime, the Carters say the pH of these soils is now around 4.8 throughout the 0–40cm range.

The Carters source their lime from Green Head, having determined that the higher cost to transport lime from Dongara makes it more economical for them to cart lower neutralising value lime from Green Head and apply it at higher rates. They use contractors to spread their lime and cart around 50% themselves with the balance being carted by contractors.

“We would prefer to cart all our lime, but it competes with our need to be spraying summer weeds,” said Boyd.

The Carters have tested the response of their red clay soils (pH 4.8–5.0 at the surface) to lime, but believe they are better off concentrating their lime application on their sandplain and Wodjil soils.

“We have applied lime test strips on our red clay soils and we can still see those test strips 20 years later. There is a different weed spectrum and more clover on the test strips,

but with only a limited budget for lime every year, we have done the economics and for us it is better to concentrate the lime on our sandplain and Wodjil soils.”

Boyd believes they are likely to apply around 1.0 t/ha of lime sand every three years on an ongoing basis on their sandplain country to maintain their pH levels at the 4.8–5.0 range they have achieved through the profile. The Carters soil test each paddock at least once every three years, testing at 0–10cm and 30–40cm as a minimum. These samples receive a full pH and nutrient analysis and the results are sent to Adriaan Dewaal (Soil Fertility Management) who advises the Carters on their lime and fertiliser requirements. The Carters tissue test their wheat crops at least every three years and do additional tactical sampling if they see any problems arising.

MANAGING WEEDS

The Carters consider weed management as the single most important driver of their farming system. All management decisions are based on the weed spectrum and density in each paddock.

Harvest weed seed management

To manage weed seeds at harvest, the Carters windrow burn their wheat and barley stubble and have been using a chaff cart to manage lupins residues since 1996. They swath their canola to help prevent weed seed set, but then spread their canola harvest residues with chaff spreaders as this is important feed for their sheep flock.

“We windrow burn our wheat and barley harvest residue as it burns well and windrow burning uses less horsepower than towing a chaff cart and is not as time consuming as burning chaff cart dumps,” said Boyd. “We use a chaff cart in lupins because they are often weedy and the chaff cart allows us to concentrate the weed seeds and the stubble and the sheep get a lot of feed value out of these. Ideally we would burn these lupin dumps every year, but we sometimes run short of time as the burning season is short. We prioritise the burning of any wheat and barley stubbles, so we sometimes don’t get time to burn the lupin dumps, however there is generally not much left of them by the time the sheep finish with them.”

“We also use the chaff cart in any wheat and barley paddocks that have high weed burdens as it allows us to concentrate and then burn the weed seeds. At the end of the day, weed burden is the deciding factor that determines whether we windrow burn or use the chaff cart.”

Summer weed management

The Carters have seen summer weeds proliferate over the years and they now consider melons, roly-poly (*Salsola tragus* L. var. *kali*), windmill grass (*Chloris truncata*), button grass, caltrop (*Tribulus terrestris*), Afghan thistle (*Solanum hoplopetalum*) and couch grass (*Cynodon dactylon*) to be their most significant summer weeds. To tackle

summer weeds more efficiently, the Carters purchased a WeedSeeker® during February 2016.

“We didn’t get the full benefit from our WeedSeeker® this summer weed season as we bought it well into summer, but we believe it will be a valuable tool in reducing our summer weed control costs and by owning our own, we can hit the weeds at the optimum time, rather than having to rely on contractors who may or may not be able to get here at the optimum time,” said Boyd. “This year, in the paddocks we used the WeedSeeker®, we were spraying between 15–60% of the paddock. The average was about 30%. We used high rates of glyphosate with saflufenacil and added 2,4-D ester when we wanted an extra boost on melons.”

“We try to get a double knock wherever we can, but to lessen the possibility of glyphosate resistance, we use paraquat for the second pass. This year we had a lot of late summer rain so after getting on top of our big summer weeds, we came back with paraquat to manage the new germination that appeared in early March. This worked well for us this year and will be something we will continue with.”

Managing winter weeds

Unlike many growers who have moved out of sheep completely, the Carters see sheep as a critical tool for low cost weed management; an important component in their system to avoid the development of herbicide resistance and a valuable source of cashflow in their low rainfall, highly seasonally variable environment.

Their farm also has a significant area of saline valley floors that have been sown with saltbush and which provide valuable sheep feed. Without sheep in their system, these valley floors would be unproductive.

“We were looking to get out of sheep completely because cropping has been more profitable,” said Boyd. “With low wheat prices and the need to have a range of rotation options open to us to manage weeds, sheep remain an important tool for us to manage grasses in particular. Sheep mean we don’t have all our eggs in one basket and they save us a lot of money on herbicides. If a paddock becomes unmanageable for grasses, particularly ryegrass and brome grass (*Bromus diandrus* and *Bromus rigidus*) and to a lesser extent silver grass (*Vulpia myuros* and *V. bromoides*), then we take the paddock out of the crop rotation and put the sheep in. They are an economical weed control tool to manage seed set in these problem grasses and they clean up radish flowers and pods effectively too.”

“We are experiencing an increased problem with wild dogs though and sheep do come at a labour cost too. We have to have someone here at all times to manage our sheep and it is getting harder to find people who want to work with sheep, but we still consider them a very important part of our system.”

The Carters are considering increasing the competitive pressure on weeds during the pasture phase by improving their pastures through the introduction of newer pasture legume varieties. They are also hopeful that the new summer forage species *Lebeckia* may have a place in their system, particularly on areas prone to wind erosion.

“Targeting grasses and radish by spraytopping in the pasture phase is also an effective strategy for us to manage seed set and reduces the pressure on our in-crop chemicals. We spraytop every time a paddock is in pasture and historically we have used paraquat at 1100ml plus 2,4-D ester 800 at 400–500ml to sweeten up the radish and make it palatable to the sheep, but based on recent AHRI research, we will probably up the ester rate to 600ml which appears to stop radish seed set completely.”

The Carters recently moved to a self-propelled Miller Nitro front mounted boom spray which Boyd says has improved weed control in paddock corners.

“Where we used to have to back into the corners of paddocks and had reduced nozzle pressure on take-off, we can now go into the corners forwards with full nozzle pressure. This is giving us a better kill in the corners.”

CASE STUDY

BRAD AND RAYLENE BURNS, BALLA

SNAPSHOT

GROWERS: Brad and Raylene Burns

PROPERTY NAME AND LOCATION: 'Kalinya', Balla

AREA: 5000ha arable

RAINFALL: 300mm average annual, 240mm average growing season rainfall

SOIL TYPES: 30% red loam, 70% deep yellow sand

LIVESTOCK: None

CROPPING: 600–700ha canola; 1200–1400ha lupins; 2800–3000ha wheat; 200ha chemical fallow

ROTATION: Wheat/lupins on yellow sands with a canola crop introduced every 6–10 years; continuous wheat on red loams with a canola crop every four–five years to control grasses; fallow is occasionally introduced to control grasses

AVERAGE YIELDS (2010–2016): Wheat 1.67t/ha; lupins 1.3t/ha; canola 0.7–1.0t/ha

BREAKEVEN YIELDS (AT 2016 COSTS): Wheat 1.5t/ha; lupins 0.8t/ha; canola 0.4t/ha

Brad and Raylene Burns farm in the low rainfall northern wheatbelt at Balla, approximately 50km north east of Northampton. Their farm is approximately 20km south of the northern extremity of the farming area, beyond which is pastoral country. Brad's parents moved to Balla from Cunderdin during 1965 and cleared and developed much of the land that now makes up 'Kalinya'. Brad and Raylene took over the management of the business in the early 1990s. Brad and Raylene's neighbours to the south, the Johnson's, also feature in this case study booklet.

The Burns' consider wild radish, annual ryegrass and brome grass as their most significant winter weeds and caltrop, melons, roly-poly, tar vine and summer grasses as their most problematic summer weeds. Wild radish from three additional blocks the Burns' purchased during the 2000s to expand their enterprise tested positive to 'SU' (sulfonylurea group of herbicides) resistance and the phenoxy herbicides had only limited effect. Ryegrass on these same blocks was resistant to grass selectives and to 'SUs'. Brad and Raylene have seen no evidence of resistant ryegrass or radish on the original 'Kalinya' farm, only on the new blocks they have purchased. Brad and Raylene have only recently begun growing canola again after previously abandoning it in the mid-2000s because of problems with emergence and survival after dry-sowing, poor results in poor seasons and weed control, especially radish.



Brad and Raylene Burns, with two of their three children, Tom and Emily

Brad and Raylene use John Deere 1820 Air Hoe Drills to sow their crops. During 2015 they began a program of deep ripping to 500–550mm with a 6m wide AusPlow ripper with Agropow tynes and saw around a 700kg/ha yield response to ripping in their 2015 wheat crops, however they are finding that depth control at seeding is difficult to achieve on the newly ripped paddocks. They are currently planning on converting their 1820 bars from the standard metal press wheels to large pneumatic press wheels to improve depth control.

Like many other growers, the Burns' believe that managing soil acidity is an important part of achieving good weed control and have been applying 2t/ha of lime sand sourced from Dongara to 1000ha of their property every year since 2008. Having applied 1t/ha of lime sand across the entire property prior to 2008, some paddocks have now had a total of 5t/ha of lime. This has raised the pH at the surface in most paddocks to 5.0 or better, but the pH of the subsoils remains low at 4.0s.

The Burns' soil test around a fifth of the farm — about 1000ha — every year, testing to depth. In the low rainfall area in which they farm, they regularly dry sow to maximise the length of the growing season. While preferring to sow into moisture, they begin dry sowing their lupins during late April if the season has not broken and will then move onto dry sowing canola and wheat provided the paddocks have low weed burdens. While not having a hard and fast cut-off date for sowing, the Burns' prefer not to sow after mid-June, but their decision is dependent on the

state of the soil cover in each paddock and they will sow a crop just to ensure some ground cover and have done so during July before. From early June, input costs are reduced.

In their low rainfall, seasonally variable environment, the Burns' must carefully manage their input costs, particularly fertiliser and herbicide costs. Based on the low wheat price during 2016, the Burns' wheat crops will need to yield at or above their long term average just to breakeven.

MANAGING WEEDS

Brad and Raylene see good weed control as one of the key economic drivers for their business.

“During the 1990s, we made some big leaps forward in weed control and reaped the benefit of higher yields and greater profit,” said Brad. “In our low rainfall environment, every millimetre of soil moisture lost to weeds is lost profit, so we are committed to keeping weed numbers down. You only need to see how much yield is lost in a weedy corner of a paddock to be reminded that you have to be vigilant with weed control.”

With relatively high densities of radish to control on their newer blocks, Brad sees the bromoxynil plus pyrasflotole mix as a particularly important herbicide in his armoury and one which he wishes to manage carefully to maintain its efficacy.

“To maximise the efficacy of our herbicides, I am always careful to apply them at the correct crop and weed growth stage; I don't skimp on rates and I won't spray under adverse atmospheric conditions. Weed control is a big cost to our business, so I see no point in wasting herbicide applications by spraying on hot dusty days when you know you are not going to get good plant uptake. It just wastes money and potentially increases resistance problems.”

Whenever the break of season allows, Brad aims for a double knockdown, using a glyphosate based mix on the first pass and following up with paraquat, either straight or in combination with an 'SU' where radish numbers are high. Brad is a firm believer in never using glyphosate straight, favouring the addition of pyraflufen-ethyl or 2,4-D ester to boost its impact on radish.

After having dropped canola from their cropping program because of expensive crop failures, the Burns' recently began growing canola again because of the price premium.

“We use a Roundup Ready canola to increase our options to control radish, blue lupins (*Lupinus cosentinii*) and to a lesser extent ryegrass in our lupin/wheat paddocks,” said Brad. “The Roundup Ready varieties are expensive, but the extra weed control options and their hybrid vigour lend themselves to our system.”

Mindful that they have had canola crops fail under conditions where they were dry sown and then received a few millimetres of rain while day temperatures were

still hot, Brad and Raylene are considering replacing their Roundup Ready canola with a Triazine Tolerant variety. This would be on the red loam where establishment is easier and the radish not as big a problem as the Roundup Ready canola has helped clean up paddocks.

“While the Triazine Tolerant varieties might not yield as much as the Roundup Ready varieties, when dry sowing Triazine Tolerant varieties the atrazine gives you some certainty of reasonable weed control and if the crop does emerge and then die because of insufficient moisture or heat stress, while not ideal, you can treat the paddock as a chemical fallow or re-seed if that is the choice,” said Brad.

Brad is a strong supporter of controlling weeds on fence lines and around trees and other vegetation.

“My philosophy is to cover as much of our country as possible with crop and then to be vigilant to control weeds on roadways and fence lines and around trees or structures. I don't want them acting as a reservoir for weed seeds.”

Brad uses a high rate mix of glyphosate, atrazine and pyraflufen-ethyl applied from a firefighter style ute mounted sprayer. This operation takes around two weeks each year and is followed by another two weeks of observation and mopping up.

“We have also spent a lot of time and money removing obsolete fence lines and isolated trees that are leftovers from the days when we ran stock to better manage these areas,” said Raylene.

Brad is also extremely careful to ensure that he and his workman spray 100% of the crop when operating the boomspray.

“We take great care when working around the perimeter of the paddock to make sure that the boom is up to or over the fence line and we back our self-propelled (SP) unit into all the corners to make sure no ground is missed,” said Brad.

Like their neighbours Chris and Matt Johnson, Brad and Raylene have recently begun hand pulling radish. Escapees are mapped and hand weeding is carried out, concentrating on their wheat paddocks where radish numbers are low.

“We would now spend around a week a year on average hand pulling radish,” said Raylene. “We rope the kids in whenever they come home too! And while we are doing that, we are on the lookout for any patches of ryegrass or other weeds that have survived the boomspray and we will come back with the tank on the ute and spray them out.”

Chemical fallow

Brad and Raylene chemically fallowed around 600–800ha per year through the late 2000s as a strategy to ensure that they had clean paddocks into which they could start dry sowing wheat with confidence if the season had not broken by late April/early May. On their red loams, the



chemical fallow system delivered additional moisture and nutrient retention benefits to the following wheat crop, but Brad believes that the deep yellow sands rarely if ever carried any stored soil moisture over into the following crop. This may be due to acidic subsoil or hardpan preventing the wheat crop accessing subsoil moisture. Chemical fallow began to lose favour when for a number of years, the Burns' found that particularly on the yellow sands, they had to spray a total of 6–8 times to adequately control both the summer and winter weeds.

"The economics just didn't stack up," said Brad. "It became that classic dilemma of whether you are better off growing a 1.8t/ha wheat crop every year, or a 2.4t/ha wheat crop every second year and nothing in the alternate years. A 1.8t/ha crop every year won out and we largely stopped chemically fallowing. We now chemically fallow around 200ha/yr as a strategic tool to manage grasses in our continuous wheat rotation on our red loams or on some of our poorer sands if we have a poor germination. In either situation, we spray late to make sure we retain cover. We know this reduces the moisture retention benefit but it is a trade off against wind erosion."

Harvest weed seed management

Prompted by a number of years in which weeds proliferated and the purchase of three new blocks during the 2000s, the Burns' began windrow burning after their lupin and canola crops during 2009 to reduce their weed seed burden. They also tactically used windrow burning in wheat crops in some lighter crop years when there was less risk of the fire escaping the windrow into the stubble.

"We fitted a chute to our header that dropped a 300–400mm wide windrow and we kept up a program of windrow burning through until around 2013," said Brad. "Now we feel we have some control over our weed numbers and we prefer to only windrow burn in exceptionally weedy years. We need to retain all the stubble we can on our country, so any burning is a last resort."

"I have also noticed that we are getting poorer crop establishment on the burnt windrows than on the rest of the paddock and I suspect it may be due to an increase in non-wetting under the windrows. We have also been working towards CTF as we have updated our machinery over time and our windrows are now being dropped in the same place in the paddock year after year."

"We've had great results from windrow burning but I don't think dropping a windrow on the same spot every year is what we always need to be doing now. I would prefer the nutrients and organic matter contained in the trash to be dispersed across the paddock."

Brad is currently looking at systems that lay chaff in the wheel tracks as an option going forward. With the move towards CTF you also need to be sure you have a solid enough crop and therefore windrow to carry the fire the length of the paddock.

"We've learned lessons on this in the past," said Raylene. "We certainly don't want to be randomly driving over deep ripped ground and negating the time and the benefits flowing from this practice."

Summer weed management

Melons, roly-poly, caltrop, tar vine and a range of summer grasses are the Burns' most problematic summer weeds.

"Summer weeds have really increased in the last few years," said Brad. "We have such a broad range of summer weeds, some of which are easy to kill and some of which aren't. They are a big, costly problem whenever we have significant summer rains."

The biggest driver for the Burns' to control summer weeds is the need to be able to seed as early as possible, followed closely by their desire to conserve as much soil moisture as possible.

Brad and Raylene have seen the variety of summer weeds dramatically increase since they got out of stock.

"When we had stock we obviously had summer weeds, but the sheep clearly preferred to graze some species ahead of others, so we didn't get the diversity of summer weeds that we see now," said Brad. "The ones the sheep liked to eat were kept in the background."

Raylene is worried about the legacy of summer weeds.

"I am not sure that we could have done anything differently, or can do anything differently now. I am concerned that in 20 years' time, whoever is farming this place might be looking at us and saying *"Why the hell didn't you get on top of 'xyz' weed when it first appeared rather than let it proliferate?"* but it's a simple reality that we would go out of business if we tried to eradicate every new summer weed chemically. It would be good if someone could come up with some work on how to successfully deal with summer weeds in a cost effective way."

The Burns' begin spraying summer weeds soon after the first significant germination. Brad prefers to blanket spray unless weed densities are low and the weeds large. Under these circumstances he will use contractors with WeedSeeker® booms. Melons are still prevalent on their farm despite having targeted these for more than 10 years.

"Despite all our best efforts to control melons, paddocks that we think must surely be free of them still sprout a healthy crop after any significant summer rain."

CASE STUDY

JOHNSON FAMILY, BALLA

SNAPSHOT

GROWERS: Chris and Pauline, Matt and Kate Johnson

PROPERTY NAME AND LOCATION: 'Helenore', Balla

AREA: 5660ha arable

RAINFALL: 285mm average annual, 185mm average growing season rainfall over last five years

SOIL TYPES: 30% red loam; 45% yellow sand; 25% shallow sand over gravel

LIVESTOCK: None

CROPPING (2016): 1100ha canola; 1000ha lupins; 3200ha wheat; 400ha chemical fallow on sand over gravel

ROTATION: Wheat/lupins/wheat/canola or wheat/lupins/wheat/lupins on better sands; wheat/wheat/canola on red loam; wheat/fallow/wheat on shallow sand over gravel

AVERAGE YIELDS: Wheat 1.7t/ha, lupins 1.3t/ha, canola 1.0t/ha



Chris Johnson (right), with son Matt, advocates hand pulling wild radish on their Balla properties

Chris and Pauline Johnson, together with their son Matt and his wife Kate, farm in the low rainfall northern wheatbelt at Balla, approximately 50km north east of Northampton. Chris' grandparents began farming the area in 1931 when they took up land under the Conditional Purchase scheme.

The Johnsons increased the size of their operation during 2006 when they purchased a new block at Nolba and increased it further during 2016 when they purchased another block adjacent to their home farm, 'Helenore'. These new blocks brought additional weed management challenges for the family, who had worked very hard for decades to clean up weeds on their home farm.

In the low rainfall area in which they farm, the Johnsons are heavily reliant on dry sowing to maximise the length of the growing season. They regularly dry sow their lupins and canola and begin dry sowing wheat if the season has not broken by mid-May. Because they have no opportunity to get a knockdown when dry sowing, low weed burdens are essential to the Johnson's farming system.

What distinguishes the Johnsons from most other growers is the intensity with which they target wild radish, and the resultant almost total absence of radish on the home 'Helenore' farm. They have worked diligently to rid 'Helenore' of wild radish and they take great care to ensure it stays free of this weed. However, the two new blocks they have added to their operation both have an abundance of wild radish. This has led to the Johnsons

treating their three farms as two separate units for weed control purposes — those with radish and those without.

The Johnsons have never tested their radish for resistance, but have had positive results for resistance in annual ryegrass to 'fops' and 'dime'. While the Johnsons consider radish as their single most important weed, doublegees (*Emex australis*), annual ryegrass, wild turnip (*Rapistrum rugosum*) and capeweed (*Arctotheca calendula*) are also significant winter weeds, with brome grass a problem in some years. Melons, roly-poly and mulla mulla (*Ptilotus polystachyus*) are their most problematic summer weeds.

MANAGING WEEDS

While most growers are only just beginning to think about using hand pulling to control radish at low densities, the Johnsons have been hand pulling radish for at least 35 years.

As Chris remembers it, radish first appeared on their family farm during 1976 or 1977 and probably arrived in a load of hay.

"Somehow Dad either knew or was told that radish was a buggger of a weed," said Chris. "That's when we started hand pulling it and I can remember as a 15-year-old, my whole family out pulling radish."

"Hand grubbing radish consistently for many years is the only reason we have been able to reduce radish numbers to almost zero on our home farm. Because the two new



blocks we bought have high radish numbers, I am not sure we will ever be able to reduce them to the level we have at 'Helenore', but we will do our best to try."

HYGIENE

Chris and Matt use very strict hygiene practices to prevent the spread of weed seeds, especially radish.

This includes carefully managing their harvest sequence so that all crops on the radish-free 'Helenore' home farm are harvested first, before the header is taken to their new blocks where radish is present.

Before the header is returned to 'Helenore', Matt spends two to three days stripping and cleaning the header from top to bottom to rid it of radish and other weed seeds. The following season, before the header turns a wheel in the paddock, the Johnsons run the header at their sheds to ensure that any weed seeds that escaped the end-of-harvest clean up are blown out at their sheds, rather than in the first paddock to be harvested.

If using contractors to spray or cart grain, the Johnsons insist that the contractors clean down their machinery in a quarantine area near their sheds where any weeds that subsequently germinate can be easily seen and controlled.

"We don't buy in any hay or grain either," said Chris. "We don't want to import weeds."

"All our seed is harvested on our home farm where the paddocks are cleanest and we grade it as a further precaution against the spread of weeds. If we want to introduce a new crop variety to the farm, we buy a small quantity and bulk it up ourselves. We don't want to buy somebody else's weed problem."

The Johnsons are using Roundup Ready canola on their new blocks to increase their radish control options, however they are experiencing problems with late germinating radish which is both difficult to spot and difficult to control.

"Whenever we are not able to get two glyphosate sprays on our Roundup Ready canola because of adverse seasonal conditions or a staggered crop germination, we are not getting good radish control," said Matt. "Late germinating radish gets through."

"We have had good results controlling ryegrass and late germinating radish using glyphosate as a desiccant on canola, but where we use diquat as a desiccant, because we are going in later, we find the late germinating radish has already set seed by the time we desiccate."

"We have been thinking about going to Roundup Ready Triazine Tolerant canola to increase our herbicide options further, but are concerned that the yield penalty inherent in these varieties will make it uneconomical for us in our low rainfall environment."

The Johnsons use chemical fallow on their shallow sands over gravel as a control strategy to manage ryegrass

which is prevalent on this soil type, opting for a continuous wheat/fallow/wheat/fallow rotation.

"Because we don't have radish on our home farm, we can use a late chemical fallow where we need to manage ryegrass numbers," said Chris.

"We spray during late July or early August with 2L of glyphosate plus a high rate of metsulfuron-methyl. When spraying this mix on the paddocks on the southern boundary of our home farm, we will add 500ml of 2,4-D ester 680 to clean up any radish that germinates from seed blown across from our neighbours by the prevailing southerly winds."

"We chemical fallow as late as possible to minimise the risk of wind erosion," added Matt. "We know spraying late costs us a bit more in lost soil moisture, but we want the weeds to have some bulk to give us protection from wind erosion. We trialled atrazine (2kg atrazine plus 2L glyphosate) to chemically fallow on wheat stubble. We got good weed control, but the paddock was very bare."

Matt and Chris have also observed wind erosion increasing on the tramlines where constant wheel traffic bares the ground. For this reason, when chemically following, Matt alternates the first pass of their 36m boom so that for the first spray operation, the machine might start 18m in from the fence. The next time he sprays that paddock, he will start 36m in from the fence so the machine is not running on the same wheel tracks as the last spray operation. Subsequent spray operations are alternated on the different wheel tracks.

The Johnsons are equally diligent when spraying fence lines and fire breaks and will either straddle the boom over the fence line, use a fence nozzle or use a firefighter-type sprayer to ensure weeds, particularly radish, are controlled along fence lines.

Like many other growers, the Johnsons are removing obsolete internal fences and individual trees to prevent these acting as weed reservoirs.

The Johnsons believe in keeping their herbicide rates up at robust levels and carefully following label recommendations for water volumes and application speeds.

"What's the point in saving \$3/ha on herbicide if that \$3 is the difference between getting 75% control and 95% control," said Chris. "How many times have growers complained about a herbicide being useless when the real problem is they are using 25% less water and are spraying at 25% faster than the label says!"

Harvest weed seed management

To manage weed seeds at harvest, the Johnsons began windrow burning during 2008, but now only use windrow burning in those years when weeds are particularly prevalent.



The Johnsons' home farm, 'Helenore'

"We prefer to retain all our stubble wherever possible, both to prevent wind erosion and to retain nutrients," said Chris. "We only windrow burn as a last resort, but if we have a big weed year, when we harvest our lupins we will fit a chute and curtains to our header so we drop a 250–300mm wide windrow and we will burn the windrows. We don't windrow burn in our cereals because it is too hard to control. We either end up with unburnt windrows wherever the stubble is too thin to carry a fire, or we are constantly worried about the fire spreading beyond the windrows to rest of the paddock."

The Johnsons will even fit the chute and curtains to their header just to do a single pass along a particularly weedy fence line and burn that single windrow.

"We'd prefer to do that than risk spreading any weeds originating from that fence line another header width into the paddock," said Matt. "If you are not vigilant, every time your harvester picks up a gut full of weed seeds, you distribute these another header width into the paddock. If you keep that up year-after-year, pretty soon the whole paddock is infested."

"We have tried baling the windrows in our wheat crops, but found unless the baler was following immediately behind the header and could bale the windrows before they settled, most of the weed seeds were left behind. Then you end up with concentrated rows of weeds, especially ryegrass, on all the old windrows for the next couple of seasons."

The Johnsons also find windrows an inconvenience because they restrict opportunistic deep ripping after summer rains.

"We can't burn our windrows until the middle of March," said Chris. "If we get summer or early autumn rains we can't deep rip in a paddock with unburnt windrows because we would just end up dragging the windrows all over the paddock. Similarly, we can't apply and incorporate lime in windrowed paddocks for the same reason. So they do restrict your options in many ways."

"We are not fans of chaff carts either. Again, we want to retain all our stubble if possible. We also find we are occasionally getting called out to neighbouring properties to fight fires that have started from neighbours burning chaff cart dumps. We don't want that problem ourselves. We would rather get good in-crop weed control and not be relying on burning."

Hand pulling radish

As discussed above, the Johnsons have invested a lot of time in hand pulling radish over the decades. Having worked hard to get radish numbers very low, they use hand pulling as a cost effective treatment for scattered plants and low density populations.

"Hand pulling radish is feasible and cost effective in cereal and lupin crops if densities are low," said Chris. "Radish plants are easy to spot in cereals and once the lupins have finished flowering, radish is easy to spot in the lupins as well. Where we run into trouble is in canola because the canola is as tall or taller than the radish."

The Johnsons have a zero tolerance approach to radish on 'Helenore'. If they see a radish plant, they pull it.

Chris rides the lupin crops on a motorbike, revisiting areas where plants have been found in previous years and



marking any new finds on a GPS plotter. He pulls all plants he finds. Any plants bearing seed are removed from the paddock and disposed of in a dedicated rubbish site. Using a GPS allows the Johnsons to consistently return to known radish locations and control any new germinations.

“If we are on the boom spray and we see a radish plant on ‘Helenore’, we mark it with the GPS and stop there and then and pull it,” said Chris. “It’s pointless thinking you will come back later to get them, because you never do. You need to pull them when you see them.”

“When I am on the header, if I spot a radish plant I will lift the comb up over it, mark it with the GPS, then get the chaser bin driver to pull it,” added Matt. “If there is a group of plants, I will go round them. I don’t want radish seed going through the header to be spread even further through the crop. We have just fitted a rubbish bin to the tractor that tows the chaser bin so that any seed-bearing radish plants pulled by the chaser bin driver are taken out of the paddock and properly disposed of.”

The Johnsons have used contractors to harvest in the past, but other than one contractor who is no longer in the business, they found that contract harvesters were not willing to be as diligent with radish hygiene as the Johnsons demanded. As a result, they no longer use contractors to harvest.

Chris and Matt estimate the family now spends a total of about 40–50hrs each year between June–October hand pulling radish.

“It’s not a fun job so we do a few hours here and a few hours there amongst other jobs,” said Chris. “We are confident we save a significant amount every year by not having to use the more expensive herbicides chasing radish, so out hand-weeding pays.”

Belinda Eastough, Chris and Matt’s agronomist, estimates the Johnsons save in the order of \$78,000/yr by hand pulling their radish.

“On their 800ha lupin program, the Johnsons typically use glyphosate plus trifluralin plus metribuzin plus simazine at sowing and then metribuzin plus simazine as a post emergent,” said Belinda. “Because they have reduced their radish to such low numbers by hand pulling for many years, I estimate Chris and Matt save \$11/ha (including application cost) across their 800ha lupin program by not having to use a second post-emergent spray of simazine plus metribuzin plus diflufenican.”

“That is a saving of \$8800/yr in their lupins alone.”

“There is an even bigger saving in their wheat program,” said Belinda. “Instead of using bromoxynil plus pyrasulfotole plus MCPA LVE at a cost of around \$26/ha, the Johnsons are able to get away with using metsulfuron plus MCPA LVE plus clopyralid at around \$6/ha. Over their 3000ha wheat program, that is a saving of \$60,000/yr. On their weedier new farms, a second radish spray is often needed, but on ‘Helenore’ where they have diligently hand

pulled radish, they very rarely have to come back with a second spray on that 1000ha of wheat, which represents another saving of around \$10/ha on 1000ha.”

Chris and Matt have recently begun experimenting with drones to determine if they can be cost effectively used to locate radish plants in canola.

“We can easily spot radish in wheat and lupins,” said Chris. “We would love to have an effective way to spot them in canola. I am confident that drones will have a place in the future, but it is very early days and the operator we trialled is still developing in this field. He could only cover 100ha per day and it is never going to be cost effective unless you can get over a lot more hectares than that in a day.”

Summer weed management

Melons, roly-poly, and mulla mulla are the Johnsons most problematic summer weeds.

A triclopyr, 2,4-D ester 680 and metsulfuron-methyl mix is commonly used to control these weeds ahead of a wheat crop. A glyphosate, 2,4-D ester 680 and triclopyr mix is used on paddocks going into lupins.

Chris and Matt occasionally use contract WeedSeekers® to control summer weeds on their new blocks where early germinated radish requires high rates of glyphosate. However, on ‘Helenore’, where radish numbers are extremely low, they find blanket spraying for summer weeds is a cheaper option than contracting WeedSeekers®.

CASE STUDY

**DEREK, PAM AND JEREMY WASLEY,
NANEKINE**

SNAPSHOT

GROWERS: Derek, Pam and Jeremy Wasley

PROPERTY NAME AND LOCATION: ‘Nanekine’, Nanekine (North-West of Morawa)

AREA: 10,000ha (8500ha arable)

RAINFALL: 330mm; 250mm average growing season rainfall, but highly variable

SOIL TYPES: 60% red loam; 30% loamy gravels; 10% sands

LIVESTOCK: 2500 Dorper ewes, 500 merino ewes

CROPPING: 5500ha cropped annually on average — 5000–5200ha wheat; 200ha lupins; 200ha oats; with 50ha cut for hay. Lupins and oats are retained for sheep feed



Jeremy Wasley on the family property at Nanekine northwest of Morawa

The Wasley family have a long history of farming at Jibberding east of Wubin, but Derek, Pam and family moved to ‘Nanekine’ during 1981 seeking more reliable rainfall.

Derek and Pam’s son Jeremy is a University of Western Australia Agricultural Science graduate and after working as a researcher on aerial seeded clovers at the Centre for Legumes in Mediterranean Agriculture (CLIMA), Jeremy returned to the farm during 1998. Jeremy now manages the farm business which employs two full time workmen, with Derek assisting at seeding and harvest.

The Wasley’s property is undulating and is dotted with non-arable, shallow gravel outcrops that have remained uncleared. Jeremy’s philosophy is to keep things as simple as possible, with wheat and sheep being the major sources of income.

MANAGING WEEDS

Unlike many farmers in the wheatbelt, sheep remain a major part of the Wasley’s business.

The family runs a flock of 2500 Dorper ewes and 500 merino ewes because they use sheep as a critical tool for managing weeds and herbicide resistance, maintaining cash flow (particularly in dry years) and as a buffer against seasonal variability.

In keeping with Jeremy’s ‘keep it simple’ philosophy, Dopers were chosen because they are not subject to flystrike and do not require shearing. The merino ewes are maintained because the flock has been built up over many years and Jeremy does not want to part with them.

There are also some portions of the Wasley’s farm that do not lend themselves to continuous cropping and the sheep provide an option generate income of these soil types.

“We have always had sheep and we have maintained our sheep infrastructure over the years,” said Jeremy. “We started experimenting with Dopers around 2003, crossing them with merinos and selling the lambs. In the 2006 and 2007 drought years, our Dopers handled the conditions so much better than our merinos, so we shifted over to a Dorper-dominant flock by building up the flock from our own stock.”

“You do have to have good fences to run Dopers though, they love going under them. We have our posts at 8m spacings to prevent that and we do 5–10km of fencing every year to keep our fences in good condition.

“It would be very hard for farmers who had let their fences and waterpoints deteriorate to reintroduce sheep, especially Dopers, into the system.”

The Wasleys crop around 5500ha per year on average, so like to keep their system as simple as possible.

“We try to keep our system a simple as possible,” said Jeremy. “Sheep are a fantastic tool for weed control in that system and wheat is the most drought tolerant crop option we have. It is the last thing to fall over, hence it dominates our program.”

“Over the years we have grown a range of crops, but have reverted to wheat as our dominant crop because of its resilience, our soil type mix and because of the difficulty and expense of controlling weeds, especially radish, in other crops.

“We grew barley up until 2005, but 50% of the time it was going feed because of colour or protein being too high, so we gave that away.

“We also used to grow 200–300ha of Albus lupins (*Lupinus albus*) per year, but radish was a problem due to limited herbicide options. At the same time, we were growing 300–400ha of chickpeas per year, but radish was too hard to control with the herbicides available at the time. We had a massive radish blow out in one chickpea crop when MCPA plus bromoxynil failed and it took us 7–8 years using a wheat/medic pasture rotation — one year in, one year out — to reduce the radish population back to where we had started. So we stopped growing chickpeas.”

“We also grew about 600ha of canola a year from 1999–2001. We averaged around 0.7–0.8 t/ha, but a combination of dry years, low price and the relatively small area we were growing led to it being dropped out of the rotation.”

“There are now more herbicide options available for in-crop weed control in grain legumes than when we were growing them and cropping is more profitable on a per hectare basis, but our Dorper flock is a low maintenance way for us to manage weeds and provides us with vital cashflow in the dry years. In the drought years of 2006 and 2007 for example, when we could see no rain on the horizon, we made a decision to leave the tractors in the shed and did not put in a crop in either year. This proved to be a wise decision in hindsight as those crops would have made a significant loss, but we still had income from our sheep.”

“At the end of the day the wheat/pasture system with low maintenance Dorper sheep is simple and works well for us with our soil types and seasonal variability,” said Jeremy.

The Wasleys typically use a wheat/wheat/pasture rotation with half of each year’s wheat crop going in on spray-topped pasture and half on the previous year’s wheat stubble.

With Jeremy’s background in pasture legume research, it is not surprising the property boasts 600ha of dense Caliph Barrel medic (*Medicago truncatula*) pasture (the balance of pastures on the farm are unimproved, volunteer pastures). A wheat/pasture/wheat/pasture rotation is used on these paddocks.

“Our medic pastures are extremely valuable to us, but we haven’t sown any more medics for a few years now as we were finding that in dry years, the nitrogen produced by the medics was burning off our wheat crops,” said Jeremy. “Nitrogen produced by pasture legumes is extremely cheap, but unlike granular or liquid nitrogen, it is already in the ground at seeding. You can’t decide not to apply it to the crop if the season is a dry one. To spread our risk, it is worth our while having other pasture paddocks that are not producing quite so much nitrogen.”

The Wasleys first suspected they may be developing herbicide resistance in both wild radish and ryegrass when, following a weedy lupin crop on one gravelly loam paddock during 2002, radish was prevalent in 6–7ha of that paddock during the 2003 wheat crop.



Jeremy Wasley inspects a paddock of Caliph barrel medic pasture during August 2001 while his Dorper flock in the background struggle to make an impression on the lush feed resulting from an early break and plenty of rain

“We hit the paddock with 700ml of 2,4-D ester 800 as early as the crop could tolerate it, but a lot of the radish survived,” said Jeremy. “So we sprayed that part of the paddock out with glyphosate before the radish could set seed.”

“The following year the paddock went into barley and we sprayed out that problem patch with glyphosate again. During 2005, the paddock was in pasture and was spraytopped.

“2005 was also the first year we began spreading lime and that paddock was one of the first to get 1t/ha, which I believe helped us get control of the weeds in subsequent years as they were healthier and so herbicide uptake was better. During 2006, when the paddock was back in wheat, we used an early application of 500ml/ha of bromoxynil plus diflufenican with the addition of 500ml/ha of MCPA LVE to target radish and we were able to get good control. That paddock now has very low radish numbers — you’re struggling to find any.”

Also around 2003, the Wasleys noticed that an increasing proportion of their ryegrass was surviving their Treflan® applications.

“We were actually starting to see more and more radish and ryegrass get through our herbicide applications across more and more of the farm,” said Jeremy. “By hammering the small problem areas, spraying them out with glyphosate if necessary, getting in early with robust herbicide rates, having a ‘no escapees’ philosophy, getting our soil pH under control, spraytopping in the pasture phase and using our sheep as a weed control tool, we have been able to keep things under control.”

“We have applied this same system to the new land we have bought over the years, some of which had very high radish and ryegrass densities, but our multi-pronged weed management system has controlled both radish and ryegrass to the point where we don’t see them as a problem anymore.

“We could actually run a lot more sheep if I wasn’t so focussed on keeping our radish and ryegrass under control. Most of our pastures are volunteer pastures and most paddocks are only in pasture for one year before going back into crop so the pasture phase does not have a high-carrying capacity. Then our spraytopping kills that pasture in early September, so we need a lot of pasture hectares for the sheep to survive the summer. I would prefer to hand feed sheep every summer rather than have radish in my crops, so we accept the relatively low stocking rate as a necessary part of our system.”

The Wasley’s sheep and pastures — both the unimproved, volunteer pastures and the improved medic pastures — are a critically important part of their weed control strategy.

“Our Dorper sheep are a really useful weed control tool,” said Jeremy. “For example, on our medic pastures the Dorsers will preferentially graze the medics early in the season then they start targeting the grasses and radish

as these begin to flower. I am not sure why this is, but it works in our favour as they clean up a lot of the weed seed heads.”

“We also spraytop our pastures every year and we get in early.

“Every paddock of volunteer pasture is spraytopped using glyphosate at around 1.6 L/ha + 2,4-D ester or metsulphuron. We start spraying in the third week of August and aim to finish by the first week in September. On our good medic pastures, I use a grass spay 3-6 weeks after opening rains and the sheep clean up any ryegrass and wild oats (*Avena fatua* and *A. ludoviciana*) not controlled by the clethodim, plus do a good job on any radish. If seed set has not been great in the medics, I will carry them over for a second year of pasture and spraytop them hard with glyphosate in that second year to ensure there is no weed seed set. It also prevents the medics from setting seed but because the barrel medics are quite hard seeded, they can cope with this treatment.

“All our spraytopping is completed by the first week in September to get good seed set control. While clearly there is an opportunity cost to having sheep versus a crop, as we forgo the income we could have got from a crop every time we have a paddock in pasture, there is a flow on benefit from the pasture because we can generally be assured of a 200–300kg/ha better wheat yield in a crop following pasture versus one following a previous wheat crop, especially if it is a dry year. Then there is the income generated by our sheep, which excluding labour, repairs and maintenance, is worth around \$270,000/annum based on the last five years’ income.”

The Wasleys trialled 400ha of chemical fallow during 2012. These paddocks received a knockdown after the seeding program was completed, then a second knockdown during late September, a single summer spray, then a knockdown at seeding the following year. Cropped to wheat during 2013, a dry year, this paddock yielded 0.5 t/ha better than wheat after pasture.

“Because 2013 was a drier year, 2012 was a good year to have tried chemical fallow,” said Jeremy. “The chemically fallowed paddocks were our best performing paddocks in a year where our wheat averaged 2t/ha, but I suspect we wouldn’t have got such a marked increase in yield had 2013 been a wetter year.

“There are problems with chemical fallow. There’s the 3–4 extra spray operations for a start so there is the cost of the extra chemical plus application and I don’t enjoy sitting on a boomspray. I also found that melons were germinating through September–October on 5mm of rain because there was extra soil moisture in the chemically fallowed paddocks, so I had to get in and control them. Had the paddock just been in pasture, I could have turned off better than one whether lamb per/ha, needed only one spraytopping operation and still got 200–300kg/ha better wheat yield in the following crop. On those numbers, the return from our Dorsers is very similar to the return



from chemical fallow, without the need for me to sit on a boomspray for three–four additional sprays.”

Jeremy can see a place for chemical fallow in the drier areas to the east, especially for those prepared to invest in WeedSeeker® technology, but does not see it as something he will continue. The Wasleys weed control practices are so effective that Jeremy says their stocking rates are relatively low.

“Our sheep, our early spray topping and good in-crop weed control are giving us clean paddocks, which means we can’t run as many sheep in the pasture phase, but that’s a situation I am happy to have,” said Jeremy.

MANAGING SOIL ACIDITY

The Wasleys first began applying lime to address soil acidity during 2005; applying lime sand at 1t/ha and then later increasing the rate to 2t/ha as they began to observe the benefits.

“We began applying lime to the gravelly soils on our farm,” said Jeremy. “With an average pH of around 4.3–4.5 at the surface, these were some of our poorer performing soils, yielding significantly less than our red loams. In the drier years the crops on the gravelly soils would run out of water, while the red loams hung on better. Our gravelly soils have now had around 4–6 t/ha of lime and the pH at the surface is now around 6.0. The crops are able to explore more soil volume and hang on much longer and today, our gravelly soils yield as well as our red loams.”

The Wasleys began to see the improvements in their soil pH and their crops within 3–4 years after applying 1t/ha of lime and while this gave them the confidence to continue, they decided to increase the application rate to 2t/ha seeking a more rapid response.

“Another driver for increasing our liming program was that we were able to significantly reduce the amount of phosphate we were using on the limed paddocks because as the pH increased, it made the residual phosphate more readily available,” said Jeremy. “Consequently we were able to drop the rate of Agflow down from 80 to 50–55kg/ha. We could then invest the savings in more lime.”

During 2013, Jeremy calculated the economic benefit of applying lime. He assumed a 10-year benefit to the applied lime and a cost to apply 1t/ha (cost of lime plus cartage and spreading at full contract rates) of \$30/ha. Assuming 50,000t are spread over 10 years, this represented a cost of \$1.5 million over 10 years.

Jeremy then assumed a fertiliser saving of \$80–\$100,000/yr and a 10–12% crop yield increase due to the increase in pH, which equates to an extra 1000t of grain per year for Jeremy and assuming \$250–300/t for that grain, means an extra \$2.5–3 million in income over 10 years.

On these numbers, he arrived at a benefit of \$3.5–4 million over 10 years for the investment of \$1.5 million in lime — or a profit of \$2–2.5 million over 10 years.

“On these sort of numbers, liming is a no brainer,” said Jeremy. “It’s what prompted us to move from spreading 1500–2000t/yr to 7000t/yr, which we have done every year since 2013. The benefits are also supported by our wheat yields which before liming averaged 1.6–1.8t/ha in a really good year. Now we get well above 2t/ha on those paddocks in a good year, including 3t/ha during 2011.”

Since 2013, the Wasleys have been applying 7000t of lime per year at 2t/ha. By 2017, the whole farm will have received a total of 6t/ha of lime since liming commenced during 2005.

Their gravelly soils, which prior to liming had a pH of 4.3–4.5, now average 5.5–6.0 at the surface and the pH of the red loams has increased from 5.0–6.0 on average.

The Wasley’s source their lime from Dongara and put it on ahead of a crop so it is incorporated by the seeder.

“We are lucky to have a high quality lime source relatively close by at Dongara,” said Jeremy. “It makes the decision to lime even easier.”

The Wasleys soil test every paddock going into wheat, but currently only test at the surface (0–10cm).

“That will change during 2017 when we will begin testing to 30cm to see if we have achieved the changes we wanted at depth,” said Jeremy. “I will use the results of that deeper testing to fine tune our lime program as we enter the maintenance phase after 2017.”

Based on an estimated removal rate of 200kg/ha of lime sand equivalent in crops and animals every year, Jeremy estimates that he will need to apply 2t/ha of lime every 7–8 years across the whole farm to maintain the pH in the target range of 5.5 at the surface.

“At a removal rate of 200kg/ha/yr of lime sand equivalent, it should take 10 years for us to have removed the equivalent of 2t/ha of lime sand, but I don’t want to run the system to its limit, so I plan to apply 2t/ha every 7–8 years,” said Jeremy.

Jeremy’s approach is strongly supported by DAFWA.

CASE STUDY

ROD AND SHELLEY BIRCH, COOROW

SNAPSHOT

GROWERS: Rod and Shelley Birch

PROPERTY NAME AND LOCATION: ‘Catalina Farms’, Coorow

AREA: 9000ha

RAINFALL: 300mm average annual; 250mm average growing season rainfall

SOIL TYPES: 50% deep loamy yellow sand, 30% sandy loam, 20% gravelly sand

LIVESTOCK: None

CROPPING: 1000–1600ha canola; 800–1300ha lupins; 600–800ha barley; 4000–5000ha wheat

ROTATION: Yellow sandplain — lupins/wheat/canola/wheat; sandy loams — wheat/wheat/canola/wheat/lupins/wheat

AVERAGE YIELDS: Wheat 2.5t/ha; lupins 1.5t/ha; canola 1.4t/ha; barley 3.0t/ha (barley grown for the first time during 2016)



Rod Birch uses lupins as the foundation of his crop rotations

The Birch family first began farming in Coorow during 1960 when Rod’s father purchased a partially cleared, mostly unimproved property that had been taken up during the 1950s to run sheep and grow an occasional crop.

Rod’s father developed the block and during 1981 Rod took over the management of ‘Catalina Farms’ from his father. Rod and his wife Shelley now run the business with the help of two full-time farm workers and additional seasonal casual labour.

Catalina Farms is run as a 100% cropping operation after the family moved out of sheep during 1995 when wool prices were very low.

“We got out of sheep when the wool price was low, but maintained our infrastructure with the idea of getting back into sheep if the wool price increased sufficiently,” said Rod. “We never did get back into them and I now believe sheep don’t fit well into our cropping system, especially with respect to weed management.”

“To run sheep well you need to have good legume-based pastures and the sheep then manipulate those pastures and maintain their legume composition. On our soil types and rainfall, we can’t grow good legume-based pastures. Instead, we could only grow patchy, low biomass pastures which then acted as a weed seedbank for the following crop.”

To compensate for the lack of good legume-based pastures, Rod introduced lupins during 1988 and has treated them as a critical part of his farming system since.

“I treat lupins super-seriously,” said Rod. “On my farm, they are the foundation on which my crop rotations are built.”

“Introducing lupins was another factor in our decision to get out of sheep. During the mid-1990s I was starting to windrow and burn my lupin harvest residues. When sheep were put on those lupin stubbles, they soon discovered the windrows were where any grain that went through the header was to be found and set about destroying the windrows searching for grain. By the time we could begin burning the windrows in mid-March, we could not achieve a good weed seed kill because the windrows were too dispersed. It was this, the low wool price and the incompatibility between pastures and cropping that led us to get out of sheep.”

The Birchs have steadily increased the size of their operation as properties within close proximity of their home farm have become available at an affordable price. During 1993, land next door was purchased, doubling the size of the operation. Additional blocks were acquired during 2006 and 2010, and during 2016 the Birchs expanded further when they acquired their latest farm.

These new blocks have all brought additional weed management challenges for Rod who has a low tolerance for weeds and has worked very hard for many years to reduce weed numbers on his home farm.



When summarising his weed management philosophy for this case study, Rod recalled a conversation he had with Peter Newman from Planfarm/AHRI.

“A few years ago I travelled to Argentina with Peter Newman and Bill Crabtree, a well-known consultant and no-till advocate. Peter asked me to describe my attitude to weed management for a presentation he was giving at a conference we were attending in Argentina. On my farm, I fight a constant battle with weeds, so I told Peter that my attitude was “to never declare a ceasefire in the war on weeds”. That philosophy hasn’t changed; if anything, it’s intensified.”

Rod also describes himself as having two ‘religions’; these being liming and deep ripping.

“On our soil types, there are two things I do religiously and that is to apply lime and deep rip,” said Rod. “Making sure I maximise my crops access to subsoil moisture and nutrients is paramount. To make sure they can, I need to manage soil acidity and sub-soil compaction. So our program includes regular applications of high quality (high neutralising value and fine particle size) lime sand from Dongara and regular deep ripping.

“I started liming about 20 years ago and was probably one of the earlier growers to do so. Our standard lime program is to spread 2t/ha of lime sand plus 400kg/ha of gypsum for the sulphur benefit. We now spread around 5000t of lime sand and 800t of gypsum annually. Potash is also applied separately at a rate determined by soil testing.

“We spread most of the lime sand after a lupin crop then begin deep ripping if we get suitable summer or autumn rains to get some incorporation of the lime and gypsum. We see the benefit of the lime and gypsum for at least the next three years in the following wheat/canola/wheat component of our rotation. With the exception of the new block we bought during 2016, most paddocks on our farms have now had an average of 6t/ha of lime applied since I commenced liming.”

Rod believes so strongly about managing soil acidity, that the first thing he does when buying new land is to apply lime according to soil test results. He, like a number of the growers featured in this case study booklet, also firmly believes that weeds are easier to kill when soil pH is optimal.

Rod deep rips each of his sandplain paddocks every four years on average. He uses a 12m Ausplow Easitill E600-20 ripper with 600mm tyne spacings and rips to 400mm after summer or autumn rains. Rollers are towed behind the ripper to leave a smoother finish and help trap moisture. He combines the ripping operation with his lime application program wherever possible, using the ripping operation to incorporate the lime.

The Birchs have not yet adopted VRT or CTF, but Rod is likely to do so in the future.

“The only reason I haven’t yet started using CTF is the difficulties involved with matching machine widths,” says Rod. “When we upgraded our second header for example, we opted again for the 45 foot (13.7m) comb, the same width as we have on our primary header. The 45 foot comb allows us to cover as much ground as quickly as possible, rather than opting for a 40 foot (12.2m) comb which is a better match for our seeder width.”

“I have been looking seriously at VRT, especially for nitrogen application which is one of our bigger costs. Moving to VRT is a substantial investment, but maximising the value of every dollar spent on high value inputs such as nitrogen by using VRT makes perfect sense. So I will be implementing it as soon as possible.”

MANAGING WEEDS

Rod considers weed management to be one of, if not the most important driver of his farming system. All management decisions are based on the weed spectrum and density in each paddock and crop rotations in each paddock are regularly adjusted in response to the weed spectrum and densities in the preceding year’s crop and in response to summer weed numbers.

Rod began to notice it was becoming harder to control annual ryegrass around the mid-1990s. Testing confirmed he had widespread resistance to the sulfonylurea (Group B) herbicides.

Rod is fastidious in rotating herbicide groups to maintain the efficacy of all available herbicides and prevent the development of herbicide resistance. Table 1 below illustrates the various herbicide groups Rod uses to maximise his weed control options and avoid the development of resistance. Rod strives to maximise the number of herbicide groups he uses within his various crop rotations to ensure his weed populations are not exposed to repeat applications of the same herbicide group. He carefully uses various group combinations to achieve the synergies possible through multiple modes of action.

TABLE 1 The wide variety of herbicide groups used by Rod Birch to maximise weed control options and avoid the development of resistance

Herbicide	Crop type	Herbicide Mode of Action Groups used*
Knockdowns	All	B, G, I, M
In-crop	Lupins	A, C, D, F
	Canola – Triazine Tolerant varieties	A, C, D
	Canola – Roundup Ready varieties	A, D, M
	Wheat and barley	B, C, D, F, H, I, J, K
Crop-topping	Lupins and canola	L, M

* For a list of herbicides grouped by mode of action and ranked by resistance risk, see www.grdc.com.au/Resources/Bookshop/2010/12/HERBICIDE-RESISTANCE-MODES-OF-ACTION-GROUPS

“I consider maintaining the efficacy of every available herbicide to be vitally important to maximising my weed control options and profitability,” said Rod. “However, I guess if pushed to nominate the most valuable herbicides in my system, I would have to lean towards the knockdowns – glyphosate, paraquat and diquat – as being absolutely critical in my system. That’s why I have just sent some ryegrass from the block I acquired during 2016 off for testing.”

“During September 2016 I asked Dr Steve Powles (AHRI), who was visiting our farm, to look at some ryegrass in a wheat crop on the new block because I was concerned it might have ‘hard to destroy ryegrass’. The paddock was thick with ryegrass in places and had scattered plants surviving throughout the paddock. Steve shared my concern and we agreed it was best to chemically fallow the 100ha paddock.

“I used 4L/ha of glyphosate plus 1L/ha of diuron during late September, but that did not kill all the ryegrass. So I then applied 2L/ha of paraquat during late October. I took samples of the ryegrass and have sent it off to Dr Peter Boutsalis’ Plant Science Consulting labs for testing. I am now waiting on the results of the testing to develop a plan to manage that ryegrass population.”

To keep weed numbers low, Rod estimates he uses chemical fallow on about 60-100ha/yr on average as a strategic tool to manage patches in crop where weed numbers are higher than he is prepared to tolerate.

“My workmen and I keep notes on where weeds have survived the pre- and post-emergent spraying as we drive around the farm,” said Rod. “We then compile a map from these and before they set seed, mix up a robust brew and apply to those areas. I would prefer to sacrifice a bit of crop than allow hard-to-control weeds to set seed.

“That old adage of ‘one year’s seed equals seven year’s weeds’ resonates with me!”

Harvest weed seed management

During 1998, in an effort to control high ryegrass numbers, Rod was one of the first growers in WA to begin concentrating harvest residues into windrows and burning the windrows.

During 2001, Peter Newman (DAFWA, now Planfarm/AHRI) began monitoring ryegrass numbers on Rod’s farm as part of his GRDC funded (project number DAW672 and DAW00123) Focus Paddock project (Newman, 2009). Rod used a combination of windrow burning, crop rotation and careful herbicide selection to successfully reduce surviving (in August) ryegrass numbers from 300 plants/m² to almost zero within 3-5 seasons in the paddocks being monitored. Tables 2 and 3 below show the treatments Rod used between 2001 and 2009 to achieve the reduction in ryegrass numbers shown in Figures 1 and 2 (page 58) respectively.

Despite the Focus Paddock project winding up some years ago, Peter Newman has continued to measure ryegrass numbers in Rod’s two Focus Paddocks. As can be seen in Figures 1 and 2 below, Rod’s careful ongoing management (described further below in this case study) have kept surviving ryegrass numbers in-crop to near zero.

Rod used windrow burning on almost all paddocks for all crop types for many years, but has since become more selective. He now only using windrow burning in those years when weeds are particularly prevalent or on newly acquired land as a means to reduce weed numbers.

“On our home farm and on those blocks acquired up until 2010, I have reduced weed numbers to a level where we only need to windrow burn when it has been a particularly bad weed year or in those paddocks where we have had a weed control failure for some reason,” said Rod. “Otherwise I prefer to retain as much stubble as possible for its wind erosion protection and nutrient content values.”

“Concentrating residue into windrows also tends to concentrate nutrients into the windrows. In fact this is what alerted us to the fact that our potassium levels were becoming marginal. I was getting ridges in my crops where the plants growing on the windrows were looking markedly better than in the rest of the paddock. Dr. Bill Bowden who was then with DAFWA, came up to look at them and attributed it to the potassium that was being concentrated in the windrows and diagnosed that the rest of the paddock was approaching deficient levels.

“Windrowing also creates problems for our deep ripping operation. Because of burning restrictions, we can’t burn until mid-March at the earliest and if we get suitable summer or autumn rains, that means we can’t deep rip unburnt, windrowed paddocks because the ripper drags the trash into piles which then won’t flow through the seeder.”

In those paddocks that he does want to windrow burn, Rod fits curtains and a chute to his two Case 8240 headers to leave a concentrated, 400mm wide windrow.

Rod is not a fan of chaff carts and has never used them on his farm.

“They have a place,” said Rod. “However the practicality of burning individual dumps is something I don’t want to deal with.”

Rod is keeping a keen eye on the development of the integrated Harrington Seed Destructor. He believes it is an exciting innovation and is something he is likely to invest in in the future.

Summer weed management

Summer weed management is an important part of the Birch’s farming system.

“Summer weeds use an enormous amount of soil moisture, more than you think they would when you look at the spindly above ground biomass,” said Rod. “They also

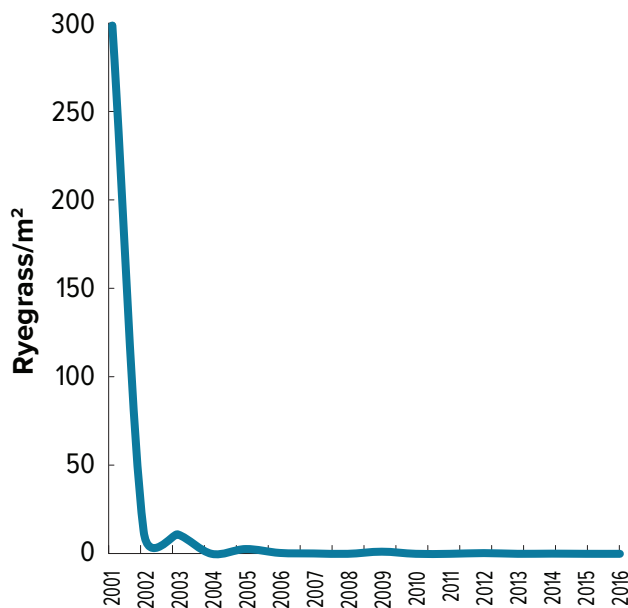


Figure 1. Surviving ryegrass plants (in August) / m² in Rod Birch's Paddock 5 (Newman, 2009 and pers.comm.)

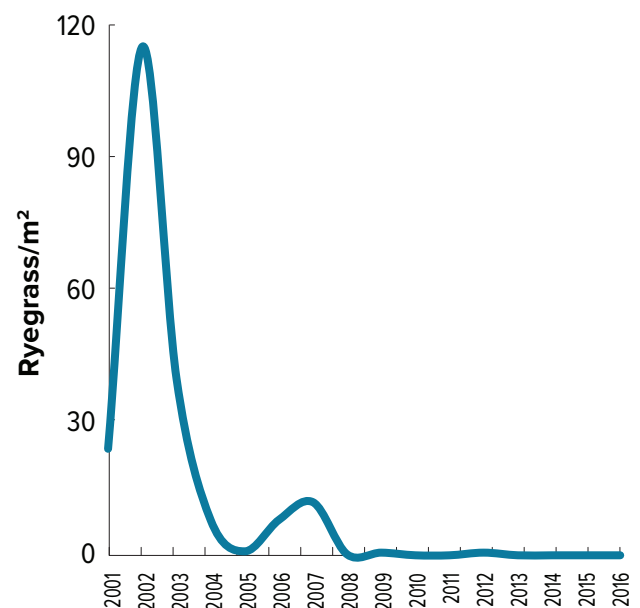


Figure 2. Surviving ryegrass plants (in August) / m² in Rod Birch's Paddock 10 (Newman, 2009 and pers.comm.)

TABLE 2 Treatments applied on Rod Birch's Paddock 5 from 2001 – 2009 (Newman, 2009)

Year	Crop	Herbicide	Other
2001	Lupins	Simazine Fusion®	Windrow and burn
2002	Wheat	Trifluralin + SU*	Windrow and burn
2003	Canola	Atrazine Select®	Windrow and burn
2004	Wheat	Trifluralin + SU	Windrow and burn
2005	Lupins	Simazine Motsa®	Windrow and burn
2006	Wheat	Trifluralin + SU	
2007	Canola	Glyphosate / Paraquat (sprayed out patchy / low yielding crop)	
2008	Wheat	Trifluralin + SU	
2009	Lupins	Simazine Early Targa® for volunteer wheat Select®	Windrow and burn

* SU = sulfonylurea herbicide group

extract nitrogen that is being mineralised at high rates when the soil is moist and warm in summer/autumn."

"I can replace lost nitrogen, at a cost of course, by applying more to the crop if needed, but that stored summer moisture the summer weeds are sucking up is absolutely critical for yield. Summer weeds also make dry seeding more difficult and create problems by blocking seeding machinery at seeding time, so controlling them at the lowest possible cost is a very high priority on my farm."

TABLE 3 Treatments applied on Rod Birch's Paddock 10 from 2001 – 2009 (Newman, 2009)

Year	Crop	Herbicide	Other
2001	Lupins	Trifluralin + Glean®	Windrow and burn
2002	Wheat	Simazine Select®	Windrow and burn
2003	Canola	Trifluralin + SU*	Windrow and burn
2004	Wheat	Simazine Motsa®	Windrow and burn
2005	Lupins	Trifluralin + SU	Windrow and burn
2006	Wheat	Simazine Select®	Windrow and burn
2007	Canola	Trifluralin + SU	
2008	Wheat	Trifluralin + SU	
2009	Lupins	Trifluralin + SU	Accidental total burn pre-sowing

* SU = sulfonylurea herbicide group

Melons, roly poly, caltrop, tar vine and windmill grass are the Birch's most problematic summer weeds.

Like many growers, Rod has also seen the weed spectrum on his property change over the years, with one contributing factor likely to be the removal of sheep from the system.

"If you had asked me what windmill grass looked like 10 years ago I wouldn't have been able to tell you," said Rod. "Now the stuff's everywhere, to the point that it's now one of my most problematic summer weeds."



One of Rod's two Case 8240 headers set up with curtains and chute for windrowing harvest residue. (Photo courtesy of Ben White)

Rod believes getting out of sheep has forced many growers to get better at summer weed management.

"I don't believe sheep are particularly good at controlling summer weeds," said Rod. "They tend to selectively graze the more palatable weeds and leave the woody ones. By getting out of sheep, I had to stop kidding myself that they were managing my summer weeds for me. I have no excuse now – I have to get out there and spray them."

To ensure he gets maximum efficacy from the herbicides he uses to control his summer weeds, particularly glyphosate mixes, Rod is fastidious about applying them under optimum conditions. For this reason he uses high water volumes (70-90L/ha) and regularly commences spraying at 2 or 3am when temperatures are optimal for spraying.

"We use Delta T – the relationship between relative humidity and temperature that is indicative of evaporation rate and droplet lifetime – as our main guide to spraying conditions, particularly for glyphosate mixes," said Rod.

He also uses a Challenger RoGator® 1300B self-propelled boom spray which has nozzles at 25cm spacings.

"With 25cm nozzle spacing, the RoGator® achieves quadruple overlap instead of the double overlap of booms with 50cm nozzle spacings achieve," said Rod. "The quadruple overlap ensures every weed gets good herbicide contact. Being a rear-mounted boom, we also back into corners with the RoGator® to make sure no part of the paddock is missed."

Rod is also considering adopting spot spraying technology (eg. WeedSeeker® or WEEDit® sprayers) to control summer weeds in the future.

Managing weeds in crop

Annual ryegrass, wild radish, brome grass and capeweed are the Birch's most problematic winter weeds.

As described above, Rod is passionate about achieving weed-free crops and very carefully manages his crop rotations and herbicide group rotations (see Table 1 on page 57) to get optimal weed control while preserving the efficacy of the herbicides available to him.

Seeking a grain legume to replace poor quality pastures on his deep loamy yellow sandplain and gravelly sand soils, Rod began growing lupins during 1988 and has treated them as a critical part of his farming system since, sowing 800–1300ha/yr.

"I treat lupins super-seriously," said Rod. "On my farm, they are the foundation on which my crop rotations are built. They are an important break crop and significantly broaden the range of herbicides available to me."

"The release of varieties like Gunyidi, Coramup and Jurien that have a higher tolerance to metribuzin has increased the ability to control wild radish in lupins even further. Additionally, the ability to crop-top lupins to control residual ryegrass is a very important tool."

Rod crop-tops approximately 30% of his lupin crop every year when the lupins are in their late maturation phase and the ryegrass is at soft dough stage.

Rod also grows 1000–1600ha of genetically engineered Roundup Ready canola each year as a break crop and regards this as having made a major step-change in his ability to control weeds.

"Genetically engineered canola has revolutionised cropping," said Rod. "I have been growing Roundup Ready canola since it first became available during 2010 and since then, the rate of varietal development has been astronomical. Improvements in yield, disease and herbicide tolerance characteristics of the new varieties continue to improve at a rapid rate."

Rod has been exclusively growing Roundup Ready varieties for the last three years. He currently grows Hyola 404 Roundup Ready (a Pacific Seeds [now Advanta Seeds] Roundup Ready variety) and Pioneer 43Y23(Roundup Ready) (a Pioneer® Roundup Ready variety), but is considering adding a Triazine Tolerant open-pollinated variety into the rotation on the new block he acquired during 2016 where he suspects there may be glyphosate resistant annual ryegrass populations in some paddocks (see *Tackling high weed burdens* section to follow).

Rod desiccates approximately 30% of his canola crop each year, using 1.8L/ha of glyphosate (540g/L formulation) to control ryegrass escapees and if necessary, uses 2L/ha of glyphosate applied when wheat is at the firm dough stage to control seed set in any wild radish that has survived through to October/November in his wheat crops.

"The RoGator® boom spray we use has crop dividers in front of all four wheels that part the crop and minimise crop damage from wheel traffic," said Rod. "That helps a lot when we go in late into crops to desiccate or crop-top."



Rod also places a very high priority on removing old fence lines, rock heaps, isolated trees, shelter belts and banks that can act as point-sources for weeds.

“Anything that can act as a ‘weed incubator’, as I call them, is removed so we can get over the area with a boom spray,” said Rod. “Or if something can’t be removed, I make sure we come back to these after seeding and spray with a ute-mounted spot-sprayer to make sure there is no weed seed set.”

To reduce wild radish numbers as much as possible, Rod and his workmen spot-spray using utes or quad bikes and hand pull isolated plants.

“My father first began hand pulling radish during the late 1970s when he noticed it appearing in our crops,” said Rod. “It’s something I have continued as a low-cost way of controlling small patches or scattered plants that survive pre- and post-emergent treatments.”

“We concentrate the hand pulling on our home farm which has the lowest wild radish populations due to years of diligent weed control, but as radish numbers are reduced on our newer blocks, it will be something we do more of.”

Tackling high weed burdens

As mentioned above, the Birchs acquired a new 3600ha farm during 2016. Prior to 2016, this block had continuous wheat rotation for at least the previous 10 years.

Rod’s intention is to bring the productivity of this new block in line with the rest of his farm as quickly as possible. He estimates it will take three years to ‘repatriate’ the block, but expects that by the fourth year, he will have his preferred rotations in place, soil pH will be on the improve and there will be a significant change in weed numbers.

“Our newest block has a high weed burden as a consequence of being in continuous wheat for a long time and I would be surprised if it ever had any lime applied,” said Rod. “I want to bring the new block into line with the rest of my farm as soon as possible.”

“To kick-start that process, I applied 2t/ha of lime sand and 400kg of gypsum during February 2016 across the entire block as a basal treatment to start to raise the pH and insure against sulphur deficiency. Then each paddock received the normal in-crop fertilisers at seeding.

“In addition to introducing canola and lupins as break crops on the new block, I needed to have a cereal other than wheat in some paddocks, so I grew barley. I have never grown barley before, but because it is a vigorous grower and tillers well, it is very competitive with weeds. It also offers the opportunity of using higher rates of trifluralin than wheat will tolerate and it tolerates metribuzin, which wheat will not, so barley offered more weed control options.”

Rod acknowledges that the 2016 season was a good one in which to grow barley for the first time.

“For my first ever barley crop, I chose to grow Latrobe,” said Rod. “100% of the crop made malting grade and it yielded an average of 3.2t/ha, something I wasn’t expecting.”

Rod also used very robust herbicide rates during 2016 on all crop types on the new block to knock the weed populations down as fast as possible. This together with his lime, gypsum and potash basal treatment made for an expensive crop on this new block.

“We were lucky that 2016 was a good year and even with these high inputs, the crops on this new block were quite profitable, particularly the canola which averaged 2.4t/ha,” said Rod. “Accepting that higher inputs and extra management is needed to bring the weeds under control, I would have been satisfied just to have broken even with this first crop.”

Rod expects the costs on the new block to be higher than the rest of his farm for the next 3-4 years, but is confident his management approach will lift the productivity of the new block to that of the rest of his farm and bring the weeds under control.

“As we have expanded our farming business, I have purchased weedy blocks several times in the past and with careful management of rotations, soil pH, weed seed management, herbicide choice, application rates and timing, I have been able to cost-effectively reduce weed numbers on those blocks while ensuring that I don’t end up with herbicide resistance,” said Rod. “I get real pride out of seeing weed numbers go down and profitability go up.”

Rod acknowledges that should the test results he is waiting on show that the ryegrass populations on his newest block are resistant to glyphosate, he will have an additional challenge in achieving the weed-free crops he desires. He is confident that by adopting the recommendations of the AHRI and other researchers, with careful management he will be able to manage glyphosate resistant ryegrass.

“Grain growing in a dryland farming system is always going to be a challenge,” said Rod. “With the incredible resources we have available through our research organisations such as GRDC, and an appetite to apply good science along with sound management, we have the foundation to remain profitable and globally competitive.”

ADDITIONAL READING



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References and additional reading

The following general references are cited in the Background section above or are considered valuable additional reading on soil acidity and weed management.

Where references apply to a specific grower case study, they are listed at the end of the relevant case study.

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GRDC. The effectiveness of on-farm methods of weed seed collection at harvest time: Case studies of growers in the Albany Port Zone. www.grdc.com.au/Resources/Publications/2013/10/The-effectiveness-of-onfarm-methods-of-weed-seed-collection-at-harvest-time

GRDC. Integrated Weed Management Hub. www.grdc.com.au/Resources/IWMhub Extensive source of technical and case study information on herbicide resistance and integrated weed management

GRDC. Mal and Justin King, Bindi Bindi: surface and deep-placement liming www.agric.wa.gov.au/soil-acidity/case-studies-soil-acidity-management?page=0%2C2

GRDC. Over the Fence West: Innovation proves to be a long lasting winner for WA farmer. Stuart Smart, 'Erragulla Plains', Mingenew. Mouldboard ploughing. www.grdc.com.au/OTF-StuartSmart

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Lime WA Inc. website. Independently audited lime suppliers. www.limewa.com.au

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Weed reference table	
Common name	Scientific name
Afghan melon	<i>Citrullus lanatus</i>
Afghan thistle	<i>Solanum hoplopetalum</i>
Annual ryegrass	<i>Lolium rigidum</i>
Bluebush	<i>Maireana brevifolia</i>
Blue lupins	<i>Lupinus cosentinii</i>
Brome grass	<i>Bromus diandrus</i> and <i>Bromus rigidus</i>
Button grass	<i>Dactyloctenium radulans</i>
Caltrop	<i>Tribulus terrestris</i>
Capeweed	<i>Arctotheca calendula</i>
Couch grass	<i>Cynodon dactylon</i>
Doublegee	<i>Emex australis</i>
Mintweed	<i>Salvia reflexa</i>
Mulla mulla	<i>Ptilotus polystachyus</i>
Paddy melon	<i>Cucumis myriocarpus</i>
Roly poly	<i>Salsola tragus</i> L. var. <i>kali</i> .
Tar vine	<i>Boerhavia coccinea</i> , <i>Boerhavia dominii</i> and <i>Boerhavia schomburgkiana</i>
Wild radish	<i>Raphanus raphanistrum</i>
Wild turnip	<i>Rapistrum rugosum</i>
Windmill grass	<i>Chloris truncata</i>

