01

Maintaining profitable farming systems with retained stubble across various rainfall environments in SA, Victoria and central and southern NSW

GRDC Project codes – GRDC CSP00174, EPF00001, BWD00024, YCR00003, MFM00006, CWF00018, RPI00009, LEA00002 plus collaboration with SFS00032 & DAS00160

Project Partners

Funding Partners

Trial Site Location

5 km SSE of Temora

Report Authors

Tony Swan, Clive Kirkby, Brad Rheinheimer (CSIRO Agriculture), Paul Breust (SFS), Claire Brown (BCG), James Hunt (CSIRO Agriculture, (La Trobe University (current address)), Kellie Jones (FarmLink Research), Helen McMillian (CWFS), Sarah Noack (Hart Field Site Group), Trent Potter (Yeruga Crop Research), Cassandra Schefe (Riverine Plains), Amanda Cook, Blake Gontar, Michael Nash, Naomi Scholz (SARDI), Felicity Turner (MFMG) and John Kirkegaard (CSIRO Agriculture)

Introduction

Following a GRDC review that identified gaps regarding the impact of stubble retention in southern cropping systems, a five year program was initiated by GRDC in 2014. Ten projects comprising 16 farming systems groups and research organisations which include FarmLink Research, BCG, CSIRO, CWFS, EPARF, Hart Field Site group, ICC, LEADA, MFMG, MSF, Riverine Plains, SARDI, UNFS, VNTFA, Yeruga Crop Research are currently involved in exploring the issues that impact on the profitability of retaining stubbles across a range of environments in southern Australia with the aim of developing regional guidelines and recommendations that assist growers and advisors to consistently retain stubbles profitably.

Take home messages

- In 2017, don't let stubble compromise the big things (weeds, disease, timeliness)
- If the intent is to retain stubble:
- Pro-actively manage the stubble for your seeding system
- Diversify (add legumes to rotation), deep band N and manage invertebrates. Mice could also be a major problem
- For tined seeders, reduce stubble load by mulching, incorporation + nutrients, baling, grazing and consider sowing at 15-19 degree angle to previous sown row
- If stubbles are too thick to sow through, consider strategic late burn, especially before second wheat crop or if sowing canola into large stubbles
- Early monitoring is essential to see how effective actions are to allow for re-planning

Report One

Stubble management options

Background

In 2016, grain yields were high across most of southern and south-eastern Australia, with many cereal crops yielding $\geq$ 5t/ha and often up to 8t/ha which indicates there will be a residual stubble load of 7.5-12 t/ha. This paper examines two main management options to deal with high stubble loads ($\geq$ 5t/ha) in 2017, and incorporates many of the main findings from the stubble initiative to date.

Option 1: How to manage stubble if you plan to retain the stubble at all costs

- Tine seeder options

1. Harvest high ($\geq$30cm) and mulch or incorporate

2. Harvest low ($\leq$ 20cm), use chopper/power spreader to smash and spread straw evenly across swath at harvest or soon afterwards

- Disc seeder

Stripper fronts/harvest high, good diverse rotation

Option 2: How to manage stubble if you have a flexible approach to retaining stubble

Harvest big crops high, graze, burn, bale straw as necessary to reduce stubble to amounts that sowing equipment can manage. Focus on reducing stubble in paddocks where the stubble is likely to impact the 2017 crop yield e.g. wheat on wheat paddocks.

It has been well documented that to successfully establish a crop into a full stubble retained system requires an integrated management approach incorporating three main stages of stubble management - pre-harvest, post-harvest/pre-sowing, and finally at sowing (ref 1,2,3,4,5,6). During these periods, a series of questions (some outlined below) will need to be addressed by farmers to successfully establish a crop (ref 4).

- What is my preference for tillage system?
- What is my seeding system?
- What is my row spacing and accuracy of sowing?
- What crop will be planted into the paddock in 2017?
- What is the type of crop residue?
- What is the potential grain yield and estimated amount of crop residue?
- Is the crop lodged or standing at harvest?
- What is the desired harvest speed and harvest height?
- How uniform is the spread of straw from my harvester?
- Should I spread residue or place in a narrow windrow?
- Do I have a weed problem which requires intensive HWSC, chaff carts or chutes?
- Will the stubble be grazed by livestock?
- Am I prepared to process stubble further post-harvest: mulch, incorporate, bale?
- If incorporating stubble, should I add nutrients to speed up the decomposition process?
- What is the risk of stubble-borne disease to the 2017 crop?
- Am I likely to encounter a pest problem in 2017: mice, slugs, earwigs, weevils, snails?
- What is the erosion risk based upon soil type and topography?
- Do I need to burn or what else can I do?

Prior to harvest, all crops should be assessed to estimate grain yield, potential stubble load and weed issues. The GRDC Project YCR00003 is developing an App to assist farmers and consultants. As a rule of thumb, the stubble load following harvest will be approximately 1.5 to 2 times the grain yield for wheat and between 2 to 3 times the grain yield for canola (ref 4, 5, 6).

Remember, there is no perfect stubble management strategy for every year. Crop rotations, weeds, disease, pests, stubble loads, sowing machinery and potential sowing problems will largely dictate how stubble should be managed.

Option 1: How to manage stubble if you plan to retain the stubble at all costs

A recent survey was undertaken in the Yorke Peninsula and Mid-North of SA which showed that 82% of farmers use tined seeders, with the remaining 18% using discs (Yeruga Crop Research).

About 21% of farmers were totally committed to retaining stubbles at all costs while about 79% would consider burning stubbles if absolutely necessary.

In relation to establishing a crop in stubble retained systems, the following issues were extremely important -

- Herbicide efficacy was extremely important (80+% in both tine and disc);
- Managing weeds (approx. 65% both tine and disc);
- Managing slugs and snails (> 50% in tine and disc);
- Efficiency and ease of sowing (82% in tine and 58% in disc);

The following were more important at seeding -

- Straw length (70% tine)
- Chaff fraction (50% disc)
- Hair pinning (15% tine, 84% disc)

Stubble height

Using a stripper front or harvesting high is the quickest and most efficient method to produce the least amount of residue that needs to be threshed, chopped and spread by the combine. Harvesting high (40-60 cm) compared to 15 cm increased grain yield and combine efficiency by reducing bulk material going through the header and reduced harvests costs by 37 to 40% (Table 1). As a general rule, there is a 10% reduction in harvest speed for each 10cm reduction in harvest height (Tables 1 and 2, ref 4, 5, 8). Slower harvest speed across a farm also exposes more unharvested crop to the risk of weather losses (sprouting, head/pod loss, lodging) during the harvest period, and the cost of this is not accounted for in Table 1.

However, there are some negatives to retaining tall wheat stubble, with several groups in the initiative finding that wheat sown into taller wheat stubble (45cm cf 15cm) received less radiation and were exposed to cooler temperatures. This can reduce early growth and significantly reduce tiller numbers. In a Riverine Plains experiment in 2014, there was a significant reduction in grain yield (4.98t/ha cf 5.66t/ha with lsd @ P<0.05 = 0.45t/ha) in tall compared to short stubble. In 2015 the group found no difference in grain yield. In 2016, significantly less tillers were found in several trials in tall stubble, however in all of these trials, this did not result in any difference in grain yield.

Harvest height	Efficiency (ha/h)	Speed (km/hr)	Fuel (l/ha)	Yield (t/ha)	Cost $/ha	Cost $/ton
60cm	9.5	10.6	10.6	5.4	$63.2	$28.7
15cm	5.7	6.2	6.2	9.6	$105.3	$50.1
% Change to 15cm	-41%	-42%	-42%	+78%	+40%	+57%

Table 1: Harvesting wheat low or high using a JD9770 combine in 2014 (Ref 7). Ground speed was altered to achieve similar level of rotor losses at both harvest heights. Values are means of three replicates STS yield monitor and all differences are significant (P<0.05). Operating costs determined at $600/hr.

Harvest height	Efficiency (ha/h)	Speed (km/hr)	Fuel (l/ha)	Harvest efficiency (t/hr)	Grain Yield (t/ha)	Cost $/ha	Cost $/ton
40cm	12.0	8.5	6.6	45	3.8	$50.0	$13.5
15cm	7.5	6.0	10.6	30	3.9	$80.0	$20.2
% Change to 15cm	-38%	-29%	+61%	-33%	ns	+37%	+33%

Table 2: Harvesting wheat low or high using a Case 8230 combine with a 13m front in 2015 (ref 7). Ground speed was altered to achieve similar level of rotor losses at both harvest heights. Operating costs determined at $600/hr.

(ns = no significant difference)

In 2016 like many previous years, herbicide resistant weeds, especially annual rye grass (ARG) continue to be a problem. Harvest weed seed control (HWSC) which includes narrow windrow burning, chaff carts, chaff lining, direct baling, and mechanical weed seed destruction is an essential component of integrated management to keep weed populations at low levels and thus slow the evolution and spread of herbicide resistance. HWSC requires crops to be harvested low in order for weed seeds to be captured in the chaff fraction from the combine, and if practised, provides an additional reason to harvest low. The prototype Integrated Harrington Seed Destructor (iHSD) was tested in Temora, NSW in December 2015, Inverleigh in December 2015 and Furner, SA in January 2016 at a constant speed of 4km/hr to compare the efficiency and cost with non-weed seed destruction methods (Table 3). The three large scale field trials in both states are being monitored for changes in annual ryegrass populations before and after sowing between 2015 and 2018.

In 2016 there has been less opportunity to harvest cereal crops very high in many areas due to lodged or leaning crops, and variable head heights. Cereal crops such as Compass barley often lodged badly resulting in the need to harvest very low.

A full report on the Harvest Weed Seed Control in the Southern Region project appears in this Research Report.

	Harvest height	Grain Yield (t/ha)	Speed (km/hr)	Engine Load (%)	Fuel (l/ha)	Fuel Efficiency (l/hr)
Conventional Harvest - Burn	30cm	4.7	3.8	59.8	14.3	52.7
Windrow	5.7	6.2	6.2	9.6	$105.3	$50.1
Bale/burn	15cm	4.6	4.0	65.5	16.4	59.5
iHSD	15cm	4.6	4.0	88.7	22.7	87.8
lsd @ P<0.05)		ns	ns	2.26	1.36	2.18
% Change to 15cm				+9%	+11%	+11%
% change to iHSD				+33%	+37%	+40%

Table 3: A Case 9120 harvesting wheat conventionally at 30cm, harvesting at 15cm for baling or narrow windrow burning and harvesting at 15cm with a prototype iHSD at Furner, SA in 2016. (Data supplied by GRDC project SFS00032)

MULCH and incorporate

Lightly incorporating the stubble into the surface soil using a disc chain or disc machine (i.e. Speed Tiller, Grizzly, Amazone Cattross, Vaderstad Topdown or Lemken Heliodor) soon after harvest while the stubble is higher in nutritional value is another option for farmers wanting to maintain all of their stubble, especially where a tined seeder is the primary sowing implement, or where lime and stubble needs to be incorporated into the soil in a disc-seeding system. On the lighter sandier soils in SA, the recommendation would be to delay incorporation until 3-4 weeks before seeding as these soils are more prone to wind and water erosion. Mulching and incorporation requires soil moisture, warm soil temperature, soil/stubble contact and nutrients to convert a carbon rich feed source into the humus fraction. Early mulching and incorporation allows time for the stubble to decompose and immobilise N well before sowing, reducing the likelihood of reduced N availability.

When trying to decompose a large quantity of stubble in a short period of time (i.e. to convert stubble into humus), it may be beneficial to add some nutrients to the stubble prior to incorporation. To assist in minimising the amount of fertiliser required to add to the stubble, determining the concentration of the nutrients in the stubble is important. As humus is so nutrient rich and the stubble residues are relatively nutrient poor, only a small proportion of the total carbon in the crop residues can be converted into humus. Dr Clive Kirkby has found that a maximum of 30% of the total carbon from stubble residues could be converted to humus, so recommends lowering the humification rate to 20% rather than 30%. In our example (Table 4), the quantity of fertiliser (sulphate of ammonia) that would need to be applied to the 10t/ha residual cereal stubble load where the stubble had a nutrient concentration of 0.7%N, 0.1%P and 0.1%S and the farmer wanted a humification rate of 20% would

Stubble Nutrient Humification Calculator		C	N	P	S
Stubble load (kg/ha)	10000				
Humification required (%)	20				
Stubble nutrient concentration (%)		45.0	0.700	0.100	0.100
Nutrients already in stubble (kg/ha)		4500	70	10	10
Carbon to be humified & nutrients required (kg)		900	77.0	9.2	11.7
Carbon remaining (kg)		3600			
Extra nutrients required (kg/ha)			7.0	-0.8	1.7
1. Fertiliser type and Nutrient concentration (%)	SOA		21.0		24.0
2. Fertiliser type and Nutrient concentration (%)					
Fertiliser required to supply exact nutrients (kg/ha)			33		7
Fertiliser cost ($/ha)			$14.9		
Fertiliser and spreading cost ($/ha)			$23.4		

(Financial support provided by NIEI, EH Graham Centre, CSIRO and GRDC project DAN00152)

be 33.1kg/ha of nitrogen and 7kg/ha of sulphur at an estimated cost of $14.90/ha for nutrients only. In contrast, if a farmer was trying to build up their organic carbon concentration in the soil from this stubble residue to the maximum possible amount (30% humification rate), the quantity of nutrients required increases to 45.4kgN/ha, 3.8kgP/ha and 7.6kgS/ha, at a cost of $74.40 for nutrients (Table 5). The nutrients applied are not lost, but should form a source of slow release nutrition to the following crop while avoiding "nutrient tie-up" caused by late incorporation of nutrient poor residues. Thus, later inputs could potentially be reduced if costs were of concern.

In an experiment at Harden, NSW between 2008 and 2011, Dr Kirkby incorporated between 8.7 and 10.6 t/ha of cereal or canola stubble without nutrients or with nutrients at a humification rate of 30%. In May 2009, following the incorporation of 8.7t/ha wheat stubble in February 2009, they measured the quantity of wheat stubble that had broken down and found that only 24% of the stubble remained where nutrients had been added whereas 88% remained where the stubble had been incorporated only (Kirkby et al. 2016). A couple of groups (Riverine Plains, MFMG) have included light incorporation (+/-) nutrients in their treatment mixes. Although no group specifically examined residue breakdown, they found that the cultivated (+ nutrient) treatment often yielded the same or more than cultivated (no added nutrient) treatment (i.e. Wheat grain at Yarrawonga January 2017 in Cultivate +40kgN/ha = 6.7t/ha compared to Cultivate only = 5.9t/ha, lsd = 0.58).

Stubble Nutrient Humification Calculator		C	N	P	S
Stubble load (kg/ha)	10000				
Humification required (%)	30				
Stubble nutrient concentration (%)		45.0	0.700	0.100	0.100
Nutrients already in stubble (kg/ha)		4500	70	10	10
Carbon to be humified & nutrients required (kg)		1350	115.4	13.8	17.6
Carbon remaining (kg)		3150			
Extra nutrients required (kg/ha)			45.4	3.8	7.6
1. Fertiliser type and Nutrient concentration (%)	Urea		46.0		
2. Fertiliser type and Nutrient concentration (%)	Single super			8.8	11.0
Fertiliser required to supply exact nutrients (kg/ha)			99	43	69
Fertiliser cost ($/ha)				$74.4	
Fertiliser and spreading cost ($/ha)				$82.9	

(Financial support provided by NIEI, EH Graham Centre, CSIRO and GRDC project DAN00152)

Cropping system	Crop Type	Average Total Cost 2014-16	Average Net Margin 2014-16	Average 3yr Profit: Cost ratio
		($/ha/yr)	($/ha/yr)	($/ha/yr)
Aggressive	Canola RR	$524	$722	1.4
Aggressive	Wheat (yr 1)	$525	$378	($/ha/yr)
Aggressive	Wheat (yr 2)	$504	$394	1.4
Conservative	Canola TT	$452	$694	2.26
Conservative	Wheat (yr 1)	$415	$289	+9%
Conservative	Wheat (yr 2)	$419	$261	1.5
Sustainable	Vetch (Hay)	$463	$416	
Sustainable	Canola TT	$426	$769	1.5
Sustainable	Wheat	$492	$422	
Sustainable	Barley	$478	$441	0.6
SYSTEM AVERAGES				0.9
Aggressive		$517	$498	1.8
Conservative		$429	$415	0.9
Sustainable		$465	$512	1.0

Table 6: Average net margins (EBIT) – effect of crop strategy at Temora, NSW, 2014-2016

Diverse cropping sequence

A diverse cropping sequence provides many benefits for farmers wanting to retain all their stubble annually. Diversity allows each crop to be sown into a less antagonistic stubble by reducing physical, disease, pest and weed constraints.

A fully phased systems experiment was established in Temora in 2014 at a site with high levels of Group B resistant ARG to examine if a diverse crop rotation ('sustainable' - vetch hay-TT canola-wheat-barley) could improve the profitability of stubble retained no-till (Flexi-Coil tine seeder with Stiletto knife points and deep banding and splitting boots) and zero-till (Excel single-disc seeder with Arricks' wheel) systems. Three cropping systems (aggressive, conservative and sustainable) were compared with the rotations for each as aggressive (RR canola-wheat-wheat), conservative (TT canola-wheat-wheat) and sustainable (as above). In the cereal crops in the aggressive and sustainable system, new-generation pre-emergent herbicides (Sakura® and Boxer Gold®) were used for grass weed control. In the conservative system, trifluralin and diuron were used for grass weed control in the tine system, and diuron alone in the disc system.

The introduction of diversity in the sustainable system has allowed it to achieve a net margin ($512/ha/year) which is higher than in the aggressive systems ($498/ha/year) and at lower cost ($465 cf $517/ha/year) and thus higher profit:cost ratio ($1.12 cf $0.98) (Table 6). The reduced costs in the sustainable system are driven by lower fertiliser N inputs from the inclusion of vetch hay, which requires no fertiliser N itself and provides residual N for subsequent crops. The barley phase of the sustainable system has also been more profitable than the second wheat crop in either the aggressive or conservative system (Table 6), despite record low barley prices in this 2016/17 season.

The Riverine Plains group compared a wheat-faba bean-wheat rotation against a wheat-wheat-wheat (+/- burning) and found there was no significant difference in wheat yield following wheat stubble that was retained or burnt (average 3.42t/ha), but there was a 2t/ha increase in wheat yield following faba beans. The wheat stubble also acted as a trellis assisting to keep the beans off the ground and improve airflow and the higher nitrogen concentration following the bean crop combined with the increased decomposition of the wheat stubble resulted in the bean crop "resetting" the system and burning was not required. Similar findings have been observed by the Hart Field Site group in relation to lentils using the wheat stubble as a trellis. Earlier maturing varieties such as Blitz were found to be taller with increasing stubble height (30 and 60cm stubble height cf 15cm or baled). They also found that the type of stubble was important for the following crop, with wheat maintaining its supportive structure better than barley.

Margin	Net Margins 2014 ($/ha)		Net Margins 2015 ($/ha)		Net Margins 2016 ($/ha)		Average Net Margins 2014-2016 ($/ha/yr)		Profit:Cost ratio 2014-2016	
Seeder	Tine	Disc	Tine	Disc	Tine	Disc	Tine	Disc	Tine	Disc
Aggressive	$424	$422	$569	$591	$533	$449	$508	$487	$0.98	$0.94
Conservative	$441	$171	$540	$463	$537	$336	$506	$323	$1.14	$0.75
Sustainable	$488	$493	$520	$525	$552	$495	$520	$504	$1.14	$1.10

Table 7: Average net margins across all crop types for each crop system by opener type between 2014 and 2016 at Temora, NSW.

Establishing crops with disc and tined seeders

It has been well documented that a disc seeder can handle higher stubble loads in comparison to a tined seeder, have less variability in seeding depth and higher sowing efficiencies than a tined seeder. Over the three year trial at Temora, there has been little difference in the net margin of either the disc or tine openers where ARG was effectively controlled by pre-emergent herbicides in the aggressive and sustainable cropping systems. However, in the conservative system, the combination of trifluralin and diuron were able to achieve a reasonable ARG control in the tined system, but diuron alone was largely ineffective in the disc system, and this has reduced yields and profit in this system (Table 7).

Southern Farming Systems have been comparing the advantages of establishing crops with a disc and tined seeder over the past 3 years. They found that although there was no significant difference in wheat yield at the 95% confidence level (0.5 t/ha increase in yield at the 90% confidence level), there were significant improvements in efficiencies in the disc system with quicker sowing, quicker harvesting (harvest high) and fuel savings in 2015 (Table 8). It must be remembered that both types of seeders have advantages and disadvantages in different circumstances and the main aim is to establish seed reliably in a wide range of sowing conditions!

	Sowing	Harvest time	Fuel Usage
Disc vs tine	4.8km/hr faster*	1.81 ha/hr faster#	2.11 L/ha##
Value of difference	$2.10	+$13.23	$2.53

Table 8: Cost calculations for sowing efficiency, harvest efficiency and fuel usage in a Southern Farming Systems disc vs tine trial in Victorian HRZ in 2015.

Deep banding vs surface applied Nitrogen at sowing

One mechanism by which large amounts of retained cereal stubble can reduce yields in subsequent crops is through immobilization of N. Banding N fertiliser either at sowing using a deep, side or mid-row banders or in-crop using mid-row banders is a way of separating fertiliser N from high carbon stubble that microbes use as an energy source when immobilising N. In 2016, an experiment was established at Temora on 5.1 t/ha of retained wheat stubble where 122 kg/ha N as urea was either banded beside and below wheat seed using Stiletto splitting boots, or spread on the soil surface before sowing with the same boots. Starting soil mineral nitrogen concentration was 58 kg/ha N (0-150cm) and no additional nitrogen was applied. By Z30 more nitrogen had been taken up by the plant where the N was deep banded (4.3% cf 3.8%), a pattern which continued with greater plant dry matter and nitrogen uptake at anthesis and higher grain yield (Table 9). However, there was no significant interaction with the presence/absence of stubble, indicating that banding N may improve N use efficiency in all systems (with or without stubble).

		GS30	GS30	GS30	Anthesis	Anthesis	
Pre-sowing Nitrogen Application	Emergence	Plant Dry Matter	Plant Nitrogen	Nitrogen uptake	Plant Dry Matter	Nitrogen uptake	Grain Yield
	Plants/m^2	(t/ha)	(%N)	(kgN/ha)	(t/ha)	(kgN/ha)	(t/ha)
Deep	132	1.4	4.3	60.0	9.2	136.4	5.2
Surface	137	1.4	3.8	51.6	7.9	102.5	4.1
P value (interaction)	0.257	0.570	0.016	0.074	<0.001	0.007	0.001
lsd (P<0.05)	ns	ns	0.394	ns (9.58)	0.3	17%	0.43

Table 9: Wheat (Lancer) emergence, dry matter, % nitrogen in the tissue, nitrogen uptake and grain yield where 122kgN/ha was applied at sowing either below the seed using stiletto points or on the surface pre-sowing into either 5.1t/ha of wheat stubble or where stubble was removed at Temora in 2016.

Option 2: How to manage stubble if you have a flexible approach to retaining stubble

There are many reasons why a flexible approach to retaining stubble may be required as there is no perfect stubble management strategy for every year. Crop rotations, weeds, disease, pests, stubble loads, sowing machinery and potential sowing problems will largely dictate how stubble is managed

A flexible approach to manage stubble means crops can be harvested high or low depending on the season and situation, stubbles can then be grazed with considerable economic advantage, or straw baled and sold, or burnt.

Grazing

For mixed farmers, the option to graze the stubble soon after harvest can be quite profitable. In a long term no-till controlled traffic grazing experiment in Temora between 2010-2015 with crop rotation of canola-wheat-wheat, four treatments were compared including a full stubble retention system (nil graze, stubble retain) and a post-harvest grazing of the stubble (stubble graze, stubble retain). Each of these were split to accommodate a late burn pre-sowing (i.e. nil graze, stubble burn and stubble graze, stubble burn) (Table 10). All plots were inter-row sown with deep knife points and machinery operations conducted using controlled traffic. Stubble grazed plots were grazed within 2-3 weeks of harvest at approx. 300 DSE/ha for five days ensuring > 3t/ha remained for soil protection and water retention. All plots were sown, fertilised and kept weed free such that weeds, disease and nutrients did not limit yield. Over seven years, the experiment has shown that there is a $44/ha increase in gross income where sheep were used to graze the stubbles compared to nil grazing if no grazing value was assumed. This increase was related to higher yields and grain quality in subsequent crops driven by greater N availability in the grazed stubble. There was a $159/ha increase if a grazing value for the stubble was assumed (see GRDC paper 2015 Hunt et al. for details).

Graze treatment	Stubble treatment	Gross income ($/ha/year)	
Nil graze	Retain	$1,153	$1,153
	Burn	$1,179	$1,179
Stubble graze	Retain	$1,197	$1,312
	Burn	$1,193	$1,307

Table 10: Gross income per year averaged across two phases where stubble was either grazed post-harvest or not, and either burnt just before sowing or retained, 2010-2015 at Temora, NSW.

		Grain Yield 2009-2016							
Phase	Stubble Treatment	2009	2010	2011	2012	2013	2014	2015	2016
1	Retain	1.7	4.2	4.6	**4.4**	0.7	3.8	**4.1**	3.2
1	Burn	1.7	4.0	4.6	**5.0**	1.0	3.8	**4.6**	3.2
2	Retain		6.3	3.4	4.5	**2.0**	2.0	5.5	**5.2**
2	Burn		6.2	3.5	4.8	**3.4**	2.0	5.3	**5.7**
	Red = Canola crops					frost			

Table 11: Grain yield of wheat and canola sown using deep knife points in two phases between 2009 and 2016 where stubble was either retained or burnt (pre-sowing) at an experiment in Temora, NSW.

Similar results were observed in a crop systems experiment where wheat (first wheat) was either sown into canola stubble or into 7.2 t/ha wheat stubble (second wheat) in April 2016. The wheat was deep banded with 40kgN/ha at sowing in both treatments to assist in supplying N to the crop, however, there was a 0.6-0.8t/ha reduction in wheat yield in the second wheat crop (Table 12). Many farmers in the south west slopes also observed decreases in the grain yield of their second consecutive wheat crop compared to wheat sown after canola in 2016 in stubble retained systems.

Cropping system	Crop	2016 Disc	2016 Tine
Aggressive	Wheat (yr 1)	5.5	6.0
Aggressive	Wheat (yr 2)	4.9	5.3
P value = <0.001	lsd (P<0.05)	0.54	

Table 12: Wheat grain yield in crop following canola (wheat yr 1) compared to second wheat crop at crop systems experiment at Temora, NSW 2014-2016 in disc and tines x systems

Computer applications (Apps) for stubble management

GRDC Project YCR00003, led by Yeruga Crop Research is finalising a computer/smart phone application (App) which may be of great benefit to farmers and consultants. It provides a quick and efficient method to indicate what the benefit or cost could be for different stubble management decisions such as narrow windrow burning, burning or baling a crop to reduce stubble. A couple of examples are highlighted below for narrow windrow burning (Figure 1) and baling (Figure 2) the stubble from a 5t/ha wheat grain crop.

For more information, contact Yeruga Crop Research. The tool was developed by Stefan Schmitt in conjunction with Bill Long, Mick Faulkner, Jeff Braun and Trent Potter.

Narrow windrow burning (NWB): NWB has been practiced for several years now and has proven to be an effective tool in reducing weed seeds. One advantage of NWB compared to entire paddock burn is the reduction in nutrients lost from the stubble residue. The stubble management optimiser indicates that approximately $22.60/ha is lost from the paddock if NWB compared to approximately $76/ha if the entire paddock is burnt (Figure 1). One constraint with narrow windrow burning as AHRI indicated, would be the increased risk if the wheat grain yield was greater than 2.5t/ha (> 4t/ha stubble residue). In 20114/15 NWB was successfully undertaken in wheat crops between 3-3.75t/ha with an estimated stubble load of 4.5-6t/ha in the Riverina, NSW (Grassroots Agronomy 2014). Due to the high stubble loads in 2016/17, narrow windrow burning may be restricted to canola stubbles and other lower DM crops. It must be acknowledged that a wet cool autumn can severely reduce the efficiency of burns leading to weed strips in the paddock.

Baling: In many areas across southern Australia, a significant area of stubble has been baled in 2016/17 season. Baling allows the farmer to harvest high and efficiently (use stripper front if possible), and reduce the stubble load in the paddock to minimise problems at sowing. One of the negatives of baling stubble is the loss of nutrients from the paddock. The stubble management optimiser shows the farmer the cost to make hay including the cost of nutrient loss (Figure 2).

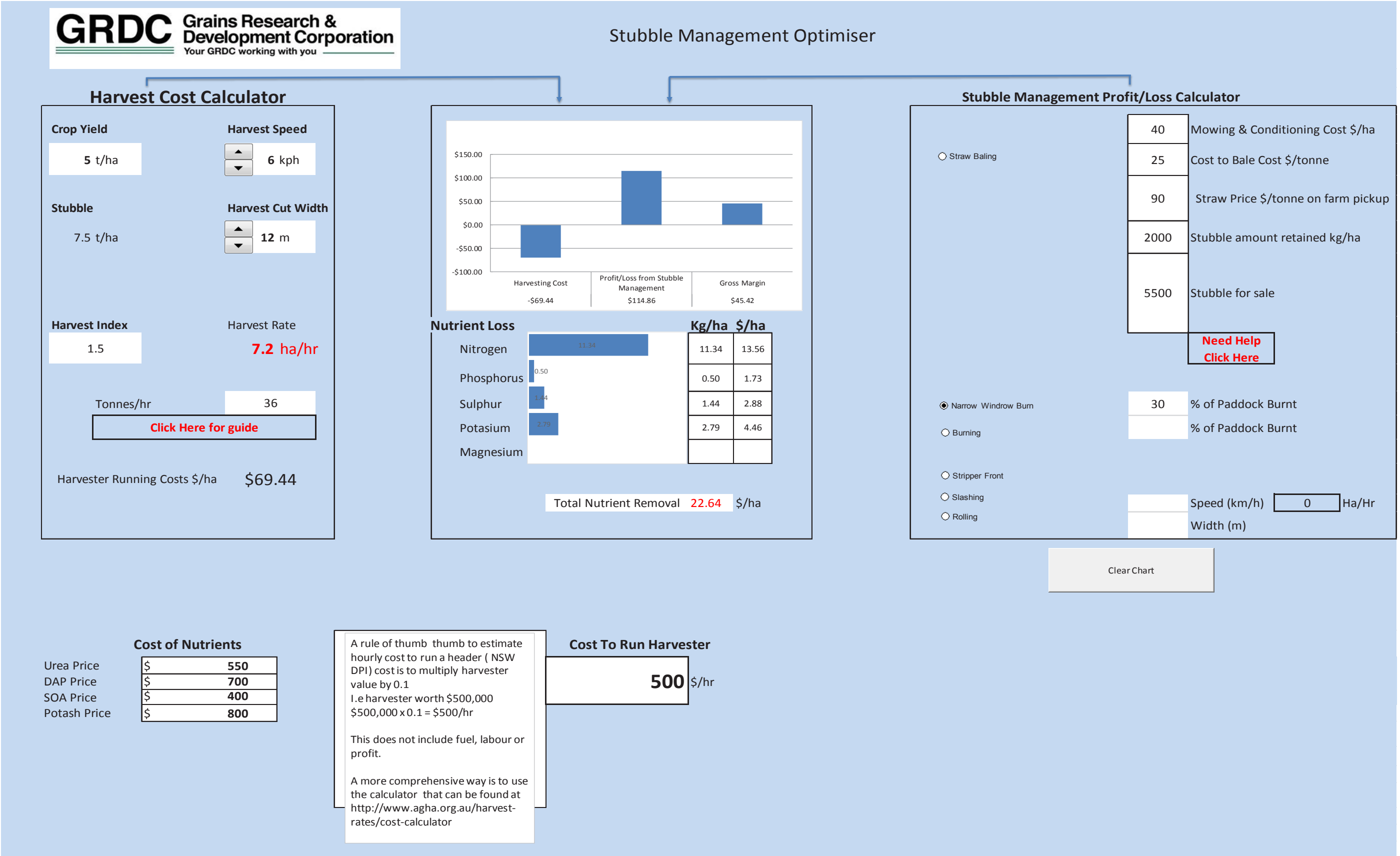


Figure 1: The estimated effect on profit from harvesting a 5t/ha wheat yield with 7.5t/ha stubble load remaining that is narrow windrow burnt, valuing the loss of nutrients.

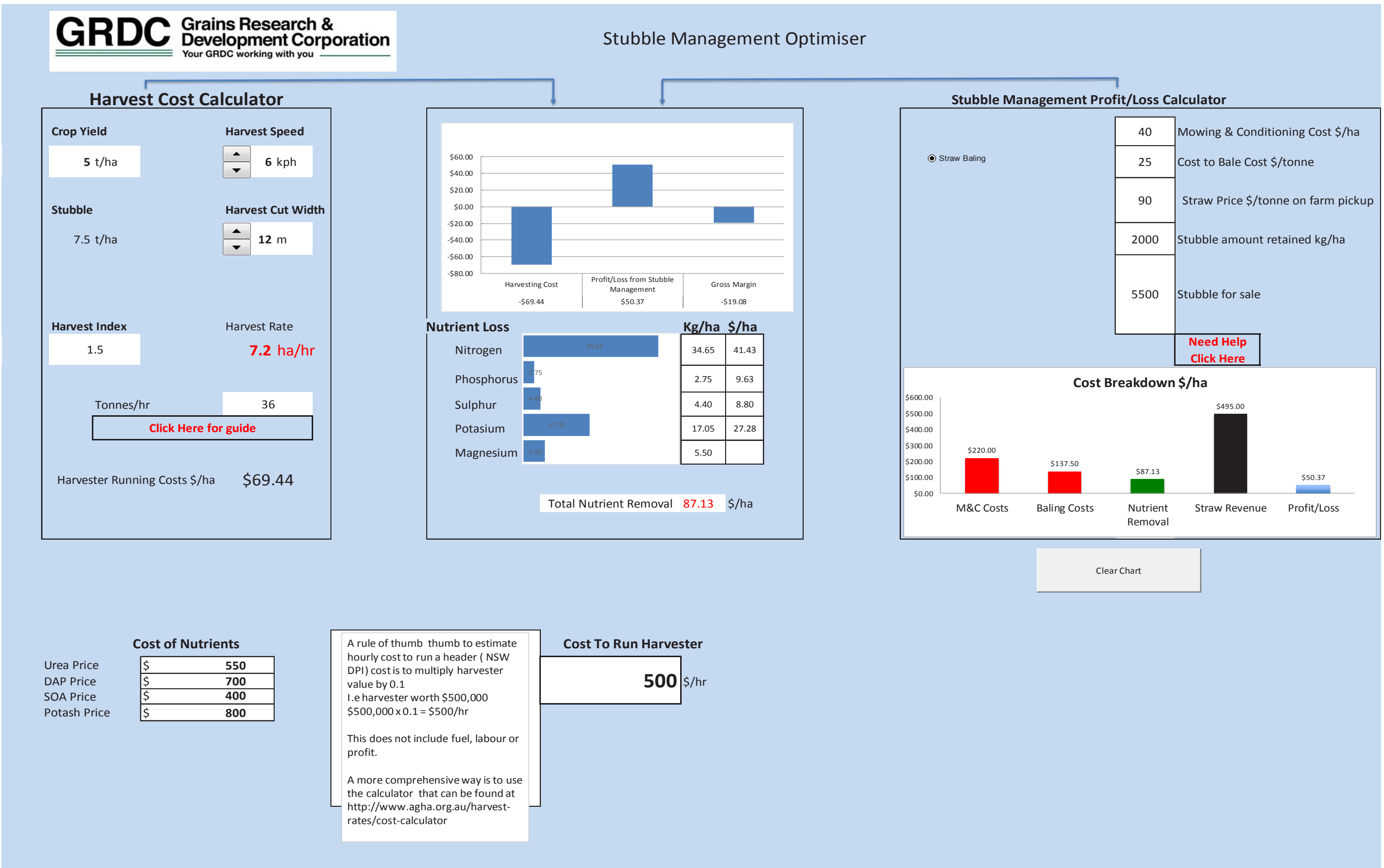


Figure 2: The estimated effect on profit from harvesting a 5t/ha wheat yield with 5.5t/ha of the remaining 7.5t/ha stubble load being baled and sold (valuing the loss of nutrients).

Pests

Invertebrate and vertebrate pests will potentially be a major problem in 2017, and may in some cases provide justification for strategic burning and tillage. Snails, slugs, mice and other insect numbers are currently being monitored and the cool wet spring has provided excellent conditions for increased numbers. The large stubble loads and plentiful grain on the ground from shedding and harvest losses is providing an excellent environment for breeding, so this needs to be factored into the equation if retaining stubble in 2017. Monitor mice numbers after harvest and bait as required.

The wet cool spring in the Victorian HRZ has resulted in an increase in the population of slugs and earwigs pre-harvest. The populations of slugs (Figure 3) and earwigs are expected to pose a greater threat to establishing crops in 2017 (Figure 3). Plan to roll then bait at sowing for slugs, monitoring problem areas and keep baiting if using cheap bran based baits. More information on slug and snail baits may be found at: http://www.pir.sa.gov.au/__data/assets/pdf_file/0004/286735/Snail_and_slug_baiting_guidelines.pdf

Snails: A field trial on the Lower Eyre Peninsula, SA demonstrated the benefits of using mechanical snail control methods over retaining tall standing stubble – either light tillage or heavy (ribbed) rolling – in conjunction with a baiting strategy (Figure 4). Carried out under optimal conditions (late February, 35°C + and low humidity) the mechanical treatments proved effective to reduce snail numbers initially, whilst also appearing to improve the accessibility of baits applied in March.

This project demonstrated a number of key points for the coming growing season. Mechanical rolling, light tillage or cabling in the right conditions (hot and dry) is an effective action which can reduce the breeding population before a crop is present when there is less time pressure from other tasks (Figure 4). Baiting efficacy after this mechanical strategy is likely to be improved, as snails will find the baits easier in a rolled/tilled surface, rather than where tall stubbles remain, providing "bridges" for snails over and around baits.

Baiting should not be applied during the same hot, dry conditions as cultural controls. Baiting should commence during moist, cool conditions. The same field trial incorporated time lapse video and micro weather station monitoring to monitor snail activity and found high levels of night time activity where RH went above 85-90 %, and feeding during wet periods in early March. The key with all management strategies is to try to reduce the breeding population prior to reproduction. This research showed snails feeding and increasing sexual maturity during March with egg laying taking place April 21st – prior to the break of season and seeding. Baiting at seeding may be too late where snails have already laid eggs. For further information http://www.pir.sa.gov.au/research/services/reports_and_newsletters/pestfacts_newsletter/pestfacts_issue_15_2016/summer_snail_activity_and_control

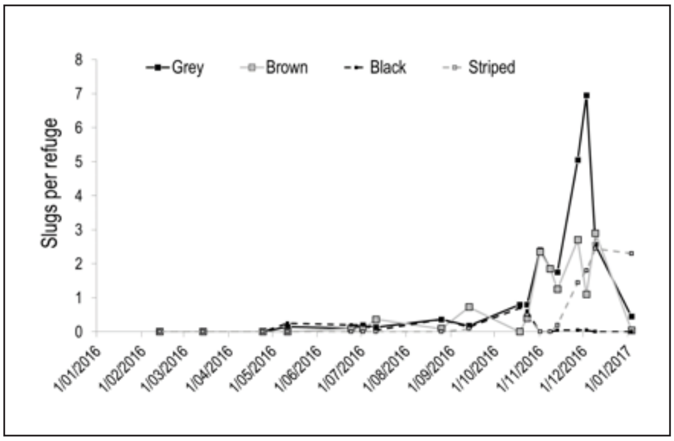


Figure 3: The change in population of four slug species between May 2016 and January 2017 at one site in south west Victorian (GRDC slug ecology project DAS00160)

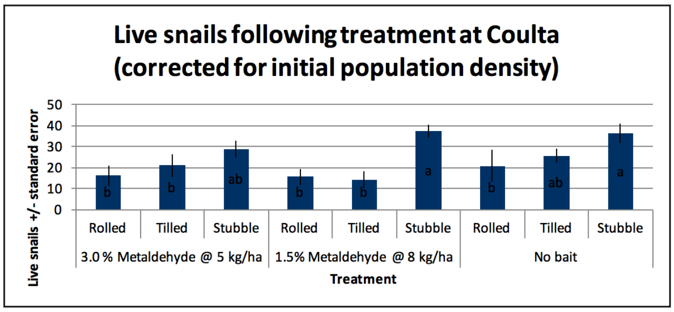


Figure 4: Mechanical treatment by baiting experiment in canola stubble at Coulta, Lower Eyre Peninsula, SA

It is also important to consider using insecticide seed treatments in canola and legumes with to supress or control early seedling pests including earwigs, slaters, aphids, millipedes and earth mites (always adhere to label guidelines).

Herbicide efficiency in retained/burnt stubble systems

Two separate experiements were setup in the EP and LowerEP to compare the effectiveness of pre-emergent herbicides in stubble retained systems

Water Rate (L/ha)	Reduction in ryegrass numbers compared to control (%)
50	52a
100	73b
150	75b

Table 13: The reduction in ryegrass populations with increasing water rate in the LEP in 2015

compared with burnt stubble in 2015. In both experiments, cereal crops were harvested low with straw spread evenly across the swath and either retained or burnt late pre-sowing. Standing stubble was also compared at one experiment. Residual stubble load was between 5 to 6.9t/ha. In both experiments there was no significant difference in the effectiveness of Sakura ®, Avadex Xtra ®, or Boxer Gold ® on the emergence of ryegrass post sowing where the spraying water application rates was 100L/ha or higher. An important finding was that a spray water volumn of 100L/ha was required to improve the effectivness of the herbicides, but this must be put in context with spray quality and nozzle type (Table 13).

The wet season in 2016 throughout much of south-eastern Australia resulted in farmers not being able to manage weeds to their normal high standard. The combination of high annual weed populations in large cereal stubble residues may mean that farmers may need to consider burning problem paddocks in 2017 to reduce weed populations and improve herbicide effectiveness where stubble loads and ground cover percentage is high. The higher the percentage of ground covered by residue, the higher the percentage of herbicide captured by the stubble (Shaner 2013).

Burning

Burning is an effective, inexpensive method of removing stubble, assisting in reducing disease carryover, reducing certain seedling pests and weed populations and if using a flexible managament approach should be considered in strategic situations. With careful planning and diverse management, burning can be kept for those occassions where the system needs to be reset which can result in farmers retaining stubble for another series of years. A late burn, conducted wisely just prior to sowing to minimise the time the soil is exposed is one option farmers may need to consider in 2017. In a long term experiment at Harden in NSW, burning late just prior to sowing is still producing some of the highest grain yields after 28 years of continuous cropping, which would indicate that a single strategic burn to re-set the sequence may do little damage. In general, late burning resulted in the largest yield benefits in wetter years, and had little impact in other years. Across a number of trials in the Riverine Plains, Victorian HRZ and those conducted by the MacKillop Farm Management group, the comparision between burning or stubble retain treatments has resulted in variable results. More often than not, there was no significant difference in grain yield between the burn and stubble retain treatment in 2014-15. However, in some years the burn treatment has resulted in good early crop vigor, more early biomass and the crop has become moisture stressed with reduced grain yield where there has been an early end to the season with a hot and dry spring.

Some negatives to burning include loss of nutrients (amount depends on temperature), increased regulation and potential losses of soil from erosion. Increasing restrictive regulations are being implemented that also make burning more difficult in the future. In some shires, a single burn requires six people, two fire control units (1 with 5000L and the other with 500L) and you are not able to leave the paddock until NO smoke is detected.

Conclusion

This paper has outlined many of the overall findings from the “Stubble Initiative” project to date and incorporated these into a series of regional guidelines to assist farmers deal with the high stubble loads from the 2016/17 harvest.

It is extremely important for farmers to NOT compromise managing weeds, disease or being able to sow their crop in 2017 due to excessive stubble loads. Farmers need to be pro-active in managing their stubble which should have commenced before harvest and continued until sowing in 2017 to ensure their stubble management will suit their seeding system. It has been shown that by diversifying a crop rotation (increasing the number of pulse crops and barley), deep banding nitrogen, managing pests and diseases, managing stubble by mulching, baling, grazing and if sowing with a tined seeder, sowing at 15-19 degrees from the previous direction, that it is easier to manage stubble without the need to burn. However, if the stubble load remains too large or the potential weed/disease/pest burden remains too high, then a one off strategic late burn can be used to “re-set” the system. In a year where stubble residue loads are greater than ever before experienced, it is also important that as new techniques are tried, to keep monitoring the results early to see how effective the actions have been.

References

1. GRDC Stubble Management Fact Sheet, March 2011: Strategies to manage winter crop stubbles without reaching for the matches

2. GRDC Managing Stubble Booklet, May 2012: https://grdc.com.au/~/media/2B5EFD71C2D04212827E2E045E022DE6.pd.

3. Mallee Sustainable Farming Inc: Stubble Management – A guide for Mallee farmers (2013)

4. Farmlink Guideline No 3. "What sort of stubble? It all begins at harvest" http://www.farmlink.com.au/project/maintaining-profitable-farming-systems-with-retained-stubble. GRDC Project 000174 - Maintaining profitable farming systems with retained stubble in NSW SW slopes and Riverina.

5. Riverine plains Stubble management guideline No 1. "Managing stubble at harvest improves sowing success" –. GRDC project RPI00009 - Maintaining profitable farming systems with retained stubble in Riverina Plains region.

6. Stubble management – an integrated approach (2010): EH Graham Centre for Agricultural innovation

7. Farmlink Guideline No 4. "Contractors and stubble. Engaging contractors with equipment suitable for stubble retention" http://www.farmlink.com.au/project/maintaining-profitable-farming-systems-with-retained-stubble. GRDC Project 000174 - Maintaining profitable farming systems with retained stubble in NSW SW slopes and Riverina.

8. Efficacy of harvest weed seed control techniques in Southern Victorian HRZ – Southern Farming Systems.

Grassroots Agronomy and GRDC extension notes. "Narrow windrow burning in southern NSW … the good the bad and the ugly"

Hunt J, Swan T, Pratt T, Rheinheimer B, Goward L, Jones K, Kirkegaard J (2015) The effect of grazing and burning stubbles on grain yield and quality in no-till and zero-till controlled traffic farming systems in SNSW. GRDC Updates Adelaide and Wagga.

Kirkby C A, Richardson A E, Wade L J, Conyers M, Kirkegaard J A (2016). Inorganic nutrient increase humification efficiency and C-sequestration in and annually cropped soil. PLOS ONE DOI: 10.1371/journal.pone.0153698 May4, 2016.

Shaner, D (2013). Interactions of herbicides with crop residue. GRDC Advisor Update, Goondiwindi.

Acknowlegements

I would like to acknowledge all the collaborating scientists, technicians, staff, farmers and consultants from all of the organisations and groups who have contributed significantly in terms of their time and research capability to each farming systems group to ensure the project in their region is producing the highest quality of work. To keep the list of co-authors to one cricket team (rather than many), only one person from each group was included as authors.

Contact Details

Tony Swan

Business Address: CSIRO Agriculture and Food, GPO Box 1700, Canberra ACT 2601

Phone: 0428145085

Email: tony.swan@csiro.au

Report Two

Opportunities and challenges for continuous cropping systems

Authors - John Kirkegaard, James Hunt (Latrobe University (current address)) , Mark Peoples, Rick Llewellyn, John Angus, Tony Swan, Clive Kirkby (CSIRO Agriculture and Food), Tony Pratt, Kellie Jones (FarmLink Research),

Project Codes - GRDC CSP00146; CSP00174; CSP00186; DAN00152; MSF00003; CSA00025

Take Home Messages

- Continuous cropping can be sustained for decades, but requires careful management.
- A larger proportion of N supply as fertiliser will be required over time even when grain legumes are included in crop sequences.
- Herbicide resistance develops faster under continuous cropping. Integrated management to keep key weed populations at very low levels is essential for long-term viability.
- Suitably diverse crop and end-use portfolios and flexible management help build resilience to climate and crop price shocks.

Background

Australian broad-acre farms have intensified crop area. In the two decades from the mid-1980s crop area doubled and sheep numbers halved (Kirkegaard et al., 2011). Many farms, or parts of farms are continuously cropped. The reasons for intensification (e.g. social, financial, logistic, biophysical) vary with individual businesses. In this paper, our aim is not to focus on the "pros and cons" of mixed vs crop-only systems. Rather we seek to highlight the main challenges faced in continuous cropping systems, and provide some recent research outcomes on best-bet management to sustain profitable continuous cropping with current and foreseeable technologies. The major challenges we foresee are (1) maintaining soil fertility (2) managing weeds and diseases and (3) managing economic risk and resilience.

Managing soil fertility

Q1. Are you mining, maintaining or manufacturing soil fertility, and at what cost to your business?

Organic matter, soil structure and fertility

Pasture phases are the most effective way to build stable soil organic matter (humus), N fertility and structure - so maintaining these assets under continuous cropping systems is a challenge (Angus and Peoples 2012). Conservation cropping systems (no-till, stubble retention) can certainly build coarse soil organic matter (i.e. plant residues), maintain cover, protect soil structure and reduce erosion but at best only maintain, rather than build stable soil organic matter. Maintaining adequate levels of humus is essential to ensure the structural stability of soils, and for the provision of nutrients (soil fertility), which will be soil type (texture) specific. Recent studies indicate that the failure to maintain or build humus may be due to a lack of sufficient nutrients (N, P, S) rather than a lack of carbon under continuous cropping systems (Kirkby et al., 2016). For example, to sequester one tonne of soil carbon as humus requires 83 kg/ha N, 20 kg P and 14 kg S. Using this knowledge, the long-term decline in soil carbon was reversed in a continuously cropped (28-year) field by adding supplementary nutrients to incorporated crop residues – because nutrient input, and not carbon input was limiting. Modern farming systems focussed on "nutrient use efficiency" (i.e. kg grain per kg fertiliser applied) may not account for the nutrients required to maintain or build the soil microbes that generate stable organic matter. As the levels of organic fertility declines, the supply of plant-available nutrients such as N from the soil will also decrease over time. Consequently there will be a requirement for progressively more fertiliser to support increases in crop yields.

Nitrogen fertility

Humus is the primary source of mineralised organic N for crops, and organic N in southern Australian soil declines at around 2-3% per year in cropped soils with a "half-life" of 34 to 23 years. In the absence of legume-based pastures, mineral N from native organic matter or pasture residue declines, and must be replaced with other legume or fertiliser N sources. Farm N budgets based on different farming system scenarios can predict the likely increase in the fertiliser needs required (Table 1).

Year	N from mineralisation (kg/ha)	Fertiliser N requirement (kg/ha)
2013	108	80
2033	54	134
2053	17	161

Table 1. Source of N for a typical 4 t/ha wheat crop in southern NSW assuming continuous cropping (Angus and Peoples, 2012).

Soil	Nil N	9 kg/ha	40 kg/ha (9+31)	1-year Pasture then 9 kg/ha N
Swale	-210a	-156c	-61a	-102b
Mid-slope	-102b	-81b	10a	-92b
Dune	-64c	-15b	60a	-21b

Table 2. Calculated N balance for different soil types under different N management during a 5-year cereal phase at Mallee Sustainable Farming Karoonda field site (from McBeath et. al., 2015).

For example in southern NSW, with 4.0 t/ha average wheat yields, a 60:40 crop:pasture ratio can maintain N balance, while continuous cropping will increasingly rely on N inputs, potentially eroding the initial economic advantage (Angus and Peoples, 2012).

The trend towards lower mineral N levels in pre-sowing tests over recent years provides evidence of diminishing organic N levels, as pasture area declines and long crop sequences with low legume frequency are not balanced with equivalent increased fertiliser N. In southern NSW, the number of pre-sowing deep soil mineral-N tests that measured <30kg/ha Min-N doubled between the periods 2008-2010 and 2013-2015, while those >120 kg/ha have halved (Jim Laycock pers. Comm., 2017). This "mining" may make sound economic sense initially, but if yield and quality levels are to be maintained or increased in the medium to long-term, improved nutrient balance must be achieved. The data for a variable soil site at Karoonda in SA Mallee (Table 2) shows how significantly more N than the current district practice of 9 to 20 kg/ha N annually is required to maintain N balance in the cereal phase.

The cost and risk of supplying an increasing proportion of N as fertiliser to support crop yield on N-depleted soils may become prohibitive. Current N prices are relatively low compared with long-term average or peak N prices, and N prices are likely to rise in future as the efficiency of production facilities reaches a peak. There are numerous strategies available to maintain N fertility and profitability under continuous cropping.

Improved efficiencies of fertiliser N use

Good agronomy and following the 4R mantra of IPNI (Right product, Right rate, Right place, Right time) are important for the provision of sufficient quantities of all plant nutrients, including N, in all farming systems - but strategies to improve fertilizer-use efficiency become critical in continuous cropping systems as the original soil organic matter levels and pools of pasture-derived N diminish. The adoption of precision agriculture techniques and variable rate technologies in broad-acre agriculture is increasing steadily in Australia, with typical economic gains estimated of around $40/ha for N-related applications. On variable soils such as in the Mallee, significant improvements in overall productivity, water-use efficiency and profit along with reduced risk can be achieved over traditional flat-rate applications by increasing N rates on sand hills and reducing N rates on flats. An example is found at Karoonda SA, where profitable responsiveness to N fertiliser

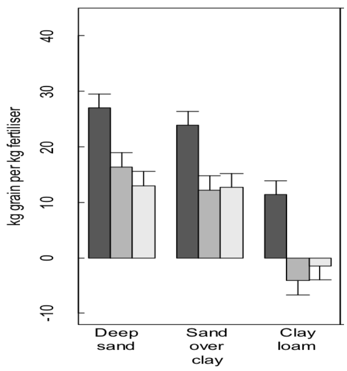


Figure 1. Grain yield responsiveness (kg/ha) per kg/ha N input on the deep sand, sand over clay and clay loam soil types across the 2010 (dark bars), 2011 (medium bars), 2012 (light bars). Data from McBeath et al., (2015) https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/07/Managing-the-profit-and-risk-of-fertiliser-nitrogen-investment-in-sandy-soils

Treatments	Z30			Anthesis			Grain Yield (t/ha)
	t/ha	N%	N-up (kg/ha)	t/ha	N%	N-up (kg/ha)	
Surface	1.4	3.8	51	7.8	1.3	103	4.0
Deep	1.4	4.4*	60	9.2*	1.5*	136*	5.2*

*Table 3. Effect of deep banding vs surface applied N (122 kg N/ha as urea) at Temora in 2016 (starting soil N, 58 kg/ha). The crop captured more N early in the season which increased biomass and yield in a wet season. (Data mean of 3 stubble treatments). *indicates significant differences (P<0.01). (Data source: Kirkegaard et. al., CSIRO Stubble Initiative 2016 CSP00186)*

is reliably achieved on the sandier soils but was profitable only in the extremely wet year of 2010 on the heavier flat soils (Figure 1).

As soil N fertility slowly declines under continuous cropping, more fertiliser may be required at sowing to ensure adequate N to achieve crop yield potential. In stubble-retained systems, surface applied N is more prone to immobilisation and the amount that can be drilled with the seed is limited. Banding N fertiliser below or beside seed rows at sowing can improve the efficiency of N uptake in crops by making more available to the plant, reducing the competition for N with soil microbes (immobilisation), and reduce leaching or denitrification losses prior to plant uptake by slowing the rate of nitrification. In an experiment at Temora in 2016, the amount of applied N captured by wheat crops was improved by deep banding N below seed in the presence or absence of stubble (Table 3).

Greater N-use efficiency of in-crop N applications may also be achieved by top-dressing just prior to rainfall during the peak period of crop demand after stem elongation or by mid-row banding equipment which has been adopted by some farmers and is being evaluated by researchers from Agriculture Victoria and NSW DPI. Banding urea between every second row (mid-row banding) may have advantages over banding under every row because the concentration of ammonium is doubled and the fertiliser remains longer in this form before its conversion to nitrate. Mid-row banded urea is effectively a slow-release fertiliser that prevents excessive vegetative growth. The ammonium it forms in soil is less prone to loss than nitrate (Angus et. al., 2014).

Slow-release fertiliser products (urease inhibitors, nitrification inhibitors and polymer coated urea) to better match N supply to crop demand are also available but currently these products may be too expensive for many broad-acre grain applications (Angus et. al., 2014). As new polymers and products become available they may have specific applications, especially in the higher rainfall zones on soils prone to leaching.

Increasing the efficiency of fertiliser use by improving the synchrony of N supply with crop N demand to reduce unnecessary losses of mineral N (leaching, denitrification, run-off) and converting those to plant uptake makes economic and environmental sense. But paradoxically, pushing for higher N efficiency by avoiding N immobilisation can lead to a heavier reliance on mineralisation to supply crops, and represents an increased net loss of organic N. Ultimately the requirement for N fertiliser will increase at a faster rate assuming crop yields (i.e. N removal) continue to improve. The total N decline can only be slowed if additional "new" sources of N enter the system to balance product removal and losses.

Integrating legumes in the system

In the absence of legume-based pasture phases, other ways to incorporate legumes into the crop system will help to maintain a better organic N balance. Legumes frequently fix around 20 kg/ha N per tonne of shoot biomass grown, but there is enormous variability in fixed and net N inputs of different end-uses, though harvested grain legumes rarely match those achieved by well-managed, legume-based grazed pastures (Table 4).

System	N fixed (kg/ha)	Net N input (kg/ha)
Grain legumes (harvested)	134 (65 to 310)	45 (-40 to 96)
Grain legumes (brown manured)	144 (86 to 246)	144 (86 to 246)
Pastures	174 (102 to 256)	132 (70 to 199)

Table 4: Average and range of N fixed and Net N input for crop legumes (harvested for grain or brown manured) and pasture systems (Data courtesy Mark Peoples, collated from field experiments during 2011-2015 GRDC Crop Sequence Initiative CSP00146)

Incorporating legumes into a farming system also reduces the financial risk associated with large N fertiliser inputs, as no N is applied to the legume, and less is usually required for the following cereal crops. In the experiments reported in Table 3, the amount of extra mineral N available to crops at sowing following legumes compared to cereals is variable (5 to 92 kg/ha; median 33 kg/ha) but some simple rules of thumb can assist in predicting the likely amounts as follows (Peoples 2016);

- 0.13 kg extra Min-N/ha per mm fallow rainfall
- 9 kg extra Min-N/ha per tonne of shoot residue N
- 15 kg extra Min-N/ha per tonne legume grain harvest

The amount of mineral N supplied by legumes tends to be higher in equi-seasonal areas of NSW than in winter dominant and summer dominant rainfall areas, and tended to be higher for faba bean, and lower for lentil and vetch. We estimate that the first wheat crop can recover the equivalent of ~30% of the N in legume stubble and root residues, with <10% being taken up by the second crop grown after a legume. This compares to a 50-60% apparent uptake of top-dressed fertiliser N applied to wheat at Z30.

Higher value grain legumes such as chickpea and lentil can provide a highly profitable option as a regular part of a continuous crop sequence in suitable environments, although net removal of N by high-yielding grain legumes is common. The area sown to these grain legumes is expanding with improved varieties and agronomic packages, however variable prices and marketing issues can increase the economic risks from year to year. Meanwhile the halving in the area of lupins, in the last decade or so means that legume crop area in 2015 was no greater than in the 1990s (htttp://www.pulseaus.com.au/storage/app/media/industry/AU-lentil-area.pdf).

Legumes with lower grain value (e.g. lupin, pea, vetch) can provide a range of other flexible and diverse end-uses in continuous crop sequences such as grazing, hay or brown-manure where the N benefits combine with weed control and water conservation to reduce production risk and input costs, and provide a significant benefit to the overall crop sequence (Table 5). In this example from a fully-phased experiment at Temora (2014-2016), compares a typical C-W-W sequence, with a sequence that includes vetch hay, the major difference in the total costs incurred was the savings in N application to the canola following the vetch hay.

The income from hay combined with highly effective non-chemical weed control (see later) and water conservation, especially preceding higher value and risky crops such as canola, can make this a good option. The N inputs and soil cover are reduced in the hay option compared with brown manuring, and low cover can also be an issue with low biomass grain legumes on erosion-prone areas. Brown manuring of grain legumes (or long fallow) is less economic in more reliable rainfall areas because of the income forgone in the year it is used, but along with hay may be viable in lower rainfall areas (Kirkegaard et al., 2014), or in areas as part of a "double-break" where it precedes a higher value but riskier crop such as canola (see later in Weed section).

Legume intercrops (where more than one crop species are grown together) are common in subsistence and organic agriculture or where labour costs are low (e.g. China), and frequently demonstrate "over-yielding" where the mixture is more productive then the monocrops due to biological synergies (typically by a factor of 1.2). Mixtures of legume and non-legume crops to date have been used less in broad-acre, mechanised agriculture. A recent review by Fletcher et al., (2016) suggests there may be potential for some promising mixtures (e.g. Peaola) with Australian experiments finding productivity increases by a factor of 1.5 compared to monocultures. Commercial peaola crops have been grown in this way for more than 10 years on some Canadian farms where growers have innovated to overcome the main practical issues. An excellent interview

System	Average N costs ($/ha/yr)	Average total costs ($/ha/yr)	EBIT ($/ha/yr)
Aggressive (C-W-W)	**$109**	$515	$508
Sustainable (Vetch-C-W-B)	$70	$464	$520

Table 5. Comparison of N input costs, total inputs costs and profit of two systems in a phased experiment at Temora (2014-2016) demonstrating that a more diverse ('Sustainable') cropping systems including a vetch hay crop can be as profitable with less N input cost. Data courtesy CSIRO and FarmLink Research Stubble Initiative "Sequences for Seeders" Project CSP00174.

with one of the key growers (Colin Rosengren) can be found here https://www.realagriculture.com/2014/07/agronomy-geeks-west-ep-15-ins-outs-intercropping/

Phosphorus

Phosphorus is a significant input cost and crop recoveries are commonly poor so improved efficiencies should always be sought (Peoples et. al., 2014). Though "peak phosphorus" concerns have generally abated, the depletion of subsoil P (mostly in northern regions) where it may be hard to replace, and the stratification of P in long-term no-till soils, where the P becomes concentrated in the surface layers and unavailable to plants when the soil dries remain important issues. Strategic tillage provides a suitable option to deal with stratification, and deeper banding of P can provide another solution. Novel products that are more mobile in soil, techniques for deep placement and novel root P foraging traits are all areas of current research interest.

*Though N and P have been singled out for discussion, continuously cropped soils can clearly be depleted in any of the essential nutrients - but few would threaten any business where regular monitoring of soil and plant fertility is conducted and relevant action taken.

Acidity

Crop production primarily acidifies soil by removal of alkalinity in grain and hay. Leaching of nitrate along with associated cations down the soil profile will also acidify soils, but this has become less common as soil N levels decline and agronomy of crops and pastures improves. It is still an issue on lighter soil types in higher rainfall regions more prone to leaching. Leaching of nitrate may in fact be lower under continuous cropping than in annual legume pastures.

Acid soils remain an issue in many Australian grain-growing areas, but with an estimated 300+ years of available lime reserves and a long history of well-researched and widely available liming strategies, it should theoretically not be an insurmountable problem with best management practices. The main challenge is to deal with acid, or acidifying subsoils, which become difficult to treat due to the immobility of lime in soil. Once again strategic tillage and regular lime application at adequate levels will ensure that the lime moves to depth rather than remain in surface layers. In naturally acid deep sandy soils such as in WA, deep placement of lime using specially designed machinery, or even carefully timed mouldboard ploughing (every 10 years) are approaches that have been used successfully.

The search for genetic tolerance to soil acidity and the aluminium toxicity it induces is ongoing as the mechanisms and the genes responsible for tolerance in wheat have been identified and moved into barley. Research into tolerance in other sensitive crops is underway (Peoples et al., 2014). Genetic tolerance will continue to be of greater importance in low rainfall regions where yield responses to liming are uneconomic.

Weed, disease and pest management

Continuous cropping can lead to greater weed and pest pressures such as herbicide resistance, and increasing weeds that are favoured by modern, no-till cropping systems (e.g. brome grass). Well-managed pasture phases provide excellent opportunities to control most biotic threats to crop production, but a range of integrated weed, pest and disease management approaches are available for application in continuous cropping systems. A diverse cropping sequence (i.e. a sequence of different crop species and end-uses) provides the most cost-effective defence against most of these threats.

Herbicide resistant weeds

A key challenge and a major cost to continuous cropping systems that are primarily reliant on herbicides for weed control is the development of herbicide resistance. Maintaining a diversity of crops, control practices and herbicides is the key to staying ahead of this problem. The number of weed individuals to which a given mode of action is exposed, and how often, determines the speed at which resistance develops. Therefore, development of resistance is slowed by maintaining weed populations at very low levels, and preventing seed set in individuals that have survived chemical control. Keeping weed populations at very low levels by a variety of complimentary practices forms the basis of integrated weed management, which is essential to ensure the sustainability of continuous cropping systems. The large areas sown under continuous cropping has contributed to increasing use of dry seeding which, in the absence of knockdown herbicides, can place increasing reliance on selective herbicides if weed seed banks are not kept low.

Rotate & Mix Herbicides

Maintaining adequate diversity in crops and their end-uses provides the best opportunity to rotate and mix herbicides with different modes of action to slow the development of herbicide resistance.

Under continuous cropping, greater application of herbicides in summer also increases the risk of herbicide residues in soil causing crop damage. The increasing use of more sensitive crops such as pulses in alkaline low rainfall areas on sands with low biological activity adds to these concerns. Herbicide residues from Group B chemistry can commonly limit crop choice but a range of other residues are also being investigated for their potential impact and careful management requirements (https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Herbicide-residues-in-soils-are-they-an-issue). Different crop types allow the use of different chemical and non-chemical control measures e.g. crop-topping in legume crops and narrow windrow burning (usually more effective in canola and grain legumes than in cereals). Maintaining low weed levels also provides an opportunity to use cheaper herbicide options where possible to reduce input costs.

Recent experiments in fields with high levels of multiple post-emergent herbicide resistant annual ryegrass (HRARG) have shown that it is difficult to reduce weed seed banks without adequate crop diversity, even with the use of expensive herbicides (Table 6). The experiments show that although high yielding and profitable intensive wheat sequences can be managed in the medium term, considerable weed populations are maintained, which are able to develop resistance to further modes of action as they are exposed to them. Round-up ready (RR) canola followed by wheat with high gross margins provided the highest gross margin, but was less effective at reducing the seed bank than most of the double-break options. Sequences that involved either canola or a spray-topped lupin grain crop in year 1 followed by cereal hay or RR canola in year 2 provided high gross margin with the most effective weed control.

In addition to diverse crop species, including fallow or different end-uses such as hay or brown-manure also provided opportunities to drastically reduce seed set using non-selective herbicides with different modes of action (e.g. glyphosate and paraquat) in tandem ('double knocking'). Brown-manure crops have the disadvantage of providing no income in the year they are grown, so that the residual water, N and weed control benefits must compensate for lost income, and the extent to which this is possible varies for specific circumstances, but have been demonstrated to be economic at farm level https://www.grdc.com.au/Research-and-Development/GRDC-Update-Papers/2013/02. In severely infested fields it may take a "double-break" (two years with very high levels of weed control) to reduce weed seed banks to manageable levels.

Competitive Crops

Competition from crop plants can be very effective at reducing weed seed production, and is a vital component of integrated weed management. The aim of crop competition is to reduce the amount of light that gets to weeds in the crop canopy,

Break Type	Crop x Input Year 1 (2013)	Crop x Input Year 2 (2014)	Crop x Input Year 3 (2015)	ARG Seedbank Year 4 (2015) (seeds/m^2)	Average Annual 3yr Gross Margin ($/ha/yr)
Double	Fallow	RR Canola	Wheat (H)	56	$603
Double	Lupin grain	RR Canola	Wheat (H)	63	$790
Double	Lupin BM	RR Canola	Wheat (H)	110	$552
Double	RR Canola	Wheat (Hay)	Wheat (H)	122	$834
Single	Lupin grain	Wheat (H)	Wheat (H)	142	$757
Single	Pea BM	Wheat (H)	Wheat (H)	162	$486
Single	RR Canola	Wheat (H)	Wheat (H)	219	$883
Nil	Wheat (H)	Wheat (H)	Wheat (H)	366	$585
Single	RR Canola	Wheat (L)	Wheat (H)	2387	$845
Single	Pea BM	Wheat (L)	Wheat (H)	3118	$397
Nil	Wheat (L)	Wheat (L)	Wheat (H)	3140	$388

Table 6. Average annual 3-year gross margin and annual ryegrass (ARG) seedbank following 3 years of various crop sequence and input strategies at Eurongilly, NSW (2013 to 2015). Sequences included double- and single breaks of pulses (grain or brown manure - BM), canola, fallow and cereal hay and wheat with high or low (H, L) N and herbicide input costs. Initial ARG seedbank in 2012 was 1815 seeds/m2. (Data source, Swan et al., 2015).

particularly those that emerge after knockdown herbicides have been applied and residual activity from pre-emergent herbicides has ceased. There are four main components to crop competition;

- Row spacing. Crops on narrow rows (<250 mm) cover the ground faster, let less light through the canopy to weeds and reduce seed set (Borger et al. 2016a) and crop yields can be higher on narrow rows, particularly in high yielding environments (Scott et al. 2013). Operational benefits of wider rows (>250 mm) include better stubble handling (including the ability to inter-row sow), lower cost of machinery, lower draught and horsepower requirement, and greater crop safety for pre-emergent herbicides. Row spacing is thus a trade-off between these factors and higher yields and crop competition. The need for vigorous and competitive crop canopies has seen a recent trend back to narrower rows on some continuous cropping farms, particularly those in higher rainfall areas.
- Row orientation. Crop rows that are sown east-west shade the inter-row more effectively than when sown north south. This helps the crop be more competitive with weeds growing in the inter-row, and has been shown to reduce seed set in ryegrass by about 50% (http://ahri.uwa.edu.au/sow-west-young-man/). Paddocks should be set up with east-west seeding runs where it is efficient to do so. Row orientation becomes increasingly critical on wider row spacing.
- Plant density. Crops are able to compete more effectively with weeds when they are planted at higher density, as there are less gaps in the crop and the canopy closes over faster.
- Vigorous crops. Maintaining healthy and vigorous crops assists with crop competition (e.g. early sowing into warmer soils, liming to adequate pH, good nutrition and disease management). Crop species vary in their ability to compete (oats and barley > wheat; canola > pulses) and crop varieties also vary (hybrid canola > OP canola > TT canola). New wheat germplasm has been selected for early vigour, and has levels similar to barley, and these have been shown to have much better weed competitive ability.

Harvest Weed-Seed Control

Numerous methods have been developed and tested in recent years to collect and destroy weeds that have escaped in-crop control (Borger et. al., 2016b). These options include narrow windrow burning, chaff carts, chaff lining, mechanical seed destruction and direct bailing. These tend to be more effective in controlling some weeds (e.g. ryegrass) more than other early shedding weeds (e.g. barley grass). Some form of harvest weed seed control is essential in continuous cropping systems situations, particularly those that do not have hay crops or a high frequency of crops that can be crop-topped in their crop sequence. Together with sustaining new herbicide technology, further increases in the extent of use of weed seed control options is likely to be a key factor in sustaining continuous cropping.

New Developments

Increasingly sophisticated seeding systems including precision row and seed placement are likely to bring further benefits for weed control and crop performance in intensively cropped environments (better establishment in difficult conditions, greater early vigour and targeted disturbance and nutrition to benefit crops over weeds. New forms of novel, non-chemical control are also under development (mechanical, microwave, steam, compressed air) and may provide options to reduce the pressure on herbicide usage if affordable options for broad-acre applications emerge.

Disease and pest control

Maintaining a diversity of crops and practices is also the key to managing pests and diseases in continuous cropping systems. Particular attention must be paid to diseases and pests that:

- Develop resistance to available fungicides or pesticides (e.g. Green Peach Aphid)
- Overcome genetic resistance that was once reliable (e.g. Blackleg in canola)
- Infect a wide host range, so less controlled by diversity (e.g. Rhizoctonia, Pratylenchus, Sclerotinia)
- Are exacerbated by current agronomic practice (e.g. Crown rot, slugs and snails under no-till)
- Are novel or exotic pests not previously encountered (e.g. Russian Wheat Aphid, WSMV)
- Become expanded in severity or range by climate change (e.g. Clubroot in canola)

An assessment of the relative risk posed by these threats within continuous cropping systems is needed to develop the most cost-effective and sustainable way to avoid economic loss. Sensible, flexible and pragmatic approaches to soil and crop management will be necessary in circumstances where diverse crop sequences alone are inadequate to manage pest damage.

System	Mean Yields (t/ha)	3 Yr System Financials				2016* ARG (seeds/m²)
		Input cost ($/ha/yr)	Total cost ($/ha/yr)	EBIT ($/ha/yr)	Profit/Cost ratio	
Aggressive (C-W-W)	2.3, 4.1, 3.9	354	515	508	0.98	442
Conservative (C-W-W)	2.5, 3.6, 3.3	289	439	506	1.14	2772
Sustainable (Vetch-C-W-B)	3.9, 2.4, 4.1, 5.2	254	464	520	1.14	482

Table 7. Comparison of 3 cropping systems in a phased experiment at Temora (2014-2016) demonstrating that a more diverse ('sustainable') cropping systems can be as profitable with less cost and risk while achieving similar control of annual ryegrass as more conventional high input approaches (Note: initial ARG seedbank in March 2014, 1864 pl/m2). In the 'aggressive' system, ARG control is based on hybrid RoundUp Ready® canola followed by Sakura® and Boxer Gold® in subsequent wheat crops. In the 'conservative' system, ARG control is based on open pollinated TT canola, and trifluralin in subsequent wheat crops. In the 'sustainable' system, ARG control is based on hay-cutting and double-knocking in vetch, open pollinated TT canola followed by Sakura in wheat and Boxer Gold plus crop competition in barley.

Economic resilience

Q. Productivity, profitability and peace of mind

The recent, medium-term (3-5 year) farming systems experiments such as those reported here (in Tables 4 and 5) can carefully account for the variable input costs to provide useful information on the likely economic impact of different management strategies. They also support the value of maintaining diversity in species and end-use to not only maintain profitability and the biophysical assets of the farm (N fertility and weed seed burden) but to do so while reducing financial risk, in this case the profit to cost ratio (Table 7).

However, medium-term, small-plot experiments while valuable, cannot adequately account for the broader economic and logistical issues that are encountered at farm-scale. Often these issues can dominate financial planning and relate to labour, equity, debt levels and farm size. These considerations can dictate what is feasible in implementing the advice arising at experimental scales.

Several recent studies of real farm businesses have emphasised the dramatic changes in the economics and risk of grain farming in recent years as cropping intensity has increased. As farm size, cropped area and land values increased, so too have debt levels, machinery costs and total interest so that despite improvements in productivity, farm income to cost ratios have decreased significantly. For the Victorian Mallee farmers in the example below (Figure 2), a net farm income of around $100K involved costs of around $400K in early 2000s, but that has doubled to $800K today.

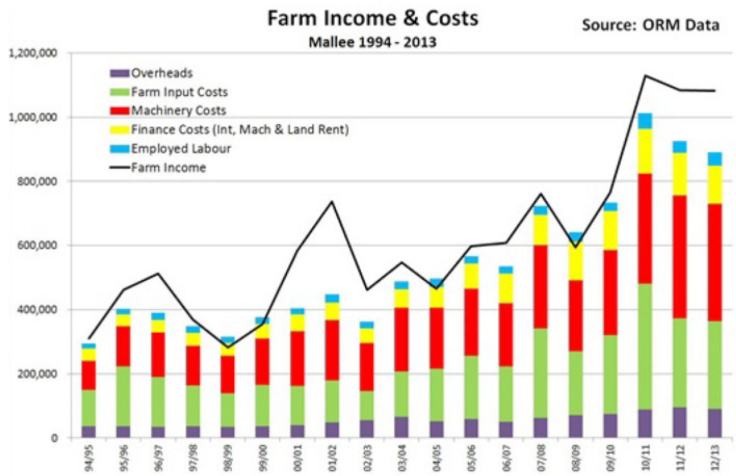
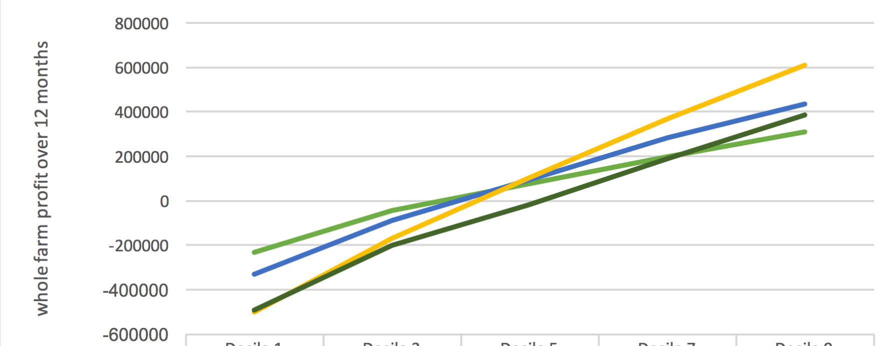


Figure 2. Average annual farm income and costs for 12 Mallee farms 1994 to 2013. As reported in van Rees et al., (2015) and by Ed Hunt (2015). Data source, ORM Pty Ltd.



	Decile 1	Decile 3	Decile 5	Decile 7	Decile 9
50%	-232000	-42000	76000	196000	308000
70%	-331000	-89000	94000	281000	435000
100%	-501000	-171000	102000	366000	608000
100% cereal	-493000	-199000	-17000	190000	384000

Figure 3. Average whole farm profit for typical farms at Karoonda (2,400 ha) assuming 80% equity. The numbers represent whole-farm profit predicted under different seasonal conditions (Decile 1=driest 10% of years, Decile 9 = wettest 10% of years, Decile 5 = Average year) and are graphed for ease of comparison (Data courtesy: Ed Hunt, Michael Moodie and Mallee Sustainable Farming).

Subsequent economic modelling to compare continuous cropping and mixed farms in this and other regions have demonstrated that it is very important to consider economic outcomes on actual yields over a number of years, rather than using long-term averages. Such analyses revealed that while continuously cropped farms (100%) and mixed farms may have similar profitability in average seasons, the continuously cropped farm was able to better capitalise in good seasons but was at greater risk in poor seasons (Fig 3). The study also demonstrated that the less diverse, continuously cropped farm (100% cereal) had the lowest economic performance in all but the very best of seasons, supporting much of the experimental data related to the benefits of diversity.

Though the absolute numbers shown above will change across different locations, the general trends will be consistent and the best strategies will be dependent on physical (soil type, rainfall), economic (equity, debt), and social (labour, skill levels, family circumstances) situations on individual farms. In riskier, low rainfall environments profits in high rainfall seasons are constrained by a (sensible) unwillingness to fertilise to levels required, increasing the need for legume nitrogen sources. As has been demonstrated above, reliance on increasingly expensive herbicide bills to maintain productivity also becomes a problem. In the absence of pasture phases with livestock, other ways to reduce risk must be sought including finding greater off-farm income, maintaining higher levels of equity, more consideration of machinery investments, use of contract services, or value adding.

Studies in other areas of intense cropping using real farm data support these findings. Lawes and Kingwell (2012) conducted a study of the economic resilience of 123 farms in the intensively cropped northern wheat belt of WA during the years 2004 to 2009 which included a period of significant drought. Indicators included business equity, operating profits, return on capital and debt to income ratio. Business equity declined on 60% of farms during the period, but the other indicators varied over time with no trends. The most resilient farms had the following features; (i) cropped more than 50% of the farm, (ii) were prudent with expenditure, (iii) maintained enterprise diversity, and (iv) grew wheat yields that were close to potential. Interestingly there was no impact of farm size which averaged 3200 ha.

In relation to mixed vs continuous cropping, most consultants agree that "it is not what you do, but how well you do it" that defines the success of the farm business, whether a mixed farm or continuously cropped (Kirkegaard et al., 2011). However with the biological and economic buffer of the pasture phase absent, a consistent message in studies of successful intensively cropped farms (in addition to sound financial management) is the importance of more frequent monitoring and measurement to assist in management decisions, and timeliness in implementing them. The fact that the top 25% of grain specialists make double the return on capital (8.8%) as the other 75% (4.5%) (ABARES 2015) emphasises that point.

As researchers and agronomists our challenge is to test and develop innovations that can continue to increase production efficiency, decrease costs and reduce risk in the face of the biological, climatic and economic challenges that we have discussed here.

Conclusion

Based on currently available technologies and price relativities, it is likely that continuous cropping can be sustained over many decades. However, in order for these systems to be sustainable, careful attention to key aspects of the farm is required, particularly control and provision of N and weeds. Under continuous cropping it becomes necessary to provide a greater proportion of crop N supply as fertiliser, and expend greater resources in maintaining low weed populations. As a result, production costs usually rise, and risk of substantial economic loss following price or climate shocks needs to be managed. Maintaining diverse crop species and end-uses forms the foundation of the solution to many of the biophysical as well as economic challenges faced in continuous cropping systems.

Useful Resources

http://www.farmlink.com.au/project/crop-sequencing

https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/09/Farming-Systems-Managing-Profitability-and-Risk-in-SA-Grain-Business

http://www.agronomy2015.com.au/papers/agronomy2015final00274.pdf

https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2015/02/Leading-farmers-have-closed-the-yield-gap

References

Angus JF, Peoples MB (2012) Nitrogen from Australian dryland pastures. Crop & Pasture Science 63, 746-758.

Angus JF, et. al. (2014) Effects of banded ammonia and urea fertiliser on soil and the growth and yield of wheat. Crop and Pasture Science 65, 337-352.

Borger, CPD et. al., (2016a). Eleven years of integrated weed management: long-term impacts of row spacing and harvest weed seed destruction on Lolium rigidum control. Weed Research doi: 10.1111/wre.12220

Borger CPD, Riethmuller GP (2016b) Long-term impact of harvest weed seed destruction on annual ryegrass. 20th Australasian Weeds Conference. http://caws.org.au/awc/2016/awc201610311.pdf

Fletcher AL et. al., (2016) Prospects to utilise intercrops and crop variety mixtures in mechanised, rain-fed, temperate cropping systems. Crop and Pasture Science http://dx.doi.org/10.1071/CP16211

Kirkby CA et. al., (2016) Inorganic nutrients Increase humification efficiency and C-Sequestration in an annually cropped soil. PLOS ONE DOI:10.1371/journal.pone.0153698

Kirkegaard JA et. al., (2011) Diversity and evolution of rain-fed farming systems in southern Australia. In 'Rainfed Farming Systems' (Eds P Tow, I Cooper, I Partridge, and C Birch) pp. 715-754, Springer, Dordrecht, Netherlands.

Kirkegaard JA et. al., (2014) Improving water productivity in the Australian Grains industry—a nationally coordinated approach. Crop and Pasture Science 65, 583-601.

Lawes RA, Kingwell RS (2012) A longitudinal examination of business performance indicators for drought-affected farms. Agricultural Systems 106, 94-101.

McBeath T, et. al., (2015) Managing nitrogen nutrition under intensive cropping in low rainfall environments. http://www.agronomy2015.com.au/papers/agronomy2015final00260.pdf

Peoples MB et. al., (2014) Soil: Nutrient Cycling. In: Neal Van Alfen, (Ed-in Chief), Encyclopedia of Agriculture and Food Systems, Vol. 5, San Diego: Elsevier; 2014. pp. 197-210.

Peoples MB et. al., (2016) Soil mineral nitrogen benefits derived from legumes and comparisons of the subsequent apparent recovery of legume or fertiliser nitrogen by wheat.

Scott et. al., (2013) Developments in stubble retention in cropping systems of southern Australia. https://www.csu.edu.au/__data/assets/pdf_file/0009/922725/Developments-in-Stubble-Retention-in-Cropping-Systems-in-Southern-Australia-11Dec2013.pdf

Swan T et. al., (2015) Profitable crop sequences to reduce ryegrass seed bank where herbicide resistant ryegrass is a major constraint to the sustainability of cropping systems. Proc. 17th ASA Conference Hobart www.agronomy2015.com.au.

van Rees H et. al., (2014) Leading farmers in South East Australia have closed the exploitable wheat yield gap: prospects for further improvement. Field Crops Research 164: 1-11.

Zerner MC et al., (2016) Genotypic stability of weed competitive ability for bread

wheat (Triticum aestivum) genotypes in multiple environments. Crop and Pasture Science 67, 695-702.

Acknowledgements

The authors would like to acknowledge the collaborative partnerships in farming systems research with FarmLink Research, Mallee Sustainable Farming and Birchip Cropping that have contributed to published and unpublished data presented here, and to the useful discussions with numerous consultants including Greg Condon, Tim Condon, Chris Duff, Kate Burke, Alan McKay, Matt McCallum and Michael Moodie. We acknowledge the technical teams behind the research and GRDC funding support.

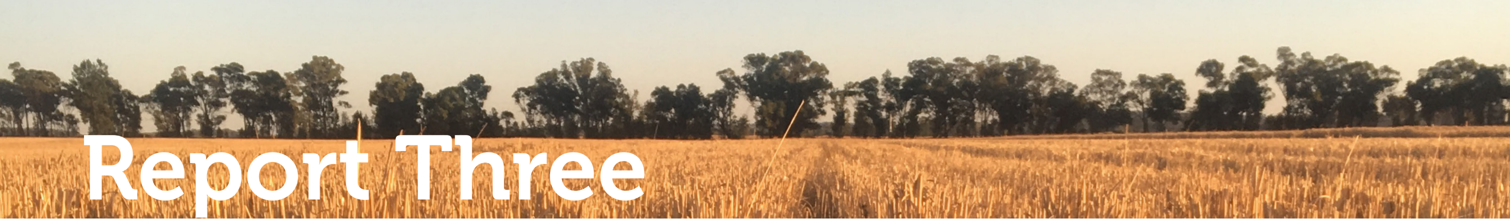
Contact Details

Name: John Kirkegaard

Business Address: CSIRO Agriculture and Food, GPO Box 1700, Canberra ACT 2601

Phone: 0458354630

Email: John.Kirkegaard@csiro.au



Sheep grazing on crop residues increase soil mineral N and grain N uptake in subsequent wheat crops

Authors - James R Hunt (CSIRO Agriculture, La Trobe University (current address)), Paul D Breust (FarmLink Research, Southern Farming Systems (current address)), Antony D Swan, Mark B Peoples, John A Kirkegaard (CSIRO Agriculture)

Abstract

In southern Australia, the majority of farms combine a sheep enterprise with cropping to form a mixed farming business. Crops are grown in sequence with pastures, and sheep graze crop stubble residues after harvest. Recently, growers practicing no-till, controlled traffic cropping, became concerned that grazing livestock would damage soil and reduce soil water capture, crop yield and profitability. Sheep grazing on stubbles remove residue cover and compact surface soil, but there is little published research on potential impacts on subsequent crop performance. A long-term experiment was established in 2009 to quantify trade-offs between grazing stubbles, resource capture and subsequent crop performance. Here we report effects on soil mineral nitrogen (N) accumulation and grain N uptake due to stubble grazing in the seven phase years of the experiment in which wheat crops were grown. Grazing wheat and canola stubbles on average increased mineral N prior to sowing of the subsequent wheat crop by 19 kg/ha, and grain N uptake by 7 kg/ha N. This could have arisen from 1) rapid mineralisation of N in livestock excreta, and/or 2) the reduction in stubble carbon inputs to soil due to grazing lowering rates of N immobilisation. Further research is necessary to confirm the relative importance of these processes, and to explore how they could be exploited to greater advantage to manage soil N availability in mixed farming systems.

Introduction

A livestock enterprise, particularly sheep, in conjunction with a wheat-based cropping has long formed the basis of mixed farming systems in southern Australia (Kirkegaard et al. 2011). In southern New South Wales (NSW) where livestock often comprise 50% of farm enterprise by area, rainfall is equi-seasonal, but crops are grown only during the cool half of the year from April to December. During summer, cropping land is left fallow and sheep graze stubble residues and weeds that germinate in response to summer rain. Recent research has re-evaluated the contribution that summer fallow rain makes to winter crop yield (Hunt and Kirkegaard 2011) versus grazing value of summer weeds (Moore and Hunt 2012) and weeds growing on fallows are now predominantly controlled with herbicide to allow accumulation of soil water and mineral nitrogen (N) for use by subsequent crops (Hunt et al. 2013). However, crop residues are still a highly valuable feed source and stock are grazed on them in situ following chemical control of summer fallow weeds. This is somewhat different to other regions of the world where sheep are grazed on fallows specifically to control fallow weeds (e.g. Hatfield et al. 2007; Sainju et al. 2014).

Previous studies have speculated that increased mineral N is a possible benefit from grazed crop fallows (Hatfield et al. 2007), but in practice few have demonstrated it. Sainju et al. (2014) reported significantly lower soil nitrate in grazed fallows compared to tilled or chemical fallow, and Allan et al. (2016) report inconsistent responses in levels of soil mineral N to grazing. However, the above studies focused on or retained fallow weeds as a treatment effect, and summer fallow weeds are known to greatly reduce levels of soil mineral N available prior to the planting of subsequent crops (Hunt et al. 2013) and grazing them is unlikely to substantially reduce water or N use (Fischer 1987). Further research into the effect of grazing crop residues on the N availability to crops could potentially be rewarding given the economic and environmental imperative to improve the nutrient use efficiency of cropping systems.

A long-term field experiment was established to determine the impact of sheep grazing on stubbles during the summer fallow period on soil properties, crop resources and growth under no-till, controlled traffic cropping with strict weed control. Here we describe the effects of grazing on soil mineral N and grain N uptake using the seven phase years of the experiment in which wheat was grown.

Methods

The experiment was located on a red chromosol soil with surface pH of 4.7 (CaCl2) and little slope 5 km SSE of the township of Temora in SE NSW (S 34.49°, E 147.51°, 299 m ASL). The experiment consisted of three grazing treatments (nil graze – NG, stubble graze – SG, winter and stubble graze – WSG) applied in a factorial randomised complete block design with two stubble management treatments (stubble burn – SB, stubble retain – SR) and four replicates. Treatments were applied in two different phases in adjoining areas of a farmer's paddock which had been in lucerne pasture (Medicago sativa) since 2005. In Phase 1, lucerne was terminated with herbicide in late spring 2008, in Phase 2 it was terminated in late winter 2009. Following lucerne removal, large plots (7.25 x 16.00 m) were established which allowed all operations to be conducted using controlled traffic. All plots were fenced so they could be individually grazed by sheep.

All crops were inter-row sown using a plot seeder equipped with contemporary no-till seeding equipment.

Crops were sown in mid-late April in all years of the experiment, and both crop phases were kept in a rotation of canola (Brassica napus)-wheat-wheat. Only results for years in which wheat was grown are reported here. Following harvest in each year (late November-early December), weaner ewes grazed stubbles in SG and WSG treatments (average 2263 sheep/ha.days). The stubble burn treatments were applied in mid- to late-March of each year. Summer weeds that emerged at the site were controlled with herbicide within 5-10 days of emergence, and all in-crop weeds, disease and pests were controlled with registered pesticides such that they did not affect yield. Synthetic fertilisers were applied as required such that nutrient deficiency did not limit yield.

Prior to seeding each year two soil cores (42 mm diameter) were taken per plot to a depth of 1.6 m and segmented into 0-0.1, 0.1-0.2, 0.2-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0, 1.0-1.3, 1.3-1.6 m. Six additional cores were taken for 0-0.1 m depth, and cores were bulked according to depths. Soil from each depth increment was analysed for mineral N (NH4 and NO3). Grain yield was measured using a plot header harvesting only the middle four rows of each seeding run to remove edge effects from rows adjacent to tram tracks. Wheat grain protein was estimated by NIR, and grain N content calculated by dividing protein content by 5.75. Wheat grain N uptake was calculated by multiplying grain N content by grain yield. Amount of residue returned to plots prior to grazing was measured by hand harvesting large areas (>1.0 m^2) of crop and threshing and weighing grain and subtracting from total weight. Crude protein content of stubble was estimated by NIR, and stubble N content calculated by dividing protein content by 5.75 for wheat and 6.25 for canola. The amount of stubble present in plots was measured after grazing to calculate how much sheep had consumed.

Soil mineral N and grain N uptake were analysed using a three-way analysis of variance (ANOVA) in randomised blocks with grazing, stubble treatment and phase year as factors in the GenStat 18 software package (VSN International Ltd.). Significance is assumed at the 95% confidence level and tests of mean separation were made using Fisher's least significant difference test calculated at the 95% confidence level.

Results

The amount of stubble that was grazed prior to the years in the study in which wheat was grown varied seasonally, but averaged 3.3 t/ha (Table 1). The N content of the stubble varied with crop type and averaged 1.2% for canola and 0.7% for wheat. The average N in grazed stubble varied from 3 to 68 kg/ha, but averaged 33 kg/ha.

Phase year & crop type	Mean stubble grazed (t/ha)	Mean stubble N content (%)	Mean N in grazed stubble (kg/ha)
Ph 1 2010 Canola	2.9	1.5	45
Ph 1 2011 Wheat	5.7	0.8	44
Ph 1 2013 Canola	3.5	1.0	34
Ph 1 2014 Wheat	1.6	0.7	11
Ph 2 2011 Canola	4.9	1.4	68
Ph 2 2012 Wheat	3.9	0.7	27
Ph 2 2014 Canola	0.3	0.8	3
Mean	3.3	1.0	33

Table 1. Mean amount and N content of stubble grazed for the years preceding the seven phase years in which wheat crops were grown.

Averaged across all phase years, grazing stubble increased mineral N prior to sowing from 102 to 121 kg/ha N (P<0.001). There was a significant interaction between phase year and grazing, with positive effects of grazing in Phase 1 in 2011, 2012 and 2015 and in Phase 2 only in 2015 (Table 2). There was no significant main effect of burning stubble on soil mineral N (P=0.911), or interaction with either grazing (P=0.389) or phase year (P=0.617) (data not shown).

As a main effect, grazing stubble increased wheat grain N uptake from 85 to 92 kg/ha N (P<0.001) reflecting the observed increase in soil mineral N prior to sowing. However, there was a significant three-way interaction with phase year, grazing, and burning (Table 3). Grazing significantly increasing grain N uptake in the SR treatment in Phase 1 in 2012 and 2015, and in Phase 2 in 2013. Grazing increased N uptake in the SB treatment in Phase 1 in 2014 and Phase 2 in 2015.

Phase year	Nil graze	Stubble graze
Phase 1 2011	79	107
Phase 1 2012	99	127
Phase 1 2014	132	121
Phase 1 2015	90	145
Phase 2 2012	73	81
Phase 2 2013	93	94
Phase 2 2015	145	170
P-value **LSD (P=0.05)**	**0.018** **26**	

Table 2. Soil mineral N (NO3 + NH4, kg/ha N) sampled to 1.6 m depth prior to sowing for the two grazing treatments and seven phase years at the site in which wheat was grown. P-value and LSD are for the graze x phase year interaction.

Phase year	Graze treatment	Stubble management	
		Stubble burn	Stubble retain
Phase 1 2011	Nil	107	108
	Stubble	111	110
Phase 1 2012	Nil	92	79
	Stubble	89	92
Phase 1 2014	Nil	99	112
	Stubble	109	106
Phase 1 2015	Nil	63	61
	Stubble	77	84
Phase 2 2012	Nil	88	81
	Stubble	86	86
Phase 2 2013	Nil	77	51
	Stubble	79	73
Phase 2 2015	Nil	81	88
	Stubble	92	94
P-value **LSD (p=0.05)**		**<0.001** **8**	

Table 3. Wheat grain N uptake (kg/ha N) for the two grazing treatments and stubble management treatments and seven phase years in which wheat was grown. P-value and LSD are for the graze x phase year x stubble management interaction.

Discussion

Grazing stubbles significantly increased accumulation of soil mineral N during the summer fallow in four of seven phase years. Averaged across all seven phase years the mean increase was 19 kg/ha N, but the highest observed was 55 kg/ha. There are several mechanisms that could collectively be responsible for this effect. The first is more rapid cycling of organic N in stubble residues into mineral forms by animal digestion. The majority of the N in crop residues consumed by sheep (59%, Freer et al. 1997) is returned to the soil as urea in urine, which under warm summer temperatures would rapidly hydrolyse to ammonia before nitrifying (Haynes and Williams 1993) resulting in elevated levels of soil mineral N. By contrast the organic N in stubble (C:N ratio ~40-80) is likely to be immobilised by decomposing microbes in NG treatments (Kumar and Goh 1999). Based on the mean N content (1.0%) in stubbles grazed in this experiment, and amount of stubble consumed (3.3 t/ha), cycling by animals could on average provide an additional 19 kg/ha of N in mineral form, up to 25% of which could have been lost as ammonia prior to soil sampling (Haynes and Williams 1993).

The second likely mechanism is reduced immobilisation of N in the grazed treatments due to the reduced input of high C:N crop residues compared with ungrazed treatments. The majority of carbon (C) in plant residues consumed by animals is emitted in gaseous form (58%=CO2, 4%=CH4) and lost from the system, or separately excreted to plots as faeces (37%) with a C:N ratio of 25 (Freer et al. 1997). Carbon in stubble will immobilise N at a ratio of 25:1 (Kumar and Goh 1999), meaning that in faeces will not immobilise any more N other than that contained in the faeces itself. Therefore, in this experiment grazing on average either removed C from the system or neutralised C with potential immobilising power of 52 kg/ha N. Immobilisation would be spread over several years as under the no-till management practised at this site residues take numerous years to fully decompose.

Conclusion

Grazing crop stubbles makes more mineral N available to crops which increases grain N uptake and is perhaps an overlooked benefit of keeping livestock in stubble-retained farming systems. There are two mechanisms that are likely to be responsible for this 1) more rapid mineralisation of N in livestock excreta, and 2) a reduction in stubble C inputs into soil that encourage N immobilisation. Further research is necessary to confirm the mechanisms and their relative importance, and to explore how they could be exploited to greater advantage to manage nitrogen in mixed farming systems in the longer term.

References

Allan, CJ, Jones, B, Falkiner, S, Nicholson, C, Hyde, S, Mauchline, S, Ferrier, D-A, Ward, P, Siddique, KHM, Flower, KC (2016) Light grazing of crop residues by sheep in a Mediterranean-typeenvironment has little impact on following no-tillage crops. European Journal of Agronomy 77, 70-80.

Fischer, RA (1987) Responses of soil and crop water relations to tillage. In 'Tillage.' (Eds PS Cornish, JE Pratley.) pp. 194-221. (Inkata Press: Melbourne)

Freer, M, Moore, AD, Donnelly, JR (1997) GRAZPLAN: Decision support systems for Australian grazing enterprises—II. The animal biology model for feed intake, production and reproduction and the GrazFeed DSS. Agricultural Systems 54, 77-126.

Hatfield, PG, Goosey, HB, Spezzano, TM, Blodgett, SL, Lenssen, AW, Kott, RW, Marlow, CB (2007) Incorporating sheep into dryland grain production systems: III. Impact on changes in soil bulk density and soil nutrient profiles. Small Ruminant Research 67, 222-231.

Haynes, RJ, Williams, PH (1993) Nutrient Cycling and Soil Fertility in the Grazed Pasture Ecosystem. In 'Advances in Agronomy.' (Ed. LS Donald.) Vol. 49 pp. 119-199. (Academic Press:

Hunt, JR, Browne, C, McBeath, T, Verburg, K, Craig, S, Whitbread, AM (2013) Summer fallow weed control and residue management impacts on winter crop yield through soil water and N accumulation in a winter-dominant, low rainfall region of southern Australia. Crop & Pasture Science 64, 922-934.

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

Kirkegaard, JA, Peoples, M, Angus, JF, Unkovich, M (2011) Diversity and evolution of rainfed farming systems in southern Australia. In 'Rainfed farming systems.' (Eds P Tow, I Cooper, I Partridge, C Birch.) pp. 715-754. (Springer: Dordrecht, Netherlands)

Kumar, K, Goh, KM (1999) Crop Residues and Management Practices: Effects on Soil Quality, Soil Nitrogen Dynamics, Crop Yield, and Nitrogen Recovery. In 'Advances in Agronomy.' (Ed. LS

Donald.) Vol. Volume 68 pp. 197-319. (Academic Press:

Moore, AD, Hunt, JR (2012) Does control of summer fallow weeds improve whole-farm productivity in both Mediterranean and temperate environments? In 'Capturing Opportunities and Overcoming Obstacles in Australian Agronomy: 16th Australian Society of Agronomy Conference. Armidale, Australia', 14-18 October. (Australian Society of Agronomy. Available at http://www.regional.org.au/au/asa/2012/soil-water-management/8145_mooread.htm [Accessed accessed 21 December 2012].

Sainju, UM, Barsotti, JL, Lenssen, AW, Hatfield, PG (2014) Particulate and active soil nitrogen fractions are reduced by sheep grazing in dryland cropping systems. Nutrient Cycling in Agroecosystems 99, 79-93.

Contribution of sheep in no-till and zero-till systems

Authors - Tony Swan, Brad Rheinheimer (CSIRO Agriculture), Kellie Jones, Colin Fritsch, (FarmLink Research), James Hunt (CSIRO Agriculture and La Trobe University (current address)), John Kirkegaard (CSIRO Agriculture)

GRDC Project Code - CSP00174

Take Home Messages

- Grazing stubble with sheep speeds up N cycling and reduces N tie-up by the stubble. When yield is N limited, this can increase grain yield and quality.
- Over the seven year experiment, grazing and retaining stubble has been the most profitable treatment, with an annual Gross Income 172 higher than un-grazed, stubble retain (assuming a grazing value of the stubble) or $55 higher if no grazing value assumed.
- Over the seven years, there was on average a 0.5 t/ha reduction in wheat grain yield in the 2nd wheat crop where stubble was retained and not burnt – mostly related to N tie-up.

Background

A livestock enterprise, particularly sheep, in conjunction with a wheat-based cropping enterprise has long formed the basis of mixed farming systems throughout south eastern Australia. This enterprise mix is symbiotic, with sheep able to consume and give value to by-products from cropping (crop residues, weather damaged and spilt grain, early vegetative crop growth) whilst the legume-based pastures used for sheep production spell paddocks from crop production, increase soil nitrogen and reduce crop weed and disease burden. The presence of both livestock and crops also diversifies the farm business, offsetting climate and price risk and increasing resilience. In recent times much attention has been given to the potential for conservation farming practices such as no-till seeding with complete stubble retention and controlled traffic to increase crop yields and water-use efficiency. Advocates argue that the full potential of no-till and controlled traffic may not be realised if sheep are grazed on cropping country, removing residue and trampling soils. However, there is little contemporary research evidence to support this view. We report results from a long-term experiment (established in 2009) testing the impact of sheep grazing no-till and zero-till farming systems on soil conditions and crop yields. Results from the first four years of this experiment (2009-2012) are available online www.farmtrials.com.au/trial_details.php?trial_project_id=16648). Results from 2013-2015 were presented in the FarmLink 2016 annual report. This paper updates the results with 2016 data including a summary of grain yield and gross income from continuously cropped treatments between 2010 and 2016.

Methodology

The experiments were located on a red chromosol soil 5 km SSE of the township of Temora in SE NSW (519 mm average annual rainfall, 313 mm average Apr-Oct rainfall, 206 mm Nov-Mar rainfall) and consists of three stubble grazing treatments;

1. Nil graze (NG)
2. Stubble graze (SG)
3. Winter graze and stubble graze (WGSG)

These were applied in a factorial design with two stubble retention treatments;

i. Stubble retention (SR)

ii. Stubble burn (SB)

Between 2013 and 2016 these treatments were also split for three different seeding furrow opener types;

A. Deep knife-point (AgMaster 12 mm - disturbs soil below seed)

B. Spear-point (Keech - does not disturb soil below seed)

C. Single disc (Excel with Arricks Wheel residue managers)

These treatments were applied in two different phases in adjoining areas of a farmer's paddock which had been in 4 years of lucerne pasture since 2005. In phase 1, lucerne was sprayed out in late spring 2008, in phase 2 it was sprayed out in late winter 2009. Following lucerne removal, large plots (7 x 16 m – incorporating three individual plot-seeder runs of 1.83 m width and 1.5 m of permanent tram tracks) were established which allowed all operations to be conducted using controlled traffic. All plots were fenced so they could be individually grazed by sheep. Between 2009 and 2012, all plots were sown with deep knife points attached to FlexiCoil 250 kg break-out tines on a linkage mounted plot-seeder on 305 mm row spacing. From 2013, both spear Keech points and deep knife points were attached to the FlexiCoil, and the discs were mounted on a trailing bar with air-seeder also on 305 mm row spacing. Crops were sown from mid-April to early May in all years of the experiment which followed a canola-wheat-wheat sequence.

In 2016, phase 1 was sown to Hyola 650TT canola on the 27th April at 3.1kg/ha with MAP & impact @ 40kg/ha, following pre-emergent application of propyzamide @ 1L/ha, Dual Gold ® @ 250ml/ha, Lorsban ® @ 1L/ha and Fast-tac Duo ® @ 150ml/ha. In-crop herbicides included Atrazine 900WG @ 1.1kg/ha, Lorsban @ 1L/ha and Venom @ 200ml/ha. Phase 2 was sown to Lancer wheat at 80kg/ha with MAP & impact @ 40kg/ha, following pre-emergent applications of Sakura ® @ 118g/ha, Avadex Xtra ® @ 2L/ha, Lorsban ® @ 1L/ha and Fast-tac Duo ® @ 150ml/ha.

From late June to mid-July each year, large weaner ewes grazed in treatment 3 (winter and stubble graze - WGSG). The amount of plant dry matter was assessed pre and post grazing. In 2016, the wheat treatment was grazed between Z29-31 and the canola between 6 leaf and bud emerged on wet soil (not saturated) for the equivalent of between 500-700 DSE/ha/days (7-8 sheep for 15-21 hours).

In 2016 in phase 1, Prosaro® was applied at 450ml/ha with Transform® @ 100ml/ha at 20% flowering with a 2nd application of Prosaro® @ 450ml/ha on the 20th September. In phase 2, broadleaf weeds were sprayed with a mix of Paridgm® @ 25ml/ha, Ally® @ 5g/ha, MCPA lve @ 500ml/ha and Lontrel Advance® @ 75ml/ha after grazing. Prosaro® was sprayed @ 300ml/ha with Transform® @ 100ml/ha on the 23rd August. Nitrogen was top-dressed on both phase 1 and 2 as urea at 100kg/ha on the 29th June and 120kg/ha on the 29th July.

Grain yields were measured using a plot header harvesting only the inside 4 rows only of each seeder run to remove edge effects from rows adjacent to tram tracks. Grain yields were also measured by hand harvesting large areas (>1.0 m^2) of crop and threshing which also allowed total dry matter production, harvest index and amount of the residue returned to plots to be calculated. Grain protein, moisture and test-weight were estimated from NIR, and screenings as per receival protocols. Binned grades were determined from quality parameters, and prices determined using 2016 grain prices for the day of harvest. Inputs and non-tonnage dependent operations in all treatments were identical, therefore only gross income is calculated in the economic analysis.

Following harvest in each year (late November-early January), large weaner ewes grazed the stubble residues in both treatments 2 and 3 (SG and WGSG treatments) for an average period of 2263 DSE/ha/days. In 2016-17, four medium sized weaners (55kg) grazed the canola stubble and five weaners grazed the wheat stubble for 4.5days (2000-2500 DSE/ha/days). The amount of stubble present in plots was measured before and after grazing to calculate how much sheep had consumed. Stubble was analysed for feed quality (metabolisable energy), and the number of grazing days was calculated based on one dry sheep equivalent (DSE) consuming 7.6 MJ of energy per day. Grazing value was priced assuming an agistment rate of $0.4/DSE/week. Sheep were not removed from the plots if it rained during grazing.

The stubble burn treatments were applied in mid- to late-March of each year. Summer weeds that emerged at the site were promptly controlled with herbicides.

Results 2016

In 2016 there was 103mm of summer rainfall (Dec 2015-March 2016), 591mm growing season rainfall (April-Oct inclusive) and a total annual rainfall of 704mm. Between the 30th April and the 9th May, 65mm of rain fell resulting in an even germination and good incorporation of the pre-emergent herbicides. In May 2016, the average canola plant population was 34 plants/m2 across all treatments with fewer plants established using the disc opener and where the stubble was burnt (Table 1). The reduction in canola emergence in the disc and burn treatments may have been due a combination of herbicide damage, Dual Gold ® washing into the sown row in treatments where there was little or no stubble. There was also some effect from insects in the burn treatments, primarily from pasture cockchafers and bronze field beetles. However, in all treatments there were sufficient plant numbers for maximum grain yield.

Opener	Canola emergence (plants/m2)	Stubble treatment	Canola emergence (plants/m2)
Disc	30	**Burn**	29
Knife	38	**Retain**	39
Spear	34		
LSD (p=0.05)	**5**		**6.5**

Table 1: Canola plant populations (m^2) across all grazing treatments for each opener type and for each stubble type in May 2016.

There was no effect of grazing and stubble on wheat emergence in May 2016 (mean population 143 plants/m2). However, there were more plants emerged with the disc seeder (Table 2), but with slower emergence and reduced early vigour (data not shown).

Opener	Wheat emergence (plants/m2)
Disc	154
Knife	136
Spear	139
LSD (p=0.05)	**8.1**

Table 2: Wheat plant populations (m^2) across all grazing treatments for each opener type in May 2016.

The treatments influenced soil mineral nitrogen (kgN/ha) in both phase 1 and 2 in March 2016. The NG treatment had less mineral N (phase 1 @ 90 kg/ha or phase 2 @ 87 kg/ha) compared to either the SG or WGSG treatments @ 120 to 144kgN/ha (Table 3). Thus retaining stubble reduced Min-N available at sowing by 30-50 kg/ha.

Graze treatment	Stubble treatment	Phase 1- Canola 2016 Soil mineral N (kg/ha) Graze x stubble Graze treat		Phase 2- Wheat 2016 Soil mineral N (kg/ha) Graze x stubble Graze treat	
Nil graze (NG)	**Retain**	96	90	75	87
	Burn	83		100	
Stubble graze (SG)	**Retain**	104	120	125	134
	Burn	136		144	
Winter & Stubble	**Retain**	149	144	130	132
(WGSG)	**Burn**	139		134	
LSD (p=0.05)		No interaction	26	No interaction	26

Table 3: Soil mineral N (kgN/ha) in phase 1 (canola) and phase 2 (wheat) between 0-175cm in March 2016.

By the 14th July, across all treatments, there was approximately 1.1t/ha of wheat or canola DM. The sheep in the WGSG treatments removed between 450 to 500kg/ha of plant dry matter in both phases 1 and 2 (canola and wheat), but grazed the disc treatment more heavily in phase 1. The sheep had also removed approx. 20% of the buds from the canola plants and had trampled both the wheat and canola plots (Figure 1).

Figure 1: Pre and post winter graze in phase 2 in July 2016.

At anthesis in phase 1, the average canola DM yield was 5.1t/ha. There was no significant difference in canola plant DM between grazing treatments except in the WGSG disc treatment which had reduced biomass (3.8t/ha cf 5t/ha; data not shown). In phase 2, there was no difference in wheat DM between openers, but wheat DM was reduced in both the NG stubble retain and SG stubble retain treatments and increased in the WGSG treatment compared to the NG stubble burn treatments (Table 4).

There was no difference in canola grain yield, oil content or gross income between any of the treatments (Table 5) or between opener types (Table 7).

Graze Treatment	Stubble Treatment	
	Burn	Retain
Nil graze (NG)	9.0	7.9
Stubble graze (SG)	9.3	8.3
Winter and stubble graze (WGSG)	9.9	10.2
LSD (P=0.05)	0.85	

Table 4: Wheat dry matter (t/ha) at anthesis (28th September - 5th October) in the graze and stubble treatments in phase 2 across all opener types.

Graze treatment	Stubble treatment	Grain yield (t/ha)	Oil (%)	Gross Income ($/ha)
Nil graze (NG)	Retain	3.2	49.1	$1775
	Burn	3.3	49.2	$1805
Stubble graze (SG)	Retain	3.4	48.7	$1873
	Burn	3.1	49.0	$1708
Winter & Stubble graze (WGSG)	Retain	3.4	49.1	$1865
	Burn	3.1	49.0	$1694
LSD (p=0.05)		ns	ns	ns

Table 5: Canola grain yield, oil % and gross income from phase 1 in 2016.

However, where the 2nd wheat crop was sown in phase 2 in 2016, there was significantly more wheat grain yield in both the NG burn and the SG burn treatments compared to all other treatments which translated to higher gross incomes (Table 6). The average wheat grain protein concentration across the entire experiment was 8.5% with no significant difference between openers, however, the protein concentration in the WGSG treatment was significantly lower than the NG and SG burn treatments (Table 7). Wheat protein concentrations in all treatments were low, indicating that the crop was nitrogen limited in this wet year. The wheat grain yield was slightly higher when sown with the knife opener compared to the disc (Table 7).

Graze treatment	Stubble treatment	Grain yield (t/ha)	Protein (%)	Gross Income ($/ha)
Nil graze (NG)	Retain	5.3	8.7	$899
	Burn	5.8	8.7	$980
Stubble graze (SG)	Retain	5.5	8.5	$934
	Burn	6.0	8.6	$1024
Winter & Stubble graze (WGSG)	Retain	5.3	8.4	$891
	Burn	5.2	8.3	$876
LSD (p=0.05)		0.3	0.26	$49

Table 6: Wheat grain yield, protein % and n the wheat in phase 2 in 2016.

Opener	Wheat Grain Yield (t/ha)	Canola Grain Yield (t/ha)	Wheat Gross Income ($/ha)	Canola Gross Income ($/ha)
Disc	5.4	3.1	$916	$1721
Knife	5.6	3.2	$951	$1762
Spear	5.5	3.4	$934	$1876
LSD (p=0.05)	0.14	ns	$23	ns

Table 7: Grain Yield and Gross Income across all treatments by opener type in 2016

Results for 2010-2016

Across the seven years of the experiment in both phases, there has been a significant decrease in wheat grain yield (~0.5 t/ha) when stubble was retained rather than burnt in the nil graze treatments. (Tables 8 and 9). In 2012, 2015 and 2016, this resulted in a 0.5t/ha reduction in grain yield and was associated with lower soil N concentrations and presumably increased N tie-up by the retained stubble (Table 8). The soil mineral N concentration was always 15 to 20 kgN/ha lower in March of each year in the NG stubble retain compared to the NG stubble burn treatment (data not shown). The combined effect of lower soil mineral N concentrations and lower air temperatures (i.e. frost) in 2013 in NG stubble retained treatment resulted in a 1.6t/ha decrease in wheat grain yield in phase 2 compared to the NG stubble burn treatments (Table 9). The 0.6t/ha decrease in grain yield in the SG stubble retain compared to the SG stubble burn treatment was also due to frost (Table 9).

Graze treatment	Stubble treatment	Canola 2010	Wheat 2011	Wheat 2012	Canola 2013	Wheat 2014	Wheat 2015	Canola 2016
NG	Retain	**4.2**	4.6	4.4	**0.7**	3.8	4.1	**3.2**
	Burn	**4.0**	4.6	5.0	**1.0**	3.8	4.6	**3.2**
SG	Retain	**4.3**	4.5	4.8	**0.9**	3.7	5.3	**3.3**
	Burn	**4.2**	4.6	4.7	**1.1**	3.8	5.2	**3.3**
WGSG	Retain	**3.9**	5.2	4.5	**0.7**	3.4	3.6	**3.1**
	Burn	**4.1**	5.3	4.9	**0.7**	3.2	3.9	**3.2**

Table 8: Grain yield between 2010 and 2016 in Phase 1 sown with knife point.

Graze treatment	Stubble treatment	Canola 2010	Wheat 2011	Wheat 2012	Canola 2013	Wheat 2014	Wheat 2015	Canola 2016
NG	Retain	**6.3**	3.4	4.5	**2.0**	2.0	5.5	**5.2**
	Burn	**6.2**	3.5	4.8	**3.4**	2.0	5.3	**5.7**
SG	Retain	**6.2**	3.3	4.8	**3.0**	2.2	5.6	**5.3**
	Burn	**6.4**	3.3	4.9	**3.6**	2.0	5.7	**6.1**
WGSG	Retain	**6.5**	3.1	4.7	**2.4**	1.5	3.9	**5.1**
	Burn	**6.5**	3.1	4.7	**2.7**	1.7	3.8	**5.0**

Table 9: Grain yield between 2010 and 2016 in Phase 2 sown with knife point.

In most cases, (2012, 2013, 2015), the wheat grain yield in the 2nd wheat crop in the SG stubble retain treatment has been significantly higher than in the NG stubble retain treatment (Tables 8 and 9). Grazing stubble increased the soil mineral N available prior to sowing and in 2015 phase 1, it was almost doubled. This result was verified by surface N measurements taken immediately before and immediately after stubble grazing, which showed that mineral N in the SG stubble retain treatment was twice that in the NG stubble retain treatment, an effect that persisted through the summer fallow.

Gross Incomes

Averaged across both phases for the seven years of this experiment, grazing and then retaining the stubble generated the highest gross income (Table 10). If the grazing was valued assuming one dry sheep equivalent (DSE) consumed 7.6 MJ of energy per day at an agistment rate of $0.4/DSE/week, the grazing value of the stubble was $117/ha/year with an additional increase of $55/ha/year due to higher yields and higher N availability.

Graze treatment	Stubble treatment	Assuming grazed stubble has no value	Assuming grazed stubble has a value*
Nil graze	Retain	$1,231	$1231
	Burn	$1,269	$1269
Stubble graze	Retain	$1,286	$1403
	Burn	$1,277	$1397
Winter Graze	Retain	$1170	$1287
	Burn	$1196	$1313

Table 10: Gross income per year averaged across both phases for all years (2010-2016) of the experiment

Grazing value of the summer stubble only in both SG and WGSG treatments. No grazing value was calculated for the grazing in winter.

Conclusion

In 2016, the average canola grain yield was 3.1t/ha with an oil content of 49% and a gross income of $1787, with no significant difference between treatments or openers. In 2016, wheat grain yield and gross income was higher in both the nil graze and stubble graze treatments where stubble was burnt than where stubble was retained.