The effect of grazing and burning stubbles on grain yield and quality and gross margins in no-till and zero-till controlled traffic farming systems in SNSW (2017 update)

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

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Take home messages

- In 2017, the average canola grain yield was 2.3t/ha with an oil content of 45.5% and a gross income of $1239, with the highest grain yields and gross incomes attained when sown with a disc opener or spear point opener when retaining stubble.
- The wheat grain yield and gross income were significantly higher when the stubble was retained and not burnt ($3.5t/ha cf 3.2t/ha and $928/ha/yr cf $838/ha/yr), with higher plant dry matter (DM) at anthesis when sown with either a disc or spear point opener compared to the deep knife point. There was no significant main effect of opener type on wheat grain yield or gross income.
- In both phases, the stubble graze (SG) treatments had higher starting soil mineral nitrogen. Grazing stubbles 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 nine-year experiment, grazing and then retaining stubble has been the most profitable treatment.
- Over the nine years, there was on average a 500kg/ha reduction in wheat grain yield in the 2nd wheat crop where stubble was retained and not burnt.
- Following four years of comparing grazing (Nil Graze, Stubble Graze, Winter & Stubble Graze) by stubble (Burn or Retain) by opener type (Disc, Spear point, Deep knife point), the surface soil strength and soil bulk density were increased when using a disc opener, but there was no significant difference in water infiltration between the disc and tine openers. Similarly, grazing reduced water infiltration under both disc and tine openers, with less water infiltrating following the WGSG or SG treatments compared to the NG treatment.
- The bulk soil pH measurement (0-10cm) does not always provide a good guide for soil pH!
- The subsurface soil (7.5-20cm) acidified between March 2009 and March 2017. The addition of 2.5t/ha of lime in April 2009 and incorporated with deep knife points inter-row sown annually was not sufficient to move the lime down to the subsurface layer.

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 otherwise wasted by-products from cropping (crop residues, weather damaged and spilt grain, early vegetative crop growth) whilst the legume-based pastures used for sheep production allow paddocks to be spelled from crop production, increase soil nitrogen and reduce crop weeds and diseases. The presence of both livestock and crops also diversifies the farm business, offsetting production 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 cropped country, as they remove residue cover and trample soils, but there is little contemporary research evidence to support this view. We report results from a long-term experiment designed to test whether sheep grazing in no-till and zero-till farming systems damage soil and reduce 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 2013-2016 were presented in the FarmLink 2016 and 2017 annual reports. This paper presents results from the final year of the experiment in 2017 and includes a summary of grain yield and gross income from continuously cropped treatments between 2010 and 2017.

Methodology

The experiment was 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 2017 these treatments were 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 experimental treatments were applied in two different phases in adjoining areas of a farmer's paddock which had been in 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. Lime was spread at 2.5t/ha in April 2009 across both phases prior to sowing in 2009. 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 and followed a canola-wheat-wheat rotation.

Table 1: Crop sequence of Canola (C) – Wheat (W) – Wheat (W) in Phase 1 and Phase 2 of the experiment following lucerne pasture (P) since 2005. Second wheat crop is shown in bold.

	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Phase 1	P	W	C	W	**W**	C	W	**W**	C	W
Phase 2	P	P	W	C	W	**W**	C	W	**W**	C

In 2017, phase 1 was sown to Lancer wheat at 77kg/ha with MAP & Impact Endure (200ml/ha) @ 40kg/ha, following pre-emergent applications of Sakura® @ 118g/ha, Avadex Xtra® @ 2L/ha, Lorsban® @ 900ml/ha and Fast-tac Duo® @ 100ml/ha. Mesurol® (20g/kg Methiocarb) @ 5.5 kg/ha was spread across trial post sowing to control slatters, millepedes, slugs and false wireworm. Phase 2 was sown to SF TurbineTT canola on the 2nd May at 2.9kg/ha with MAP & Impact Endure (200ml/ha) @ 40kg/ha, following pre-emergent application of propyzamide @ 1L/ha, Atrazine® 900WG @ 1.1kg/ha, Lorsban® @ 900ml/ha and Fast-tac Duo® @ 100ml/ha. Mesurol® (20g/kg Methiocarb) @ 5.5 kg/ha was spread across trial post sowing to control slatters, millepedes, slugs and false wireworm, with a follow-up application two weeks later.

No winter grazing of either the wheat or canola occurred in 2017 so that we could examine the long term effects (2009-2016) of the treatments on the 2017 grain yield.

Nitrogen was top-dressed on both phase 1 and 2 as urea at 130kg/ha on the 1st August. In phase 1, broadleaf weeds were sprayed with a mix of Paridigm® @ 25ml/ha and Agritone®LVE (570g/L) @ 600ml/ha. In phase 2, in-crop herbicides included Atrazine® 900WG @ 1.1kg/ha and Clethodim @ 500ml/ha. The wheat in phase 1 was sprayed with Prosaro® @ 300ml/ha and Transform® @ 100ml/ha on the 9th September and the canola in phase 2 at 20-30% flowering with Prosaro® @ 450ml/ha and Transform® @ 100ml/ha.

Grain yields were measured using a plot header harvesting the bordered inside 4 rows only of each seeder run to remove the 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 2017 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 over a 1 week period (SG and WGSG treatments) at an intensity of 2263 DSE/ha/days. In January 2017, four medium sized weaners (55kg) grazed the canola stubble and five weaners grazed the wheat stubble for 4.7days (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 was burnt (SB treatment) in mid- to late-March of each year. Summer weeds that emerged at the site were promptly controlled with herbicide.

Infiltration Measurement

At the end of the summer fallow period in March 2017, all crop residues were removed from a 1 m^2 area in three treatments (NGSR, SGSR and WGSR) where crops between 2013 and 2016 were sown with disc and deep knife point openers. The water infiltration rates were measured using a drip infiltrometer (McCallum et al., 2004), the surface soil strength (0-5mm) measured using a hand-held penetrometer (Geotester) and soil bulk density (0-5cm) measured using soil coring rings.

Soil pH measurement

In phase 1 in the NGSR treatment only, surface soil pH (0-20cm) was measured in March 2017 where both the disc and spear point opener had been used between 2013 -2016 for seed establishment. Soil samples were removed in 2.5cm increments to 10cm and 5cm increments between 10cm and 20cm. Soil pH ($CaCl^2$) was measured in 0.05M Calcium Chloride, and compared to initial soil pH ($CaCl^2$) results from 2009.

Monthly, annual and growing season rainfall (April-October inclusive) at Temora is outlined in Table 2.

Table 2: Monthly and annual rainfall data (mm) from Temora airport 2009-2017

Year	J	F	M	A	M	J	J	A	S	O	N	D	Annual (mm)	GSR (mm)
2009	22	14	16	53	7	58	32	8	24	23	24	44	327	205
2010	6	109	79	39	41	22	59	63	63	87	105	76	749	374
2011	62	196	72	17	17	18	25	46	30	48	108	64	702	201
2012	62	59	24	5	16	18	44	38	15	17	35	30	363	153
2013	10	40	20	2	52	87	18	25	29	15	47	9	354	228
2014	21	25	56	70	31	74	5	24	29	17	18	66	436	250
2015	61	21	3	49	20	51	79	54	10	13	90	29	481	276
2016	57	9	8	9	90	113	61	71	205	42	5	34	704	591
2017	22	8	44	16	29	0.2	18	49	0.6	63	48	101	399	175

Results 2017

In 2017 there was 108mm of summer rainfall (Dec 2016-March 2017), 175mm growing season rainfall (April-Oct inclusive) and a total annual rainfall of 399mm. Only 16mm of rain fell in April (8mm between the 25-27th April), so surface soil (0-5cm) was wetter in the SR treatments than in the SB treatments pre-sowing in phase 1 (Table 3) and phase 2 (Table 5). The soil moisture content was also 1 to 2% higher in the 5-15cm layer pre-sowing where stubble was retained. There was no significant rainfall until the 14th May (20mm), so the seedlings had to germinate and emerge on the stored surface soil moisture.

By the end of May 2017, there were no significant differences in wheat emergence between grazing and stubble treatments with the average population of 120 plants/m^2 (Table 4). However, significantly more plants emerged when sown with the disc opener compared to either the spear or deep knife points, irrespective of grazing treatment (Table 4).

Table 4: Wheat plant establishment populations (m^2) in Phase 1 in May 2017.

	Wheat emergence	NG	Wheat emergence SG	WGSG
Opener	(plants/m^2)	(plants /m^2)	(plants/m^2)	(plants /m^2)
Disc	130	125	130	134
Spear	120	120	133	106
Deep Knife	110	107	111	112
lsd (p=0.05)	4.9			

Table 3: Gravimetric soil moisture (0-5cm) and Soil mineral nitrogen (0-1.75m) in April 2017 across all opener types in Phase 1.

	Soil Mineral Nitrogen (0-1.75m)	Gravimetric soil moisture (0-5cm) Burn	Retain
Graze	(kgN/ha)	(%)	(%)
NG	83	4.4%	7.1%
SG	107	4.6%	5.9%
WGSG	106	3.8%	5.4%
lsd (p=0.05)	20	0.7%	

The increased emergence in the disc and spear NG or SG treatments was probably the result of improved seed placement and reduced soil moisture loss between sowing and the follow-up rain two weeks later. The reduced emergence in the WGSG treatment was due to the drier and harder soil surface. However, all treatments had sufficient plant populations to achieve yield potential in 2017.

By the end of May 2017, the average canola plant population was 46 plants/m^2 across all treatments. There were significantly fewer plants established in the NGSR compared to the NGSB (Table 5), but all treatments had > 34 canola plants/m^2. The reduction in canola emergence in the NGSR treatments was probably related to the heavy wheat stubble load (7t/ha in the NGSR vs 4-5t/ha in the WGSGSR and SGSR treatments) and was most affected when sown with deep knife points (Deep = 34 plants/m^2). However, all treatments had sufficient plant numbers to achieve potential yield. The NGSR and SGSR had higher soil moisture in the 0-5cm layer and at least 1% higher moisture in the 5-15cm layer, which assisted the plants in early growth.

Table 5: Gravimetric soil moisture (0-5cm) and Soil mineral nitrogen (0-1.75m) in April 2017, and canola plant populations (plants/m^2) across all opener types in Phase 2 in May 2017.

		Gravimetric soil moisture (0-5cm)	Mineral Nitrogen (0-1.75m)	Canola emergence
Graze	**Stubble**	(%)	(kgN/ha)	(plants/m^2)
NG	**Burn**	5.2%	91	53
SG	**Burn**	5.8%	95	47
WGSG	**Burn**	5.7%	93	43
NG	**Retain**	8.0%	103	38
SG	**Retain**	6.3%	141	46
WGSG	**Retain**	5.3%	95	52
lsd (p=0.05)		0.88%	23.7	5.7

In Phase 1 following the 2016 canola crop, there was significantly more soil mineral nitrogen (23 to 24 kgN/ha) remaining in the SG and WGSG treatments compared to the NG treatments in April 2017 (Table 3), with 65-75% of the mineral nitrogen in the surface 35cm (data not shown). Similarly, in phase 2, following the 2016 wheat crop, there was significantly more soil mineral nitrogen (38 to 50 kgN/ha) in the SGSR compared to all other treatments (Table 5), with 61-75% of the mineral nitrogen in the surface 35cm (data not shown).

Anthesis: The average wheat DM yield at anthesis in phase 1 was 7t/ha. There was significantly less wheat DM when sown with the deep knife points and a significant interaction between openers and grazing (Table 6). In phase 2, there was significantly less canola DM when sown with the deep knife point compared to both the spear and disc openers, and significantly more canola DM in the SG treatments compared to either the NG or WGSG treatments (Table 7).

Table 6: Phase 1 - Wheat dry matter (t/ha) at anthesis (18th October) for the three opener types, and the interaction between opener type and graze treatment.

	Wheat DM	**Wheat DM NG**	**(Graze x SG**	**Opener) WGSG**
Opener	(t/ha)	(t/ha)	(t/ha)	(t/ha)
Disc	7.2	6.5	7.3	7.8
Spear	7.4	7.1	7.7	7.5
Deep Knife	6.5	6.2	7.4	6.0
lsd (p=0.05)	0.34		0.97	

Table 7: Phase 2 – Canola dry matter (t/ha) at anthesis (29th September) for the three opener types, and for the three graze treatments.

	Canola DM		**Canola DM**
Opener	(t/ha)	**Grazing**	(t/ha)
Disc	6.0	**NG**	5.5
Spear	6.1	**SG**	6.3
Deep Knife	5.4	**WGSG**	5.6
lsd (p=0.05)	0.51		0.61

Crop Maturity

In Phase 1 at crop maturity, there was an average wheat DM yield of 7.2t/ha, wheat grain yield of 3.3t/ha with a protein concentration 12.2%. There were no grazing effects, but there was a significant main stubble effect with a 0.8t/ha increase in DM and 0.3t/ha in grain yield where stubble was retained (Table 8). There was also a significant main effect of opener type on wheat DM with a reduction of 0.4t/ha and an increase in protein concentration of 0.4% when the crop was established with a deep knife point (Table 8).

Table 8: Phase 1 – Main effects from the stubble treatment and opener type on wheat DM, grain yield and protein % in December 2017.

Stubble treatment	**Plant DM (t/ha)**	**Grain yield (t/ha)**	**Protein (%)**	**Gross Income 2017 ($/ha)**	**Opener**	**Plant DM (t/ha)**	**Grain yield (t/ha)**	**Protein (%)**
Burn	6.8	3.16	12.2	$838	**Disc**	7.34	3.4	11.8
Retain	7.6	3.48	12.1	$928	**Spear**	7.38	3.4	12.1
					Deep Knife	6.88	3.2	12.5
lsd (p=0.05)	0.41	0.20	ns	$50.3		0.41	ns	0.29

The average wheat gross income for 2017 was $882/ha. However, there was a significant increase in gross income of $90/ha where stubble was retained (Table 8). There was also an interaction between opener type, grazing and stubble treatment for total maturity DM, grain yield and gross income (Table 9).

Table 9: Phase 1 - Interaction between grazing treatments, stubble treatments and opener type on wheat DM at anthesis and crop maturity, grain yield, protein % and gross income in 2017.

Opener	Graze	Stubble	Anthesis DM (t/ha)	Wheat DM at maturity (t/ha)	Grain Yield (t/ha)	Protein (%)	Gross Income 2017 ($/ha)
Disc	WGSG	Retain	8.4	8.1	3.7	11.8	$995
Spear	WGSG	Retain	7.5	7.7	3.7	12.1	$979
Spear	NG	Retain	7.2	7.8	3.7	12.0	$978
Disc	SG	Retain	7.5	8.4	3.6	11.8	$950
Knife	NG	Retain	6.4	7.3	3.5	12.7	$936
Knife	SG	Retain	7.9	7.9	3.5	12.1	$936
Spear	SG	Burn	7.8	7.7	3.4	12.0	$899
Spear	SG	Retain	7.5	7.5	3.3	12.4	$891
Knife	WGSG	Burn	6.0	6.7	3.3	12.9	$883
Disc	NG	Retain	6.6	7.1	3.3	11.5	$856
Spear	WGSG	Burn	7.6	6.7	3.1	12.6	$848
Disc	SG	Burn	7.2	7.2	3.2	11.9	$836
Spear	NG	Burn	6.9	6.9	3.2	11.8	$831
Knife	WGSG	Retain	6.0	6.4	3.0	12.8	$830
Disc	WGSG	Burn	7.1	6.4	3.2	12.0	$829
Knife	NG	Burn	5.9	6.5	3.1	12.1	$829
Disc	NG	Burn	6.3	6.9	3.2	11.7	$808
Knife	SG	Burn	7.0	6.6	2.9	12.6	$780
lsd (p=0.05)			ns	1.04	0.53	ns	$132
lsd (p=0.05) same level Graze x stubble							$128
lsd (p=0.05) same level Stubble							$74

In phase 2 at crop maturity, there was an average canola DM yield of 7.3t/ha, grain yield of 2.3t/ha, oil content of 45.5% and average gross income of $1239/ha. There was significantly more canola dry matter when established with both spear and disc opener (Table 10), and there was a higher gross income when the canola was established with a disc opener compared to a deep knife point (disc @ $1308/ha cf knife @ $1173/ha).There were significant interactions between opener type and stubble treatment in grain yield, oil content and gross income with lower grain yield, reduced oil content and less gross income where the SR treatment were sown with a knife point or where the SB treatments were sown with a spear point (Table 10).

Table 10: Canola DM, grain yield and oil % and gross income from phase 2 in 2017.

Opener	Stubble treatment	Canola DM (t/ha)	Grain yield (t/ha)	Oil (%)	Gross Income 2017 ($/ha)
Disc	**Retain**	7.7	2.35	45.9	$1288
	Burn		2.37	45.6	$1328
Knife point	**Retain**	6.8	2.08	45.2	$1130
	Burn		2.23	45.7	$1216
Spear point	**Retain**	7.2	2.47	45.5	$1343
	Burn		2.09	45.2	$1131
lsd (p=0.05)		0.45	0.30	0.39	$158.5
lsd (p=0.05) same level stubble			0.26	0.23	$138.5

Results for 2010-2017

Across the eight years of the experiment in both phases (2010-2017), there has been a significant decrease in wheat grain yield in the NGSR treatment compared to the NGSB treatment (Tables 11 and 12). In 2012, 2015 and 2016, this resulted in a 0.5t/ha reduction in grain yield due to lower soil nitrogen concentrations and increased nitrogen tie up by retaining the stubble (Table 11). The soil mineral nitrogen concentration was always 15 to 20kgN/ha lower in March of each year in the NGSR compared to the NGSB treatment (data not shown). The combined effect of lower soil mineral nitrogen concentrations and lower air temperatures (Frost) in 2013 resulted in a 1.6t/ha decrease in wheat grain yield in phase 2 between the NGSR and NGSB treatments (Table 12). Similarly, the 0.6t/ha decrease in grain yield in the SGSR compared to the SGSB treatment was due to frost (Table 12). Interestingly, in 2017 in the 1st wheat crop, there was a significant increase in grain yield where stubble was retained compared to stubble burnt (Tables 8 and 11).

Table 11: Grain yield between 2010 and 2017 in Phase 1 sown with deep knife points.

Graze treatment	Stubble treatment	Canola 2010	Wheat 2011	Wheat 2012	Canola 2013	Wheat 2014	Wheat 2015	Canola 2016	Wheat 2017
NG	Retain	4.2	4.6	4.4	0.7	3.8	4.1	3.2	3.5
	Burn	4.0	4.6	5.0	1.0	3.8	4.6	3.2	3.1
SG	Retain	4.3	4.5	4.8	0.9	3.7	5.3	3.3	3.5t
	Burn	4.2	4.6	4.7	1.1	3.8	5.2	3.3	2.9
WGSG	Retain	3.9	5.2	4.5	0.7	3.4	3.6	3.1	3.0
	Burn	4.1	5.3	4.9	0.7	3.2	3.9	3.2	3.3
								ns	0.49

Table 12: Grain yield between 2010 and 2017 in Phase 2 sown with a knife point.

Graze treatment	Stubble treatment	Wheat 2010	Canola 2011	Wheat 2012	Wheat 2013	Canola 2014	Wheat 2015	Wheat 2016	Canola 2017
NG	Retain	6.3	3.4	4.5	2.0	2.0	5.5	5.2	2.2
	Burn	6.2	3.5	4.8	3.4	2.0	5.3	5.7	2.1
SG	Retain	6.2	3.3	4.8	3.0	2.2	5.6	5.3	2.2
	Burn	6.4	3.3	4.9	3.6	2.0	5.7	6.1	2.3
WGSG	Retain	6.5	3.1	4.7	2.4	1.5	3.9	5.1	1.8
	Burn	6.5	3.1	4.7	2.7	1.7	3.8	5.0	2.3
								0.35	ns

In several years (2012, 2013, 2015), the wheat grain yield in the 2nd wheat crop in the SGSR treatment was significantly higher than in the NGSR treatment. Grazing stubble increased the soil mineral N available prior to sowing and in 2015, it almost doubled the amount in phase 1. This result was verified by surface N measurements taken immediately before and immediately after stubble grazing, which showed that mineral N in the SGSR treatment was twice that in the NGSR treatment.

Gross Incomes

Averaged across both phases for the eight experimental crops, grazing and then retaining the stubble has the highest gross income (Table 13). Even if no value is placed on grazing the stubble, the SGSR treatment grossed $72/ha per year more than the NGSR treatment over the eight years. However, the difference between the NGSR and the SGSR would be greater if a value was placed on grazing the stubble. Similarly, there has been no value associated with grazing the cereal or canola in winter (WGSG treatment). Over the past eight seasons, between 300 and 800kg/ha of crop DM was removed annually by grazing in winter. The additional value of this needs to be added to the long term gross income.

Table 13: Gross income per year averaged across both phases for all years (2010-2017) of the experiment when sown with tine openers (deep knife and spear points).

Graze treatment	Stubble treatment	2010-2017 Assuming grazed stubble has no value ($/ha/yr)
NG	Retain	$1201
	Burn	$1232
SG	Retain	$1273
	Burn	$1241
WGSG	Retain	$1151
	Burn	$1170
P value		0.033
lsd (p=0.05)		$34.30

Infiltration Measurements

Grazing reduced water infiltration rates measured in March 2017 in the SG and WGSG treatments compared to the NG (Table 14). Four years of establishing crops with either a disc or a tined opener, generated no effect on water infiltration rates (average 23mm/hr) across all graze treatments (NG,SG, WGSG) where the stubble was retained (Table 14). There was also no effect of stubble on water infiltration rate with an average infiltration rate of 24.7mm/hr (Table 15). However, the infiltration rate was only reduced in the WGSG compared to the SG or NG treatments when crops were sown with a tined seeder (Table 16). However, infiltration rates in all treatments were often higher than the usual rainfall intensity in the region (Meteorology, 2016).

Table 14: The main effect of the grazing treatments where stubble was retained on the steady state infiltration rate averaged across disc and tine openers, and the main effect of opener between 2010-2017.

Graze treatment	Opener	Steady State Infiltration rate (mm/hr)	Opener	Steady State Infiltration rate (mm/hr)
NG	Disc & Tine	28.1	Disc	21.8
SG	Disc & Tine	22.6	Tine	24.1
WGSG	Disc & Tine	18.0		
lsd (P+0.05)		5.86		ns

Generally, sowing with a disc seeder increased the surface soil bulk density and soil strength compared to sowing with a tined opener, with the winter grazing treatment only increasing in soil strength and bulk density when sown with a tine opener (Table 16). However, the soil strength were not to levels detrimental to plant growth (>2000 KPa).

Table 15: The main effect of the grazing treatments on the steady state infiltration rate averaged across stubble treatment (burn and retain) between 2010-2017, and the main effect of the stubble treatment where crops were sown with a tined opener.

Graze treatment	Stubble Treatment	Steady State Infiltration rate (mm/hr)	Stubble Treatment	Steady State Infiltration rate (mm/hr)
NG	Burn & Retain	28.9	Burn	25.3
SG	Burn & Retain	24.0	Retain	24.1
WGSG	Burn & Retain	17.0		
lsd (P+0.05)		5.57		ns

Table 16: Soil bulk density and surface soil strength between the graze treatments for disc and tine openers where the wheat stubble was retained between 2010-2017.

Graze treatment	Disc (g/m^2)	Tine (g/m^2)	Soil strength (kPa)	Opener	Bulk Density (0-5cm)	Soil strength (kPa)
NGSR	1.34	1.24	442	Disc	1.35	699
SGSR	1.36	1.23	503	Tine	1.27	441
WGSGSR	1.35	1.33	765			
lsd (P=0.05)	0.09		162		0.03	58.5

Soil pH measurements

The bulk soil pH measurement (0-10cm) does not always provide a good guide for the soil pH!

The soil pH ($CaCl_2$) in the surface 0-10cm has increased between March 2009 and March 2017 following the application and initial incorporation of 2.5t/ha of lime in April 2009 by deep knife points, and inter-row sowing annually until 2012, and then by either a spear/deep knife or disc opener between 2013 and 2017. However, over the same period, the subsurface layer (10-20cm) acidified (reduced from 4.85 to 4.47).

Table 17: The changes in soil pH ($CaCl_2$) between 2009 and 2017 in Phase 1 in the NGSR treatments for disc and tine openers and soil pH in 2.5cm increments.

Depth	March 2009 Soil pH ($CaCl_2$)	March 2017 Soil pH ($CaCl_2$) Disc	Tine	Depth	Average Soil pH ($CaCl_2$)
0-10cm	4.75	5.04	5.04	0-2.5cm 2.5-5cm	5.74 5.22
10-20cm	4.85	4.44	4.49	5-7.5cm	4.73
				7.5-10cm 10-15cm 15-20cm	4.48 4.36 4.57
lsd (P=0.05)	0.09	ns			0.11

There was no significant difference in soil pH ($CaCl_2$) between opener types (disc or spear point), presumably due to the initial four years of incorporation with a deep knife point. Not only had the average soil pH in the 10-20cm layer acidified, but the depth from 7.5cm to 10cm had reduced to < pH 4.5, with the 10-15cm layer acidifying to a pH of 4.36 (Table 17).

This indicates that the practice of relying on direct drilling techniques to incorporate lime to negate the acidification of the subsoil, does not work. It is therefore recommended that enough lime be applied to increase the soil pH to 5.5 ($CaCl_2$) and the lime incorporated using offset disc plough or other mixing implement to a depth of the acidification layer. The acidification of the subsurface layer has been found at numerous locations across the Riverina and South West Slopes where crops have been sown over the past 10-15 years using no till techniques on all row spacings and even where the seed was sown at 90 degrees to the previous year's crop. One method of incorporation that reduces the possibility of erosion would be to spread the lime post-harvest onto a large cereal stubble and incorporate as soon as possible post-harvest to give sufficient time for the cereal to break down.

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