The effect of grazing and burning stubbles on wheat yield and soil mineral nitrogen in a canola-wheat-wheat crop sequence in southern NSW

Antony D Swan[1], James R Hunt[1,3], Paul D Breust[2,4], Tony Pratt[2], Brad Rheinheimer[1], Kellie Jones[2] and John A Kirkegaard[1]

[1]CSIRO Agriculture and Food, PO Box 1600 Canberra ACT 2601, tony.swan@csiro.au
[2]FarmLink Research, PO Box 240 Junee NSW 2663
[3]Present address: Department of Animal, Plant and Soil Sciences, AgriBio Centre for AgriBiosciences, 5 Ring Rd, La Trobe University, Bundoora, VIC 3086
[4]Present address: Southern Farming Systems, 23 High Street, Inverleigh VIC 3321

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 access crop stubble residues after harvest. A canola crop followed by two wheat crops (C-W-W) established using no-till seeding systems is a typical three-year crop sequence in southern New South Wales (SNSW). After harvest, growers reduce residues by grazing or burning, or retain all stubble. A long-term experiment was established in 2009 to quantify trade-offs between heavy grazing and/or burning stubble compared with retaining all stubble on soil conditions and crop performance. Here we report the effects of either grazing, burning or retaining the stubble on wheat grain yield in a C-W-W sequence over the eight years. Neither burning nor grazing increased yield in the 1st wheat crop after canola. However, both grazing and burning increased yield in the 2nd wheat crop after canola by an average of 0.7 t/ha and 0.8 t/ha respectively, and by 1.0 t/ha when applied together. This yield response was at least partly due to immobilisation of N by large amounts of high C:N ratio wheat stubble retained by the 1st wheat crop. Grazing the stubble increased soil mineral N by only 13 kg/ha in the 1st wheat crop following canola, but by 33 kg/ha in the 2nd wheat crop. Burning stubble had no impact on soil N in the first wheat crop but increased soil mineral N by 13 kg/ha in the 2nd wheat crop. In one of the eight years, burning also reduced frost-induced sterility in the 2nd wheat after canola, from 59% to 30%. Our results suggest that growers wishing to retain all stubble should avoid growing wheat after wheat, or reduce the stubble load to reduce the risk of yield penalties related to N immobilisation and frost damage.

Keywords
Wheat, canola, grain yield, nitrogen, immobilisation.

Introduction
Previous studies have highlighted potential negative yield impacts of retained stubble in SNSW (Kirkegaard 1995; Scott *et al.* 2013), but strict no-till advocates recommend retaining all of the stubble to enhance water capture and storage, 'soil health' and crop yields. A canola (*Brassica napus*) crop followed by two wheat (*Triticum aestivum*) crops (C-W-W) has been a very common crop sequence during the last decade in the no-till farming systems that predominate in southern NSW. As the area comprises 50% of farms with mixed crop livestock enterprises (Kirkegaard et al. 2011), post-harvest residue management by grazing or late burning has been part of the flexible approach to stubble management. Increasing concern has been raised about the damage of these practices to soil health which prompted an experiment to be designed to investigate impacts of stubble burning and grazing on soil conditions and crop growth.

The effect of retaining or burning stubble residue on crop yields and soil properties has been investigated in long-term studies for several decades (Thompson 1992, Kirkegaard 1995, Scott et al. 2013). In SNSW, burning stubble increased wheat yields on average by 0.2 t/ha (Kirkegaard 1995), although many causes for the response were proposed. Thompson (1992) found that in southern Queensland, a barley crop following wheat had lower N concentration and less DM at anthesis in zero-till stubble retained systems compared to zero-tilled stubble burnt systems, and there was generally significantly less soil mineral N accumulation pre-sowing in the stubble retained compared to stubble burn treatments. Other studies have also speculated that increased mineral N is a possible benefit from grazed crop fallows (Hatfield et al. 2007), while Sainju et al. (2014) found lower soil nitrate in grazed fallows compared to tilled or chemical fallow, and Allan et al. (2016) reported inconsistent responses. These studies did not remove weeds from the summer fallow, which can greatly reduce levels of soil mineral N available prior to the planting of subsequent crops (Hunt et al.

2013). In a recent experiment where summer fallow weeds were controlled as per SNSW district practice, Hunt et al. (2016) found that heavy grazing increased mineral N and grain N uptake over seven years.

We report results from a long-term (8 year) field experiment in a C-W-W sequence to determine the impact of post-harvest stubble management (heavy grazing, burning, or retaining stubble) on soil mineral N and wheat yield under no-till, controlled traffic cropping with strict summer fallow weed control.

Methods

The experiment was located on a red chromosol soil with surface pH of 4.7 ($CaCl_2$) and little slope 5 km SSE of the township of Temora in SE NSW (S 34.49°, E 147.51°, 299 m ASL). Treatments were applied in two different phases in adjoining areas of a 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 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. Lime was evenly applied at a rate of 2.5 t/ha across all plots in April 2009.

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
Phase 1	P	W	C	W	**W**	C	W	**W**	C
Phase 2	P	P	W	C	W	**W**	C	W	**W**

In both phases, the two grazing treatments (nil graze – NG, stubble graze – SG) were applied in a factorial randomised complete block design with two stubble management treatments (stubble burn – SB, stubble retain – SR) and four replicates. Following harvest in each year (late November-early December), weaner ewes grazed stubbles in the SG treatment (average 2263 sheep.days/ha). The stubble burn treatments were applied in mid to late March of each year.

Crops were sown in mid-late April in all years of the experiment, and both crop phases were kept in a rotation of canola-wheat-wheat. All crops in both phases between 2009 and 2016 were inter-row sown using a plot seeder equipped with contemporary no-till seeding equipment consisting of six Flexi-Coil 250 kg break out tines set on 305 mm row spacing and fitted with Agmaster® boots, 12 mm knife points and press wheels. 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. The same rate of synthetic fertilisers were applied to all treatments determined annually following soil analysis to ensure the treatment with the lowest mineral nitrogen concentration was able to yield to 70% of maximum potential as determined by Yield Profit® for that year.

Prior to seeding each year two soil cores (42 mm diameter) were taken per plot to a depth of 1.6 m and segmented for analysis (0.1 segments to 0.2 m depth and 0.2 m segments to 1.6 m depth). Six additional cores were taken for 0-0.1 m and 0.1-0.2 m depths, and cores were bulked according to depths. Soil from each depth increment was analysed for mineral N (NH_4 and NO_3). 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. Grain yields were also measured by hand harvesting large areas (> 1.0 m^2) of crop and threshing to measure the total dry matter production, harvest index and to estimate the amount of crop residue returned to the plot.

Soil mineral N and grain yield were analysed using mixed linear models with grazing, stubble, rotational position (1st or 2nd wheat crop after canola) and year as fixed effects, and block and phase as random effects 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 for the 95% confidence level, estimated by doubling the average standard error of means.

Results

Neither burning nor grazing affected yield in the 1st wheat crop after canola (Table 2). However, both heavy grazing and burning increased yield in the second wheat crop after canola and the effects were partly additive (Table 2). Across all years, grazing and burning alone increased yield of the 2nd wheat crop on average by

0.7 t/ha and 0.8 t/ha respectively, but when applied together increased yield by 1.0 t/ha. In three of the four phase years in which the 2nd wheat crop was grown, burning increased yield by between 0.5 and 0.6 t/ha, but in one year (2013) by 1.4 t/ha.

Table 2. Mean grain yield (t/ha) for either 1st or 2nd wheat crop following canola under different grazing and stubble treatments. P-value and LSD are from the three-way interaction between grazing treatment, stubble treatment and rotational position and means followed by the same letters are not significantly different from each other.

		Rotational position	
Graze treatment	Stubble treatment	1st wheat	2nd wheat
Nil Graze	Retain	4.58[b]	3.93[c]
Stubble graze	Retain	4.63[b]	4.58[b]
Nil Graze	Burn	4.63[b]	4.68[b]
Stubble graze	Burn	4.73[ab]	4.89[a]
	P-value	0.007	
	LSD (P=0.05)	0.18	

Grazing stubble increased soil mineral N by 13 kg/ha in the first wheat crop (Table 3) and by 33 kg/ha in the 2nd wheat crop, and there was no interaction between grazing and stubble treatments. Burning stubble had no significant effect on soil mineral N in the 1st wheat crop, but increased soil mineral N by an average of 13 kg/ha in the 2nd wheat crop (Table 3).

Table 3. Mean soil mineral N (kg/ha N) to 1.6 m depth prior to sowing following either 1st or 2nd wheat crops following canola for different grazing and stubble treatments. P-values and LSDs are for two way interactions between either grazing treatment of stubble treatment and rotational position.

	Grazing treatment		Stubble treatment	
Rotational position	Nil graze	Stubble graze	Burn	Retain
1st wheat	107	120	110	117
2nd wheat	92	125	115	102
P-value	0.031		0.035	
LSD (P=0.05)	13		13	

Discussion

Grazing and burning canola stubbles had no effect on yield of the 1st wheat crop following canola, but grazing or burning the stubble of the first wheat crop increased yield substantially in the 2nd wheat crop. Whilst this difference could logically be attributed to various biotic mechanisms such as disease, no treatment differences were recorded within the very low level of stubble-borne diseases (yellow leaf spot, crown rot, *Zymoseptoria tritici*) that were present at the site in some years. It thus appears more likely that N dynamics are principally responsible for the observed differences in yield. Grazing and burning stubbles increased soil mineral N accumulation during the summer fallow to a much greater extent in the 2nd wheat crop compared to the 1st wheat crop presumably due to both higher amounts and higher C:N ratio of wheat stubble compared to canola stubble which would lead to more N immobilisation (Hunt et al. 2016). The average increase in mineral N due to grazing in the 2nd wheat treatment was 33 kg/ha N. Hunt et al. (2016) suggested that grazing either removed C from the system or neutralised C with potential immobilising power of 52 kg/ha N. Under the no till surface-retained residue management practiced at this site, immobilisation would presumably occur over several years as residues slowly decompose.

The greater effect of grazing stubble on mineral N compared to burning stubble in this experiment is likely due to differences in the timing of the two treatments with respect to soil measurement. The grazing treatment was applied immediately after harvest, giving 4 to 5 to months between removal of stubble by grazing and measurement of soil N. In contrast, the burn treatment was applied only ~1 month before measurement of soil mineral N, giving less time for differences in N immobilisation to act before the pre-sowing soil N tests. Both treatments influenced grain yield as they both would have presumably altered in-season net N mineralisation. In the experiment of Thompson (1992), a treatment in which stubble was burnt immediately following harvest was found to increase soil mineral N prior to sowing substantially (~50 kg/ha N where no N was added, or 80 kg/ha N where 46 kg/ha N added yearly for 7 years) relative to a stubble retain control and a treatment in which stubble was burnt prior to sowing. The results suggest that where disease is absent or controlled and good crop establishment achieved, N immobilisation by wheat residue can significantly reduce crop yield in subsequent wheat crops.

Beyond the effects of N dynamics on grain yield, burning stubble also reduced frost-induced sterility of the 2nd wheat crop from 59 to 30% following severe frosts of -2.6ºC, -1.8ºC and -3.6ºC (screen temperatures) that occurred on the 15, 16 and 18 October in 2013. In that year, grazing increased yield of the 2nd wheat crop by 1.0 t/ha, burning by 1.4 t/ha and combined by 1.6 t/ha. However, no differences in frost-induced sterility was measured in any other year of the experiment.

Conclusion

Grazing wheat stubbles can increase the yield of subsequent wheat crops due to less immobilisation and greater availability of mineral N to subsequent wheat crops. Burning wheat stubble residues also increased yield of subsequent wheat crops, but did not increase pre-sowing soil mineral N to the same extent as grazing, possibly due to later timing. However, both treatments presumably influenced in-crop N availability and thereby crop yield. Burning wheat stubble can also reduce frost damage in subsequent wheat crops and increase yield accordingly in frosty seasons. We recommend that growers wishing to retain all stubble should avoid growing wheat after wheat, that residue loads are reduced by grazing and/or burning where wheat is to be grown following wheat, or supplementary N is applied to offset that immobilised by the residue.

References

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

Hatfield PG, Goosey HB, Spezzano TM, Blodgett SL, Lensen AW, Kott RW and 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.

Hunt JR, Browne C, McBeath T, Verburg K, Craig S and 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 and Pasture Science 64, 922-934.

Hunt JR, Swan AD, Breust PD, Peoples MB and Kirkegaard JA (2016). Sheep grazing on crop residues increase soil mineral N and grain N uptake in subsequent wheat crops. In: Proceedings of the 2016 International Nitrogen Initiative Conference, Solutions to improve nitrogen use efficiency for the world, 4-8 December 2016, Melbourne, VIC. (www.ini2016.com).

Kirkegaard JA (1995). A review of trends in wheat yield responses to conservation cropping in Australia. Australian Journal of Experimental Agriculture 35, 835-48.

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

Sainju UM, Barsotti JL, Lenssen AW and 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.

Scott BJ, Podmore CM, Burns HM, Bowden PI and McMaster CL (2013). Development in stubble retention in cropping systems in southern Australia on Project DAN 00170. (http://www.csu.edu.au/research/grahamcentre/research/Pub_downloads/Developments-in-Stubble-Retention-in-Cropping-Systems-in-Southern-Australia-11Dec2013.pdf). (https://grdc.com.au/.../Developments-in-Stubble-Retention-in-Cropping-Systems-in-Southern Australia).

Thompson JP (1992). Soil biotic and biochemical factors in a long-term tillage and stubble management experiment on a vertisol. 2. Nitrogen deficiency with zero tillage and stubble retention. Soil and Tillage Research 22, 339-361.