

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

James R Hunt^{1,3}, Antony D Swan¹, Paul D Breust^{2,4}, Mark B Peoples¹, John A Kirkegaard¹

¹CSIRO Agriculture & Food, PO Box 1600 Canberra ACT 2601 Australia

²FarmLink Research, PO Box 240 Junee NSW 2663 Australia

³Present address: Department of Animal, Plant and Soil Sciences, AgriBio Centre for AgriBiosciences, 5 Ring Rd, La Trobe University, Bundoora 3086, Australia j.hunt@latrobe.edu.au

⁴Present 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 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.

Key Words

Wheat, canola, grain yield, protein, immobilisation

Introduction

A livestock enterprise, particularly sheep (*Ovis aries*), in conjunction with a wheat-based (*Triticum aestivum*) 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 P and S fertilisers were applied as required such that nutrient deficiency did not limit yield. N was top-dressed during stem elongation as urea according to seasonal yield potential, but grain protein contents less than 10.5% were recorded in 2012 and 2015 indicating yields were probably N limited in those years.

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 m²) 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.

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

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

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).

Table 2. Soil mineral N ($\text{NO}_3 + \text{NH}_4$, 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	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	0.018	
LSD (P=0.05)	26	

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.

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.

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	<0.001		
LSD (p=0.05)	8		

Discussion

Grazing stubbles 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 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 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 practiced at this site residues takes 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-type environment 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 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.