Improving nitrogen fertiliser use efficiency in wheat using mid-row banding

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Abstract
Experiments in controlled conditions have shown possible improvements in nitrogen use efficiency from concentrating ammonia-based fertiliser in bands mid-way between crop rows. The advantages result from delaying nitrification of fertiliser by suppressing nitrifying microbes. This is best achieved at high concentrations of ammonium resulting in a slow prolonged release of nitrogen (N) to the crop. This technique known as mid-row banding (MRB) offers potential to, reduce excess seedling growth, lower denitrification and nitrate leaching losses, reduce immobilisation and provide an opportunity for root proliferation around the ammonium band at a time of high plant N demand. These advantages have not been shown conclusively in field based studies.

In a preliminary field experiment, urea was banded at sowing between every second wheat row at concentrations sufficient to temporarily suppress nitrifying bacteria (Mid-row banding [MRB]). Nitrogen offtake in grain was higher with MRB urea than urea broadcast and incorporated by sowing for both Beckom and Spitfire at the 80, 120 and 160 kg/ha rates of N application. Apparent fertiliser recovery in grain was also higher from MRB urea than from urea broadcast and incorporated by sowing in five of the eight treatment comparisons. Soils cored at stem elongation from the MRB treatment showed higher ammonium levels in the top 20 cm and lower nitrate concentration at 60-100 cm than urea broadcast and incorporated by sowing. Roots proliferated around and below the original MRB. These results indicate potential for MRB to improve N use efficiency.

Keywords
Nitrogen use efficiency, nitrogen take-off, urea, ammonium.

Introduction
Fertiliser costs represent 20-25% of variable costs for growing grain crops and the proportion is likely to increase with continued mining of native soil N (Angus and Grace 2017). Typically nitrogen (N) fertiliser is applied to wheat at sowing (mainly MAP or DAP drilled with the seed and urea incorporated by sowing) and again as urea broadcast before or during stem elongation. The in-crop efficiencies of fertiliser N retrieval vary greatly, with approximately 44% in above-ground plant parts, 34% in soil and 22% not recovered, presumably lost (Angus and Grace 2017). Increases in the efficiency with which wheat extracts fertiliser N from the soil can result in significant fertiliser savings. In this experiment we compared three methods of N supply to wheat (surface broadcast and incorporated by sowing, MRB at sowing, and broadcasting at stem elongation) and report the N efficiency of each method.

Methods
This experiment was conducted at Wagga Wagga Agricultural Institute, NSW and included 3 wheat varieties, 6 N rates and 3 N application methods with all N applied as urea (Table 1) in a fully randomised complete block design with four replicates. Rainfall for the growing season was 614 mm (May to October).

Table 1. Varieties, N rates and N application methods.

Variety	x	N rate (kg/ha)	x	Application method
Beckom		0		Mid-row banding (May 4)
Spitfire		25		Spread before sowing (May 4)
Corack		50		Spread at DC31 (July 21)
		80		
		120		
		160		

For all application methods, the rates of N from 50 to 160 kg/ha included 25 kg N/ha applied below each seed row and the rest applied by the specified method (Table 1). Data reported are for cv. Beckom (AH classification) and cv. Spitfire (APH classification). The soil at the experimental sites is a red Kandosol, pH_{Ca} 5.1 (0–10 cm) which had a starting mineral N content of 142 kg/ha to a depth of 1.5 m (May 4). At sowing triple superphosphate was drilled 50 mm below seed at 25 kg P/ha. The mean plant density achieved at DC14 was 125 plants/m^2 and was not significantly different between treatments. The plots were direct drilled, and weeds, fungal diseases and insects were controlled with recommended agrochemicals.

The experiment was harvested on 15 December 2016 to determine grain yield. Grain protein and seed quality were estimated using NIR (Foss Infratec 1241 Grain Analyzer) and Seed Imaging (SeedCount SC5000R) respectively. Nitrogen offtake was estimated by protein (%) / 5.7 (conversion constant) x grain yield (t/ha). The proportion of apparent fertiliser N recovery in grain was calculated by ($GrainN_{+N}$ – $GrainN_{-N}$)/N rate where $GrainN_{+N}$ is the grain yield with fertiliser N, $GrainN_{-N}$ is grain yield with no fertiliser N and N rate is the amount of fertiliser N applied. Economic returns after N costs were determined on 2016 prices by multiplying grain yield (t/ha) by $160 for ASW1, $181 for APW1 (>10.5% protein), $209 for H2 (>11.5% protein) or $243 for APH2 (>13% protein). All other criteria (test weight, screenings and stained grain) were within grain category standards. N costs as urea were assumed to be $1/kg of N.

Soil mineral N was measured for the variety Beckom at sowing (May 4), DC31 (29 July) and anthesis (30 September) by coring to 200 cm and measuring soil ammonium and nitrate at depths 0-10, 10-20, 20-30, 30-60, 60-100, 100-150 and 150-200 cm. Root length was measured in the Beckom plots at 160 kg N/ha by soil coring to 150 cm. Cores were taken mid-way between the fertiliser band and the plant row. The cores were then washed and the roots retained for root length determination using Winrhizo.

Results

Beckom yielded higher than Spitfire and both had increasing grain yield in response to increasing N fertiliser. The grain protein of Beckom was generally lower than Spitfire but the N offtakes of the two varieties were similar (Table 2.) There were no yield effects of application method (P>0.05).

Table 2. Grain yield, grain protein, N offtakes and net return after N costs for the wheat varieties Beckom and Spitfire. Bold indicates the highest value within each N treatment.

	Beckom				Spitfire			
Treatment	Grain yield (t/ha)	Grain protein (%)	N offtake (kg/ha)	Net ($/ha) after N costs	Grain yield (t/ha)	Grain protein (%)	N offtake (kg/ha)	Net ($/ha) after N costs
nil_0	5.9	10.5	110.9	$1,019	5.2	10.6	97.0	$ 891
seed_25	6.2	10.3	111.7	$1,030	5.6	10.8	106.0	$ 955
MRB_50	6.8	11.3	133.7	$1,201	5.7	12.9	130.2	$1,247
MRB_80	7.1	12.0	150.2	**$1,409**	6.0	13.5	141.4	$1,322
MRB_120	**7.3**	12.2	155.7	$1,399	**6.3**	13.9	154.8	**$1,420**
MRB_160	**7.3**	**12.7**	**161.9**	$1,360	6.2	**14.6**	**159.2**	$1,355
DC31_50	6.8	11.0	132.2	$1,248	5.6	12.5	123.9	$1,174
DC31_80	7.0	11.5	142.4	$1,340	5.9	13.2	136.8	$1,253
DC31_120	**7.3**	12.4	157.2	**$1,397**	**6.2**	13.2	144.8	$1,292
DC31_160	**7.3**	**12.7**	**161.9**	$1,363	**6.2**	**14.5**	**157.2**	**$1,347**
PreSowing_50	6.6	10.5	122.2	$1,079	5.7	12.6	125.4	$1,147
PreSowing_80	6.9	11.3	137.8	$1,225	5.7	12.6	127.0	$1,166
PreSowing_120	**7.2**	11.8	147.7	**$1,343**	**6.1**	12.9	137.9	$1,252
PreSowing_160	7.1	**12.1**	**151.6**	$1,333	6.0	**13.4**	**141.7**	**$1,305**
LSD P=0.05	0.3	0.90	7.6	$ 114	0.3	0.92	7.6	$ 114

Nitrogen offtake in grain was used as an estimate of N efficiency for the different N application methods tested. These results show that applying N at sowing using MRB and surface spreading N at stem elongation (DC31) was more efficient (higher N offtake) than N spread and incorporated at sowing (Table 2). This efficiency difference was evident across most N rates from 50 to 160 kg N/ha and occurred even when different N partitioning (yield verses protein) was evident between the two wheat varieties Beckom and Spitfire (Table 2).

Economic returns after considering N costs, wheat variety, grain protein, screenings, test weight and stained grain are estimated in Table 2 for Beckom and Spitfire respectively. Returns for Beckom were highest in the N banding treatment at 80 kg N/ha ($1,409) while the highest return for the DC30 and pre-sowing treatments occurred at 120 kg N/ha ($1,397 and $1,343 respectively). Returns for Spitfire were highest in the N banding treatment at 120 kg N/ha ($1,420) and highest for the DC30 and pre-sowing treatments at 160 kg N/ha ($1,347 and $1,305 respectively). Mid-row banding was significantly more profitable in one of the four economic comparisons (Table 2).

The proportion of apparent fertiliser N recovery in grain was higher for Spitfire than Beckom. There was also a tendency for the proportion of apparent fertiliser N recovery in grain to be higher in MRB compared with the pre-sowing method of N application; although this did not occur at all N rates (Figure 1).

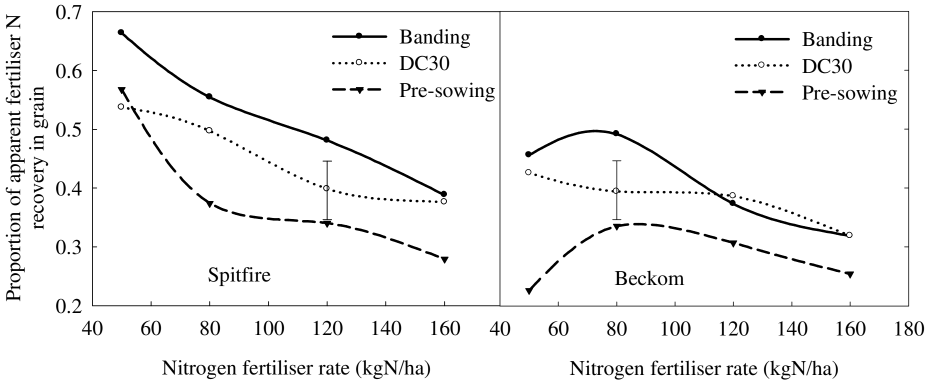

Figure 1. Apparent fertiliser-N recovery in grain for varieties Spitfire and Beckom in relation to three methods of N application and four N rates.

Root length (cm) measured in the 160 kg N/ha treatments at anthesis for Beckom were significantly higher for MRB than for the other treatments in the 10 to 20 cm layer. Root length in the pre-sowing treatment was significantly higher than the other treatments in the 60 to 100 cm layer.

Table 3. Root length (cm) measured in the 160 kg N/ha treatments at anthesis for cv. Beckom for depths 0-10, 10-20, 20-30, 30-60, 60-100, 100-150 and 150-200 cm.

Treatment	0-10 cm	10-20	20-30	30-60	60-100	100-150	Total
nil_0	2247	204	148	771	1035	65	4470
MRB_160	2375	**1126**	373	901	1436	49	6260
DC30_160	2160	510	210	755	1243	35	4913
PreSowing_160	1427	546	218	860	**1716**	70	4837
LSD P=0.05	341*						

*LSD applies to all depths.

The MRB conserved ammonium at 10-20 cm, providing evidence that the conservation of N as ammonium from sowing (May 4) to DC31 (July 29) is possible even under very wet conditions conducive to leaching. N applied pre-sowing and measured at DC31 had converted to nitrate and leached down the soil profile to a depth of 60 to 100 cm. N applied to the soil surface at DC30 (July 14) and measured at DC31 (July 29) showed N was largely in the ammonium form in the 0 to 10 cm layer (Figure 2).

Discussion

The maximum yield of ~7 t/ha achieved in this experiment is within the predicted grain yield determined by the Photothermal Quotient of Rawson (1988), suggesting that the crops at this yield were not N limited. Further evidence of this is also provided by the apparent plateau of grain yield at the two highest N rates (Table 3).

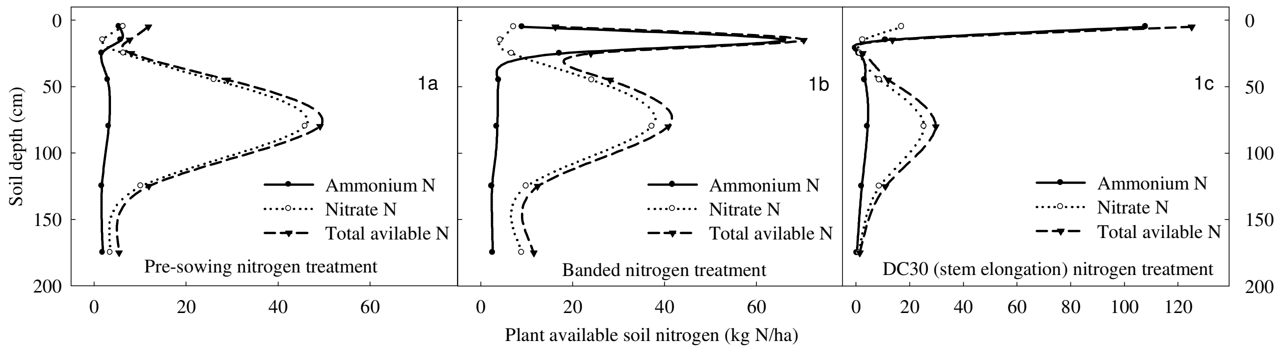

Figure 2. Nitrate, ammonium and total soil available N (kg/ha) for the pre-sowing MRB and DC30 application methods measured at DC31 (last week of July). Soil measurement depths were 0-10, 10-20, 20-30, 30-60, 60-100, 100-150 and 150-200 cm. For graphing purposes, the soil depth data is presented at the following depths 5, 15, 25, 40, 80, 125 and 175 cm. Topdressing of urea at DC30 occurred 15 days prior to soil coring.

This experiment tested part of a theoretical framework aimed at improving N fertiliser use efficiency. The components tested in this experiment related to holding applied urea in an ammonium form for longer and determining if wheat would proliferate roots around the ammonium band where the supply of nitrogen was greatest. The results show (i) increased ammonium levels from MRB at depths above 20 cm observed 86 days after banding urea, (ii) root proliferation adjacent to urea bands 151 days after sowing, (iii) higher N offtake and high apparent fertiliser recover in grain when MRB was compared with spread and incorporated at sowing.

Previous experiments examining MRB at sowing (Angus et al. 2014) were conducted under drought conditions (experiment 1) or at excessively high levels of mineral N (217 kg N/ha 0-1.6 m, experiment 2) consequently it is possible that treatment differences were masked by these conditions. Angus et al. (2014) concluded that there were no consistent grain yield differences gained by banding N at sowing however banding did reduce excessive seedling growth and reduced the potential risk of haying-off. Anon (2016) reported MRB at stem elongation provided an improvement in fertiliser N recovery in grain of between 9.7 and 33.8% compared to surface application, although significant grain yield increases where not recorded. Norton et al. (2003) found across 14 experiments in western Victoria on alkaline soils that MRB at sowing provided higher yields than spread and incorporated by sowing. These yield benefits of MRB were attributed to N being held in the top soil away from salt, sodicity and/or high boron in the subsoil.

Conclusion

The highest N removal rates were achieved by MRB and the most profitable rate of nitrogen was always lower for MRB than that for other N application methods. The method of MRB may provide growers with an alternative strategy to improve nitrogen use efficiency in wheat by providing improved recovery of N in grain compared with other methods. The results of the present experiment on the use of MRB are sufficiently promising to justify more detailed research on this topic.

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