Mid-row banding nitrogen fertiliser in-season

Improving nitrogen use efficiency of cropping systems of southern Australia

Economic Development, Jobs, Transport and Resources

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

AGRICULTURE VICTORIA

Contents

CMI number: 105479

Authors: Ashley Wallace
James Nuttall
Frank Henry
Genevieve Clarke
Jasmine Marsh

SUMMARY

- Trials conducted during 2016 in the Wimmera and Mallee, Victoria showed that mid-row banding of nitrogen increased fertiliser uptake by an average of 46% (40-52%) in wheat compared to other application methods.
- Over the last 20 years, Victoria's dryland cropping systems have moved towards in-season application of nitrogen fertilisers to manage variable seasonal conditions.
- Applying nitrogen during the growing season better matches the timing of application to crop demand, but can increase risk of losses due to volatilisation when fertiliser is surface applied.
- Mid-row banding of fertiliser during the season can improve placement compared to topdressing and decrease the risk of nitrogen loss while maintaining the benefits of deferring this significant financial outlay.
- Trials were undertaken at Quambatook and Longerenong in 2016 to assess the effect of mid-row banding nitrogen fertiliser (urea) in comparison to top-dressed granular and a range of other liquid based methods of application.
- Exceptional growing season rainfall during 2016 resulted in high yield potential and significant responses to applied nitrogen at all rates tested.
- Mid-row banding of nitrogen fertiliser consistently resulted in the highest grain yield compared with other methods of application, increasing yields by 0.2-0.5 t/ha.
- Mid-row banding of N has the potential to improve nitrogen use efficiency and is likely to offer a range of risk management and logistical benefits.
- We are validating these initial results with further trials at Ultima, Horsham and Telangatuk, Victoria in 2017

INTRODUCTION

Managing nitrogen (N) fertilisers in dryland cropping is complex; uncertainty of crop demand, difficulty in predicting in-season mineralisation, potential losses and microbial tie-up are several factors that affect the efficacy of N application. Delayed application and banding of fertiliser below the soil surface, through mid-row banding (MRB) may help to reduce some of these risks.

Timing N application to match crop demand and reduce risk

The time when crops are sown in Victoria coincides with a period when seasonal forecasts have limited accuracy, thus making decisions around N application up-front difficult and risky. Given the poor seasons experienced during the millennium drought there has been a significant swing towards in-season management of N fertiliser in Victoria's dryland cropping regions. By applying the bulk of fertiliser N during the growing season, particularly in the lead-up to peak demand during stem elongation; growers can match the timing of nutrient supply to crop demand with the additional benefit of greater knowledge of seasonal conditions and improved forecasting skill. However, this strategy also increases the risk of N loss through volatilisation of ammonia when fertilisers such as urea are surface applied. To avoid excessive losses through volatilisation, best practice is to apply fertiliser prior to a significant rainfall front (Turner et al. 2012), although achieving this is challenging.

Banding N to reduce losses and improve nitrogen use efficiency

Previous studies have indicated that applying N below the soil surface can reduce the risk of ammonia volatilization (Fenn and Miyamoto 1981; Rochette et al. 2013). It has also been found that applying N in concentrated bands below the surface is likely to slow the conversion of fertiliser N into nitrate (Wetselaar et al. 1972), potentially reducing microbial tie-up of fertiliser N as well as losses to denitrification and leaching.

The practice of MRB fertiliser; where N is applied below the surface to every second inter-row, has been tested elsewhere (Angus et al. 2014; Campbell et al. 1990; Campbell et al. 1991; Lemke et al. 2009). However, this has generally focused on fertiliser application at sowing and applying N during the season using MRB is a relatively new concept. By applying N to every second inter-row during the season using precision guidance it may be possible to reduce the risks of N losses and tie-up, improve responsiveness to seasonal conditions, more accurately apply N and improve overall nitrogen use efficiency (NUE). With regard to the 'Four-R's' framework for good fertiliser management (International Plant Nutrition Institute 2015), MRB in season may help to meet the criterion of 'Right time' and 'Right place' leaving only the 'Right rate' and 'Right form' principles to address.

This report outlines findings from a series of experiments undertaken in 2016 to assess the potential benefits of utilising MRB of N fertiliser during the season to improve NUE.

METHODS

Experimental sites

In 2016, sites were established at Quambatook (red clay loam) in the Mallee and at Longerenong (grey clay) in the Wimmera. Soil analysis prior to sowing indicated moderate levels of mineral N at both sites to a depth of 1.2m (Table 1). Colwell P levels were high and topsoil pH was neutral, increasing to slightly alkaline at depth at both sites. Plant available soil water was low at both sites.

Table 1. Soil characterisation at experimental sites a) Quambatook and b) Longerenong - prior to sowing. Values in parentheses are standard error of the mean (*n*=4).

a)

Depth (cm)	NH_4^+-N (kg/ha)	NO_3^--N (kg/ha)	Colwell P (mg/kg)	EC (dS/m)	pH ($CaCl_2$)	pH (H_2O)	Boron (mg/kg)	Total Nitrogen (%)	Total Carbon (%)	Organic carbon (%)
0-10	3.0 (1.22)	17.9 (0.79)	29.8 (4.05)	0.15 (0.037)	7.4 (0.05)	8.4 (0.1)	2.5 (0.35)	0.13 (0.002)	1.06 (0.02)	0.8 (0.02)
10-20	1.5 (0.09)	7.7 (0.77)		0.17 (0.023)	7.9 (0.14)	8.8 (0.08)	4.2 (0.49)			
20-40	2.4 (0.3)	5.3 (0.51)		0.54 (0.22)	8.2 (0.04)	9.2 (0.04)	11.4 (3.73)			
40-80	4.6 (0.44)	6.7 (0.44)		0.43 (0.045)	8.3 (0.17)	9.7 (0.1)	19.3 (1.54)			
80-120	5.1 (0.94)	8 (1.06)		0.52 (0.075)	8.3 (0.06)	9.5 (0.08)	19.3 (2.84)			
Total	*17*	*45*								

b)

Depth (cm)	NH_4^+-N (kg/ha)	NO_3^--N (kg/ha)	Colwell P (mg/kg)	EC (dS/m)	pH ($CaCl_2$)	pH (H_2O)	Boron (mg/kg)	Total Nitrogen (%)	Total Carbon (%)	Organic carbon (%)
0-10	2.0 (0.07)	21.3 (1.75)	52.5 (6.49)	0.21 (0.009)	7.4 (0.06)	8.3 (0.02)	2.7 (0.03)	0.16 (0.006)	1.6 (0.06)	1 (0.05)
10-20	2.0 (0.09)	9.4 (3.12)		0.15 (0.016)	7.8 (0.08)	8.7 (0.07)	3.6 (0.12)			
20-40	2.9 (0.15)	5.5 (0.29)		0.22 (0.04)	8 (0.14)	9.1 (0.12)	4.9 (0.32)			
40-80	5.6 (0.5)	10.3 (0.61)		0.56 (0.065)	8.2 (0.18)	9.2 (0.05)	17.2 (1.5)			
80-120	6.7 (0.62)	15.3 (4.22)		1.24 (0.107)	8.2 (0.04)	9.2 (0.14)	29.3 (2.09)			
Total	19	62								

Crop management

Wheat (*Triticum aestivum*, *cv.* Mace) was sown at Quambatook on 18-May and Longerenong on 31-May with 50 kg/ha of Granulock Z fertiliser (11% N, 22% P, 4% S, 1% Zn). Plots were sown into standing wheat residues using knife-point tynes with press wheels at a 30cm row spacing. Weeds were controlled by herbicide applications prior to sowing and in July, diseases were controlled using fungicide applications during July (Quambatook only) and September with insecticides applied during September. All chemicals and rates used were in line with local best practice.

Experimental design

Experiments were a randomised complete block design with four replicates. Treatments included a range of N fertiliser application methods, rates and times (Table 2). Mid-row banded treatments were applied using a three-point linkage mounted fertiliser banding machine (Fig 1) which used twin disc openers to place fertiliser at a depth of 25-35 mm below the soil surface. Each pair of discs was followed by a press wheel to assist with closing the furrow. Disc openers were positioned in the centre of every second inter-row space and additional controls were included where the disc openers were used without fertiliser. Mid-row surface treatments were applied using the same machine, but with fertiliser placed on the soil surface and the disc openers not engaging the soil. Streaming sprays were applied using a spray bar with nozzles spaced evenly across the plot alternating between crop and inter-row spaces and delivering a steady, low volume stream of fertiliser. Flat fan sprays were applied using 'Turbo teejet induction nozzles, TTI11003' to deliver extra course droplets across the crop canopy.

Fertiliser treatments were applied between the start of stem elongation (GS30) and second node (GS32) growth stages (Zadoks et al. 1974). This timing was chosen as previous studies have indicated that peak crop demand occurs during stem elongation and that application of N can be delayed until the start of stem elongation with limited impact on yield (Angus 2001; Fischer et al. 1993). At each site, the first time of application coincided with forecast rainfall in the days following, while the second time of application coincided with a dry forecast in the days following. This approach was used to examine the effects of rainfall following application on potential losses of N and fertiliser use efficiency of the crop. At Quambatook, N fertiliser was applied as granular urea dissolved into water at a concentration of 14% N (w/v). At Longerenong, applications were made using a commercially available urea solution; 'Ranger®' with a concentration of 24% N (w/v). Application speed was set for the highest N rate and fertiliser diluted for the lower application rates. All top-dressed treatments were applied as granular urea, spread on the soil surface.

Table 2. Post sowing nitrogen fertiliser treatments, outlining the methods, rate and time of application for various treatments at Quambatook and Longerenong experimental sites.

Site	Method of application	1st time of application	2nd time of application	Rates of application (kg N/ha)
Quambatook	0N control			0
	Mid-row banded	29-July GS30	8-August GS31	0, ^25, 50,100#
	Mid-row surface			^25, 50, 100#
	Top-dressed granular			15#, 25, 50, 90#
	Streaming spray	N/A		25, 50
Longerenong	0N control			0
	Mid-row banded			0, 25, 50
	Mid-row surface	26-Aug GS32	6-September GS32	25, 50
	Top-dressed granular			15#, 25, 50, 90#
	Streaming spray			25, 50
	Flat fan spray			25, 50

^Rate not applied at the first time of application.

#Rate not applied at the second time of application.

Figure 1. Fertiliser banding bar showing twin disc openers and press wheels with fertiliser spray boom (streaming and flat fan nozzle capable) at the rear.

Crop, soil and weather measurements

Quadrat cuts ($1.2m^2$) were taken from all plots at both anthesis and harvest. Samples were dried at 70°C with anthesis samples ground in preparation for total N analysis. Harvest samples were hand thrashed and weighed before being assessed for grain weight. The remaining straw was then ground and all plant samples were analysed for total N content by dry combustion (LECO) to determine total above ground N uptake. At harvest, the remainder of each plot was harvested using a plot harvester and grain samples analysed for grain protein, screenings, moisture and test weight. All results were analysed by ANOVA using GenStat, 17th Edition (Payne et al. 2014).

Soil cores were taken at harvest to a depth of 1.2m for the 0N control and analysed for mineral N content to enable estimation of net in-season mineralisation based on starting soil N, crop N uptake and residual N (Armstrong et al. 1999). Air temperature and rainfall was measured at each site using a TinyTag (Hastings data loggers) temperature logger installed in a screen at a height of 1.2m combined with a tipping bucket rain gauge. Prior to weather station installation or where technical failure resulted in data gaps, these were infilled using data from the nearest Bureau of Meteorology station (www.bom.gov.au).

Recovery of applied N at harvest using a ^{15}N mass balance approach

Fertiliser recovery (above ground crop and soil) was measured using a ^{15}N mass balance approach. This was undertaken for a subset of treatments; mid-row banded, mid-row surface and streaming spray applications at 50 kg N/ha and both times of application. Enriched urea (10.1% ^{15}N) was applied to microplots nested within the broader trial enabling accurate partitioning of N sourced from the enriched fertiliser versus soil derived N (typically 0.36% ^{15}N). Steel micro-plots (60 x 30 cm) were inserted into the unfertilised buffer at the end of each plot to a depth of 20 cm. Enriched urea was dissolved in water and applied at the same rates, timing and placement as the main plots. Micro-plots were harvested and processed consistent with the method used for quadrats from the main plots. Soil from each micro-plot was completely excavated at depths of 0-10 and 10-20 cm with additional cores taken from 20 to 40 cm. Soils were dried at 40°C, thoroughly mixed and subsampled prior to fine grinding in preparation for analysis. Plant and soil samples were analysed for total N and $\delta^{15}N$ by IRMS (SERCON 20-22, Sercon, UK) with samples from the 0N plots used to quantify natural abundance of ^{15}N. Fertiliser recovery was calculated using the approach of Malhi et al. (2004) and analysed by ANOVA.

RESULTS AND DISCUSSION

Seasonal conditions during 2016

Rainfall at Quambatook and Longerenong during 2016 was above average, in particular during September when rainfall was over four times the monthly average at Quambatook and more than twice the monthly average at Longerenong (Fig 2). Frosts were infrequent at Quambatook and while some frosts were measured at Longerenong through mid-October, visual indications of frost damage were minimal. Overall, yield potential was high; approximately 4.5 t/ha at Quambatook and 5.5 t/ha at Longerenong at the highest N rate.

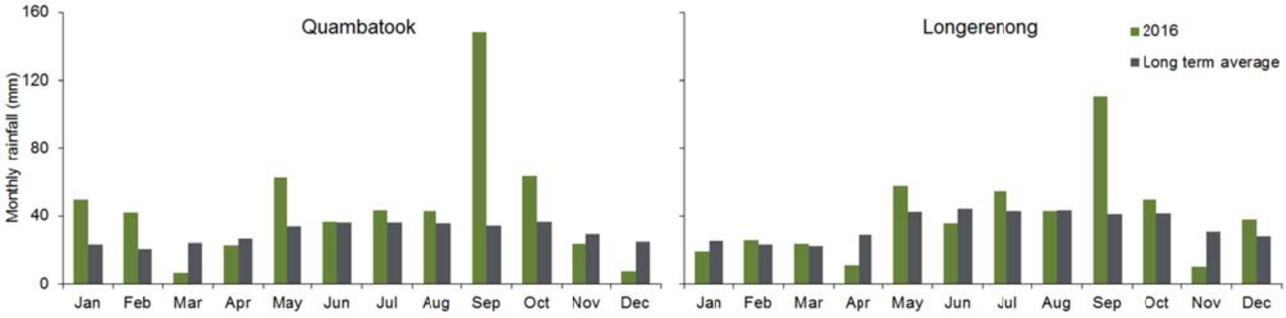

Figure 2: Monthly rainfall at Quambatook and Longerenong experimental sites in 2016 and long-term average.

Crop response to applied N

Starting soil N levels to 120 cm were low-moderate; 62 kg N/ha at Quambatook and 81 kg N/ha at Longerenong. Given the wet seasonal conditions in 2016, yield potential was high as was the likelihood of a fertiliser response, depending on additional supply from mineralisation of organic N. Retrospective estimation of net in-season mineralisation was undertaken based on the following equation (Armstrong et al. 1999):

$$ICM\ (kg/ha) = (C_N \times 1.1) + SN_M - SN_P - F_N$$

ICM = In-crop mineralisation
CN = Above ground total N uptake for the 0N control
1.1 is a correction factor to account for below ground N (Dunsford et al. 2015)
SN_M = Soil profile mineral N at crop maturity
SN_P = Soil profile mineral N prior to sowing
F_N = Fertiliser applied N for the 0N control

Net in-season mineralisation using this method was estimated to be 6 and 16 kg/ha at Quambatook and Longerenong respectively. Assuming that a wheat crop yielding 1 t/ha requires approximately 40 kg N/ha, combining these estimates with the pre-sowing soil sampling results indicates an N limited yield potential of 1.8 t/ha at Quambatook and 2.3 t/ha at Longerenong without additional N fertiliser (above the 5.5 kg N/ha applied at sowing). Final grain yield, however, for the 0N controls at each site were considerably higher than this estimate (Fig 3), potential explanations include:

- Wet seasonal conditions during 2016 were conducive to losses of N due to denitrification and or leaching causing an underestimation of mineralisation.
- The assumption that a wheat crop yielding 1 t/ha requires 40 kg N/ha is based on an assumed protein content of 11.5%. In this case protein was significantly lower (7-8%), requiring 30-40% less N per tonne of grain.

Wheat yield increased consistently with nitrogen rate at both Quambatook and Longerenong up to rates of 90 kg N/ha. At Quambatook, adding 90 kg N/ha increased yield by 1.9 t/ha and protein by 1.9% compared to the nil control. At Longerenong these increases were 1.8 t/ha and 1.4% respectively. It is also possible that yield may have continued to increase at rates beyond those tested. While yield was high at both sites, protein was low which is reflective of many commercial paddocks in 2016 and as a result, regardless of treatment or site, grain would have been classified as Australian Standard White quality.

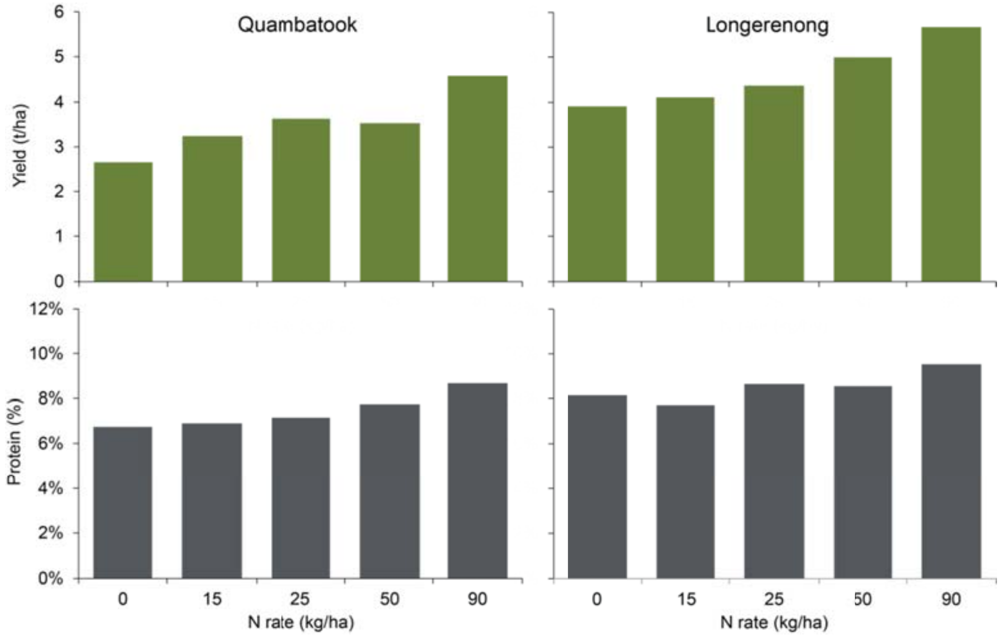

Figure 3. Grain yield and protein concentration at Quambatook and Longerenong experimental sites for a range of different N rates applied as top-dressed, granular urea at the first time of application.

Crop response to N application method

The effect of application method on grain yield and protein concentration was variable between the two sites. At Quambatook, MRB resulted in the highest average yield across both times of application at a rate of 50 kg N/ha; 4.1 t/ha compared with 3.7-3.8 t/ha for the remaining treatments (Table 3), however this was not statistically significant ($P<0.05$). At Longerenong, MRB also resulted in the highest average yield; 5.0 t/ha compared with 4.5 to 4.8t/ha for the remaining treatments across all rates and times of application (Fig 4). However only the mid-row surface application was significantly lower ($P<0.05$). Rate and timing of application also showed significant effects on yield at Longerenong, but there were no significant interactions between rate or timing and method of application.

Table 3. Crop yield and grain protein response to a range of N fertiliser application methods across both early and late times of application. Superscripts indicate significant differences ($P<0.05$). Treatments followed by the same letter are not statistically different.

Site	Application method	Yield (t/ha)	Protein (%)
Quambatook (50 kg N/ha only)	Mid-row banded	4.08	7.8^{a}
	Mid-row surface	3.75	7.5^{ab}
	Top-dressed granular	3.68	7.7^{a}
	Streaming spray	3.84	7.3^{b}
Longerenong (Both rates of application)	Mid-row banded	5.04^{a}	8.6
	Mid-row surface	4.51^{b}	9.0
	Top-dressed granular	4.84^{a}	8.5
	Streaming spray	4.83^{a}	8.7
	Flat fan spray	4.80^{ab}	8.4

Protein concentration was low at both sites (7.3-9.0%) irrespective of N application method, timing or rate of application. At Quambatook, the MRB and top-dressed granular methods produced significantly ($P<0.05$) higher protein concentration than application by streaming spray; 7.7-7.8% compared to 7.3% (Table 3). At Longerenong, the highest protein concentrations were measured for the mid-row surface application, however there was no significant effect of application method overall. Timing of application did not have a significant effect on protein concentration at either site.

In addition to the fertilised treatments, additional plots were included to test the effect of the banding operation compared to the unfertilised control. It was anticipated that disturbing the inter-row area within an established crop may result in root damage, however at both sites yield and protein concentration were not significantly affected. In absolute terms grain yield was slightly increased at both sites as was protein at Quambatook, although this was not indicative of any treatment effect.

Nitrogen use efficiency and fertiliser recovery in response to application method

Mid-row banding increased the uptake of fertiliser N by the crop at both Quambatook and Longerenong. At Quambatook, 63% of applied N was taken up by the crop compared with 41-45% for the mid-row surface and streaming spray methods (Figure 4). At Longerenong crop uptake was very high; 78% for mid-row banded applications compared with 53-54% for the mid-row surface and streaming spray methods. The benefit of MRB was significantly (P<0.05) affected by timing of application; at Quambatook the benefit of MRB compared to the other methods was greatest at the second time of application and at Longerenong it was greatest for the first time of application (Table 4). Rainfall in the 10 days following the first application at Quambatook totaled 14.2 mm compared with 4.6 mm for the second (20 mm within 12 days). In contrast, Longerenong received 5.6 mm over 10 days after the first application and 75.2 mm within 10 days of the second application. This indicates that in situations where rainfall following application is lower (and hence risk of volatilisation higher) banding of N below the soil surface may help to improve crop uptake of applied N.

Increases in fertiliser recovery were primarily driven by increased uptake to the grain, however there was a statistically significant effect of method on straw uptake also. Conversely, the proportion of applied N remaining in the top 20cm of soil was significantly lower where N was mid-row banded compared with streaming or mid-row surface application at Longerenong and significantly lower compared with streaming at Quambatook. This finding is potentially indicative of MRB causing reduced competition from soil microbes that would otherwise hinder crop uptake of applied N. Soils cores taken at a depth of 20-40 cm indicated an average ^{15}N enrichment of 0.373% where N had been applied compared with 0.369% natural background enrichment and an average of 0.453% and 0.381% at depths of 0-10 and 10-20 cm respectively. While it is not possible to rule out lateral flow of N at 20-40 cm due to it being below the depth of the steel microplots, it appears that movement of N below 20 cm was minor, even in this very wet season irrespective of application method.

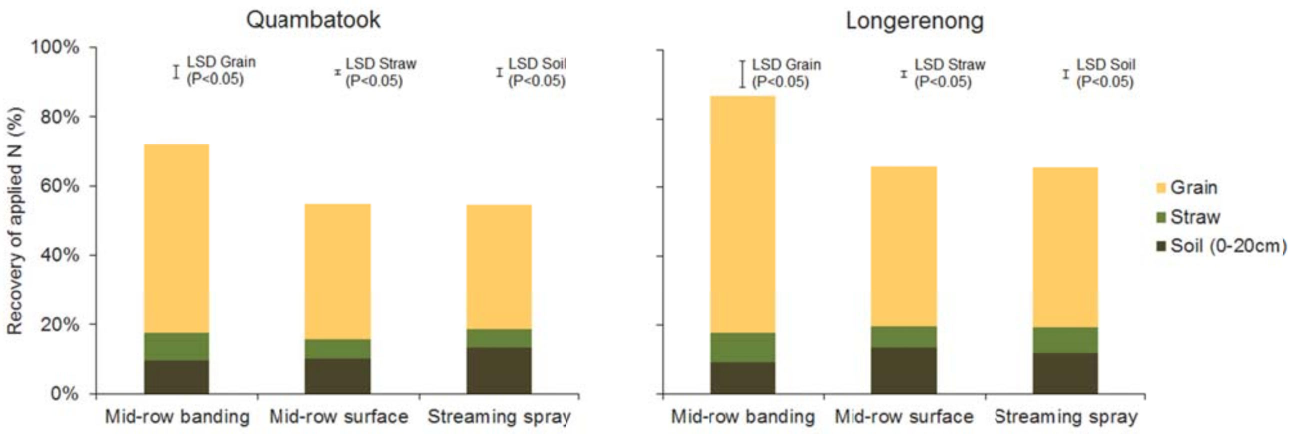

Figure 4. Recovery of applied N in above ground biomass and soil (0-20cm) at harvest for various methods of N application (average of two application times) at Quambatook and Longerenong experimental sites based on ^{15}N mass balance.

Table 4. Recovery of applied N in grain at harvest for various methods and times of application at Quambatook and Longerenong experimental sites based on ^{15}N mass balance. Superscripts indicate significant differences (P<0.05). Treatments followed by the same letter are not statistically different.

Site	Application method	N recovery in grain (%)	
		1st time of application	2nd time of application
Quambatook	Mid-row banded	52.7[a]	56.5[a]
	Mid-row surface	43.0[b]	34.9[c]
	Streaming spray	36.6[c]	35.2[c]
Longerenong	Mid-row banded	70.6[a]	67.1[a]
	Mid-row surface	40.0[c]	52.9[b]
	Streaming spray	36.8[c]	56.1[b]

CONCLUSION

Mid-row banding of N consistently resulted in the highest grain yields, coupled with the significant increases in crop uptake of applied N observed from the ^{15}N studies, this method of application offers potential benefits to improve NUE in the Wimmera and Mallee. Furthermore, the benefit of MRB to crop uptake was higher when rainfall following application was limited indicating that MRB in-season may help to reduce the requirement for rainfall soon after application. It will be important to test this method in a range of situations and seasons as 2016 was clearly an exceptional year in terms of rainfall; drier seasonal conditions may increase the benefits of applying N in this way. In addition to these specific research questions, adoption of such application methods will also require consideration of the availability and cost of machinery to apply N in this way, whether granular urea or other liquid fertilisers would be as effective and the speed with which operations can be undertaken in comparison to existing methods. An overall economic analysis considering these factors will also be important. These changes may also have impacts on other elements of the farming system that should be considered such as the effect of inter-row disturbance and fertiliser application on weed germination and growth. Nonetheless, results from 2016 are promising and this work will continue during 2017 to gather further evidence of the potential benefits of MRB N fertilisers in-season to improve uptake and NUE.

ACKNOWLEDGEMENTS

This work was funded by the 'Improving practices and adoption through strengthening D&E capability and delivery in the southern region', Regional Research Agronomists program (DAV00143) as part of the Grains Research and Development Corporation (GRDC) and Department of Economic Development, Jobs, Transport and Resources (DEDJTR), Bilateral Research Agreement. The authors also wish to acknowledge the assistance of Birchip Cropping Group staff in delivery of the experimental program.

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