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Final Technical Report Template

Final Technical Report

Mid-row banding of nitrogen in wheat in an irrigated system

Project code:	WML00002
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Date submitted to GRDC:	15th, April and 2019

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Abstract

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In 2018, mid-row banding of nitrogen was trialed as a means of delivering high rates of nitrogen to wheat in three different southern Riverina irrigated contexts. The response of yield, protein and grain nitrogen was measured, to determine the apparent nitrogen uptake efficiency (ANRE) of the applied nitrogen.

Using a randomized, complete block design, three nitrogen treatments were compared on irrigated lasered contours and a border-check layout. One site was subjected to a water-logging event to assess N losses via denitrification.

Mid-row banded nitrogen gave the same wheat growth and yield response (1.3-1.4 $t.ha^{-1}$) and protein response (2.1%) as top-dressed nitrogen. The ANRE of mid-row banded nitrogen was around 30%; similar to topdressed nitrogen. The wheat crop did not access the nitrogen until later in the season and supplied nutrition long enough to increase both yield and grain protein.

The mid-row band produced a band of high ammonium concentration that both restricted early crop nitrogen access, and resisted a major water-logging event. The concentrated band of ammonium persisted for more than 114 DAS, and until after harvest in a drought-affected site.

Mid-row banding is a useful and efficient method of applying high rates of nitrogen in southern Riverina irrigated systems, and may also be applicable in higher rainfall zones.

Executive Summary

In 2018, mid-row banding of nitrogen was trialed as a means of delivering high rates of nitrogen to wheat in three irrigated situations. The response of yield, protein and grain nitrogen was measured, to determine the apparent nitrogen recovery efficiency (ANRE) of the applied nitrogen.

This marks the conclusion of a series of mid-row banding experiments in the southern Riverina since 2015, with the aim of quantifying the benefits of nitrogen banding on heavy clay Sodosols within the region. In particular, high nitrogen rates were mid-row banded into a cereal seeded after a rice crop, which has the potential to utilize residual moisture to increase returns to irrigation water. The cereal crop after rice typically suffers from low soil nitrogen status (Huges, 1999) during the season, so farmers need to apply 150 kgN.ha^{-1} or more to achieve yields over 5 t.ha^{-1}. Irrigated crops of heavy clay Sodosols — particularly crops after rice — are highly susceptible to multiple waterlogging events during the season, which increases the risk of nitrogen loss via denitrification. Conversely, topdressed nitrogen can be less effective in dry seasons, if there is insufficient rainfall or no irrigation following the topdressing event to wash the topdressed nitrogen into the root zone. Mid-row banding nitrogen into the soil at sowing places nitrogen into the root zone and has been shown to retain root zone nitrogen in the ammonium form, protecting it from denitrification to reliably supply nitrogen to the cereal crop (Wetselaar et al., 1972; Chen et al., 2016; Sandral et al., 2017).

Both topdressed and mid-row banded nitrogen had a similar effect on a border-check wheat crop; increasing yield from 3.62 t.ha^{-1} to 4.93 – 5.08 t.ha^{-1}. The ANRE was 28.3% for topdressed nitrogen and 30.4% for banded nitrogen. The two other sites were seriously drought-stressed for much of the growing season, so had very low yields and did not respond to either form of applied nitrogen.

The mid-row banded nitrogen was shown to remain mostly in the ammonium form for more than 63 days after seeding in an actively-growing wheat crop, and for more than 160 days in a drought-affected wheat crop. The measured concentration of NH_4 decreased by 39% after a 10-day water-logging event, as compared to the non-waterlogged treatments. This may have been due to sampling error, as the mid-row was more difficult to precisely locate after the water-logging event. In 2017 it was observed that the almost no ammonium in the mid-row band was lost from an induced waterlogging event (the mid-row was easier to find after the waterlogging event in that season); only the nitrate nitrogen was lost.

In 2015 and 2016, it was observed that plants accessed the banded nitrogen from 84-86DAS in these trials and continued to utilize soil nitrogen until after GS65 at fertiliser rates above 120 kgN.ha^{-1}.

In 2017 mid-row banding gave a similar yield, grain N response, and consequent ANRE to topdressing at GS31. This was true in both water-logged and unwater-logged conditions, except where topdressing occurred directly prior to the water-logging event in 2017. In this instance, topdressing was superior to mid-row banding; with an ANRE of 41.3% (the rest of the trial averaged 19-31.1%).

Mid-row banding of nitrogen at seeding is useful in an irrigated (or high-rainfall) situation where the crop has a known high yield potential at seeding. It can provide prolonged nitrogen nutrition to a winter cereal crop, and preserve applied nitrogen from waterlogging during the season. It offers a viable alternative to topdressing at GS31, although our research showed it got no greater response than topdressing. It can suit growers that are seeking an alternative to topdressing high nitrogen rates. Current seeding machinery can be adapted to mid-row band nitrogen at a depth below 5cm, although a specially-designed seeder (with a large fertilizer box to hold required urea without slowing the seeding operation too much) would be preferable in the longer-term. Because all nitrogen must be applied at seeding, mid-row banding at seeding is unlikely to be suitable where the yield potential of the crop is uncertain at seeding.

Contents

Background

In the southern Riverina of Australia, irrigation is an important component of the cropping system to drive productivity on sodic clay soils. High rates of applied nitrogen are often required in these irrigated cropping systems, but there is a risk that topdressed nitrogen can be lost or not well accessed due to waterlogging or very dry conditions respectively. Past research investigating the apparent nitrogen recovery efficiency (ANRE, the proportion of extra applied nitrogen assimilated into extra grain nitrogen) of mid-row banded nitrogen in a wheat crop following rice has delivered encouraging results to suggest that banding may be as efficient as topdressing in those situations. This may be due to high water limited yield potential of around 5 $t.ha^{-1}$, low soil nitrogen status after rice or periods of extended waterlogging that can denitrify soil nitrate during the growing season. To test the applicability of mid-row banded nitrogen in a range of irrigation scenarios, three sites were chosen in 2018. To continue on from previous research, wheat was sown after rice on a lasered contour, in addition to wheat following a 12 month fallow after rice on a similar layout and wheat on a border check layout. Both post-rice crops were only supplementary irrigated once in the spring, while the border check layout was irrigated three times throughout the growing season, giving it the highest yield potential.

Worldwide nitrogen use efficiency (NUE, the proportion of fertiliser assimilated by the crop) in cereal production is approximately 33% (Raun & Johnson, 1999). This means that on average 67% of nitrogen is either used inefficiently of lost by the crop during the growing season. This is reflected by Dobermann and Cassman (2004) who stated that generally 50% of N applied isn't assimilated by plants. Numerous papers have claimed that mid-row banding can increase NUE by reducing N losses from the root zone via immobilisation; volatilization and denitrification (Holzapfel et al., 2007 & Brar, 2013).This is due to the process by which banded nitrogen provides a high concentration of ammonium (over 3000ppm in the soil solution) which inhibits nitrification (Wetselaar et al., 1972). Angus et al. (2014) concluded that the concentration of fertiliser was toxic to microbes responsible for nitrification, reporting an immediate fall in microbial biomass, carbon and numbers of protozoa after banding. Brar (2013) also found a corresponding increase in soil pH, which may further inhibit urea hydrolysis and nitrification. Both effects slow the conversion of urea to NH_4 to NO_3, which can reduce losses by denitrification (Malhi et al., 2001), volatilisation (Zhaoming et al., 2016), leaching and decreases immobilisation (Ladha et al., 2005). Another benefit is the slow release of nitrate-N available to wheat crops, reducing excessive seedling growth and risks of haying off (Angus et al., 2014).

Mid-row banded nitrogen may improve ANRE by placing the nitrogen directly into the rootzone, and minimising losses from denitrification and volatilisation occurring in sodic soils within the southern Riverina. The clay soil in this region is prone to waterlogging after an irrigation event or after a rainfall event in winter, particularly in rice layouts with zero or minimal slope. The severity of these events depends on the irrigation layout and moisture profile of the soil. Often the loss of nitrogen via denitrification can far exceed that of volatilisation.

Usually irrigated crops are topdressed during winter prior to rainfall or irrigation. However if the crop is only being supplementary irrigated in the spring, the risk of volatilisation from a winter topdressing event is increased as rainfall is required and more than 10mm (Malhi et al., 2001) of rain is needed after topdressing to prevent NH_3-N volatilising. Volatilisation losses can reach 40% (Fowler & Bryndon, 1989) in some circumstances; risks are increased in situations of high stubble loads, high temperatures and high wind speed.

Project objectives

The objectives of this project are to quantify the size and efficiency of response to mid-row banded nitrogen in irrigation systems within the southern Riverina of Australia. This will include the assessment of the effect of mid-row banded N on growth, yield and apparent nitrogen recovery efficiency (ANRE), of wheat as compared to the current best-practice method of topdressing at GS31 and the control.

Another key objective of this project is to assess the loss of banded nitrogen during waterlogging events to determine if denitrification losses are reduced in banded nitrogen and compared to topdressed nitrogen and the control.

The scope of this project is within irrigated wheat crops in the geographical region of the southern Riverina. The soil type being investigated is typically moderately sodic and uses irrigation to increase productivity in an average year. Other crops, soil types and dryland systems were not investigated during this research, although the results may have relevance in higher rainfall situations where yield potential is higher and waterlogging may be an issue.

Limitations for this research were the inability to do deep soil coring with the required accuracy, the exact fate of fertiliser nitrogen was not able to be tracked, and root systems could not be analysed for nitrogen content. Trials were grown in a paddock situation and so environmental factors such as weeds, pests and weather played a large role in the results obtained from this research. As such, only the Colinjen site was chosen to report on for yield and ANRE due to low yield and high variability at other sites as a result of drought circumstances and low irrigation availability for the sites.

Apparent variability in the denitrification rate of mid-row nitrogen from water-logging has posed further questions about the real risk of mid-row nitrogen loss during waterlogging. In 2018, 39% of the ammonium nitrogen was apparently lost due to waterlogging, whereas in 2017 almost no ammonium nitrogen was lost. This discrepancy may have been due imprecise sampling after the waterlogging event.

The outcome was determined to have been achieved. This research is in its fourth year and so the ability to observe trends in yield, ANRE and soil nitrogen characteristics helps to confirm the conclusions. The researchers are confident that 2018 data is consistent with previous data over the life of the research and has appropriately quantified the ANRE of mid-row banded nitrogen.

Methodology

To investigate the feasibility of mid-row banding under a variety of irrigation systems commonly found in the southern Riverina, three locations were chosen to host trials in 2018:

1. North Dale: Supplementary irrigated lasered contour, (rice harvested April 2018)
2. Collinjen: Fully irrigated border-check
3. Royal Park: Supplementary irrigated lasered contour (rice harvested April 2017)

Within these sites, three nitrogen treatments were tested to compare the nitrogen use efficiency of mid-row banded nitrogen to topdressed nitrogen:

1. DAP 1% Zn @ 100kg.ha^{-1} in the seed row (15N)
2. DAP 1% Zn @ 100 kg.ha^{-1} in the seed row + 290 kg.ha^{-1} Urea topdressed at GS31 (150NT)
3. DAP 1% Zn @ 100 kg.ha^{-1} in the seed row + 290 kg.ha^{-1} Urea banded in the mid-row[1] at sowing (150NMRB)

To continue investigating the implications of losses to denitrification on heavy Sodosols within the region, there was also a waterlogging treatment imposed at North Dale:

- No waterlogging event imposed ('Dry')
- A waterlogging event imposed, by irrigating on August 5th, then draining on August 16th ('Wet')

A randomized block design was used for site 2 & 3, investigating nitrogen treatments, whilst site 1 used a split plot design to investigate the interaction between waterlogging and nitrogen treatments, with waterlogging treatments in the main plots and nitrogen treatments in the sub-plots. All sites had four replicates with plots measuring 20m long and 8m wide.

To measure the effect on growth and yield, and interaction between waterlogging and nitrogen treatments, the following plant measurements were taken:

- NDVI, NDRE, CCCI (September 17th)
- SPAD meter (September 17th)
- Biomass cuts (September 19th & October 18th)
- Head number (November 28th)
- Grain yield, protein & 1000 grain weight (December 10th)

The following soil measurements were taken:

- Soil test pre-sowing (May 7th)
    - Three samples per site at 0-10cm, 10-20cm & 20-60cm (12 sample points per sample)
- Soil mineral N in the location of the mid-row band pre-waterlogging (July 18th), post-topdressing (September 13th), grain fill (October 23rd) and post-harvest (January 31st)
    - Two sample depths per plot (2-10cm & 10-20cm) and 5 sample points per plot
- Soil matric potential every 12 hours using the Watermark gypsum block sensors

Management

Collinjen was pre-watered about a month before sowing, but neither Royal Park nor North Dale was not pre-watered (North Dale had rice the preceding summer/autumn). Consequently Collinjen suffered less drought effects from the extremely low growing season rainfall. Wheat (*var. Mace*) was sown using a modified Bettinson disc drill with 25-27cm row spacing on the 15-16th of May at a rate of 80 kg.ha^{-1} and depth of 3-5cm. Fertiliser (DAP 1% Zn) was treated with 4L/t of Impact for fungal suppression and sown at 100 kg.ha^{-1}. Weed, insect and fungus control was conducted as per the surrounding field.

At North Dale levees were constructed after sowing to exclude water from the 'dry' plots during the winter waterlogging event beginning on the 5th of August. One spring irrigation followed this in late September. Collinjen was fully irrigated with two irrigation events in spring. Royal Park received a single irrigation in spring.

[1] During sowing, urea (46%N) was banded in the middle of every alternate inter-row (13cm from seed) at a depth of 3-5cm as mid-row fertiliser.

Urea topdressing occurred at GS31 for all sites, which occurred from 18-29th of August, 11 days after the waterlogging event at North Dale. At this time, the North Dale site was also assessed for duck damage incurred during water-logging and the variability between plots was quantified.

During grain-fill Russian Wheat Aphid also impacted both the North Dale and Royal Park sites, with Royal Park being treated subsequently. Again, this damage was assessed and noted for consideration when analysing results.

Statistical analysis was conducted using the Statistix software package for analysis of variance (ANOVA). Two-way ANOVA was used to assess the effects of nitrogen treatments and water-logging treatments on wheat yield, N uptake and N in the soil. Significances among the treatments were compared by the least significant difference at $P<0.05$ level.

Location

NOTE: Where field trials have been conducted please include location details: Latitude and Longitude, or nearest town, using the table below (please add additional rows as required):

	Latitude (decimal degrees)	Longitude (decimal degrees)
Trial Site #1 North Dale	35º02’49.16” S	143º49’34.34” E
Trial Site #2 Collinjen	35º13’08.80” S	144º06’44.51” E
Trial Site #3	35º11’27.04” S	144º07’49.44” E
Nearest Town	Moulamein, NSW, 2733 (35º05’27.21” S , 144º02’06.47” E)	

If the research results are applicable to a specific GRDC region/s (e.g. North/South/West) or Agro - Ecological Zone/s please indicate which in the table below:

Research	Benefiting GRDC Region (can select up to three regions)	Benefiting GRDC Agro-Ecological Zone (see link: http://www.grdc.com.au/About-Us/GRDC-Agroecological-Zones) for guidance about AE-Zone locations	
WML00002	Northern Region Southern Region Choose an item.	☐ Qld Central ☐ NSW NE/Qld SE ☐ NSW Vic Slopes ☐ Tas Grain ☐ SA Midnorth-Lower Yorke Eyre ☐ WA Northern ☐ WA Eastern ☐ WA Mallee	☒ NSW S/SW ☐ NSW NW/Qld SW ☐ Vic High Rainfall ☒ Vic South ☐ SA Vic Bordertown-Wimmera ☐ WA Central ☐ WA Sandplain

Results

There was a significant effect of nitrogen treatment at Collinjen, but very little effect at North Dale or Royal Park. At Royal Park, and particularly North Dale, the very dry season (GS rainfall 86.4 mm) greatly restricted crop growth. Crops were managed for a yield of 5 t/ha, however the average yield at North Dale was only 1.0 t/ha and at Royal Park was 2.6 t/ha. Water was a much greater limit than nitrogen, even though both sites were irrigated once in the spring. As such, this report focuses mostly on the fully-irrigated Collinjen site.

Growth and yield at Collinjen

At Collinjen, mid-row banding of 133 kgN.ha^{-1}gave a similar result to topdressing the same rate (Table 1). Both 150NT and 150NMRB increased all growth parameters (except biomass at 19th September), yield components, yield and grain N. All three treatments had a similar biomass on 19th September, but the SPAD meter reading, N content, N uptake, NDVI, NDRE and CCCI at the same time were greater for 150NT and 150NMRB.

150NT and 150NMRB increased grain yield from 3.62 t.ha^{-1} to 4.93-5.08 t.ha^{-1}, due to an increased number of heads/m^2 and grains/head. 150NT and 150NMRB increased grain protein from 8.6% to 10.7%, and increased grain N from 55 kgN.ha^{-1} to 93-95 kgN.ha^{-1}. Apparent nitrogen recovery efficiency (ANRE) was the same at 28-30% for both 150NT and 150NMRB.

In 2017, ANRE averaged 21-30% for N topdressed after a waterlogging event, 36-41% for N topdressed after it, and 19-31% for mid-row banded N. Our 2018 results are slightly above the reported ANRE of 21-28% in an Australian high rainfall environment (Angus et al., 2014) and similar to 24-31% reported in south-east China (Chen, 2016).

Table 1: Crop growth, yield components and yield, for three nitrogen treatments (control, 150 kgN.ha^{-1} topdressed (150NT) and 150 kgN.ha^{-1} mid-row banded (150NMRB)), Collinjen, Moulamein, 2018.

	Control	150NT	150NMRB
SPAD reading 18/9	591b	670a	688a
Biomass 19/9 (kg.ha^{-1})	5054a	5461a	5583a
Biomass 18/10 (kg.ha^{-1})	8216b	11728a	11954a
Harvest Biomass (kg.ha^{-1})	9359b	10983ab	12973a
NDVI 17/9	0.764b	0.839a	0.857a
NDRE 17/9	0.400b	0.491a	0.509a
CCCI 17/9	0.521b	0.584a	0.593a
N content 19/9 (%)	1.04b	1.79a	1.76a
N Uptake 19/9 (kg.ha^{-1})	52.7b	97.7a	98.1a
N content 18/10 (%)	0.809b	1.19a	1.07a
N Uptake 18/10 (kg.ha^{-1})	66.5b	140a	128a
Heads/m^2	416b	513a	487ab
Grains/head	20.2b	24.2a	26.1a
1000 GW	43.1a	39.7a	39.9a
Grain N	54.8b	92.5a	95.2a
Grain Yield (kg.ha^{-1})	3.62b	4.93a	5.08a
Protein (%)	8.55b	10.65a	10.70a
ANRE (%)		28.3a	30.4a

Row entries followed by different letters are significantly different (P<0.05)

<u>*Soil nitrogen*</u>

The mid-row nitrogen at Collinjen was only evident as a high [NH_4] and high [NO_3] in the first sample at 63 DAS (Table 2). By the second sample at 114 DAS, little NH_4 or NO_3 was present (8%). With 150NT, some NH_4 and NO_3 were evident below seeding depth in the third sample, presumably from leaching. There was very little N present (3%) in the shallow or deep samples at the third sample. This is consistent with data from 2017 which found around half of the initial concentration of N was still present 91DAS but only 5-8% of the banded N was available 131DAS, so the bulk of banded N was exhausted by flowering.

Table 2: The concentration of N (ppm) as NO_3, NH_4 and in total in the mid-row, for 3 nitrogen treatments (control, 150 kgN.ha^{-1} topdressed (150NT) and 150 kgN.ha^{-1} mid-row banded (150NMRB)), for 2 depths of sampling (2-10cm and 10-20cm), Collinjen, Moulamein, 2018.

[N] (ppm)	**Control**	**150NT**	**150NMRB**
1st Sample (63 DAS):[2]			
NO_3 –N 2-10cm	2.42b	2.78b	18.1a
NO_3–N 10-20cm	0.86a	1.42a	1.82a
NH_4–N 2-10cm	2.60b	2.19b	86.5a[3]
NH_4–N 10-20cm	2.00a	2.02a	3.52a
Total N, 2-10 cm	*5.02*	*4.97*	*104.6*[3]
Total N, 10-20 cm	*2.86*	*3.44*	*5.34*
2nd Sample (114 DAS):			
NO_3–N 2-10cm	0.23a	0.39a	0.44a
NO_3–N 10-20cm	0.49a	0.23a	0.37a
NH_4–N 2-10cm	3.04a	4.96a	3.48a
NH_4–N 10-20cm	4.00a	3.23a	3.34a
Total N, 2-10 cm	*3.27*	*5.35*	*3.92*
Total N, 10-20 cm	*4.49*	*3.46*	*3.71*
3rd Sample (160 DAS):			
NO_3–N 2-10cm	0.32a	0.32a	0.63a
NO_3–N 10-20cm	0.23a	0.32a	0.23a
NH_4–N 2-10cm	0.78a	1.20a	1.32a
NH_4–N 10-20cm	0.78a	0.78a	0.78a
Total N, 2-10 cm	*1.10*	*1.52*	*1.95*
Total N, 10-20 cm	*1.01*	*1.10*	*1.01*
4th Sample (Post-harvest):			
NO_3–N 2-10cm	1.94	2.65	3.52
NO_3–N 10-20cm	1.02	1.01	1.18
NH_4–N 2-10cm	1.89	2.20	5.26
NH_4–N 10-20cm	1.16	0.78	1.69
Total N, 2-10 cm	*4.12*	*4.85*	*8.78*
Total N, 10-20 cm	*2.18*	*1.79*	*2.87*

Row entries followed by different letters are significantly different (P<0.05)

[2] Sample was taken prior to topdressing at 94DAS
[3] The value recorded is indicative of the high N concentration present within a mid-row band.

Between the time of the first and second soil sample, the concentration of N in the mid-row band declined by 100 ppm. In the same period, crop N uptake increased by 30 kg.ha⁻¹. If we assume a mid-row band diameter of 8 cm (the same as the depth range of the shallow soil sample) and a bulk density of 1.40 g/cm^3, a decline in N concentration of 100 ppm represents a decline of 14 kgN.ha^{-1}.

At North Dale, the mid-row N persisted for much longer (Table 3). It was still evident in the third sample 160 DAS and a residual in the post-harvest sample in January. The mid-row N (almost all of which was present as NH_4) persisted after the 11 day waterlogging event beginning on the 81 DAS, but the measured concentration was 39% lower as compared to the non-waterlogged treatment. In 2017, mid-row NH_4 survived almost completely, although a significant concentration of NO_3 was present before the water-logging event and was subsequently lost. That decline in concentration may have been due to nitrification and subsequent leaching or denitrification of nitrate or even increased plant uptake as a result of the water-logging event. Presumably the NH_4 resisted the water-logging, so this seems a little hard to explain. Extra plant uptake seems unlikely as the wheat in the water-logged plots grew less after the water-logging event than in the dry plots. A final possibility is that sampling the mid-row band in the water-logged plots was not as precise after the water-logging event; perhaps not all samples were taken exactly in the mid-row, as the disc-seeder marks were more difficult to see after inundation and consequent intense bird activity. Less precise sampling would have reduced the concentration in the samples, as more non-midrow soil would have been included in the sample.

Table 3: The concentration of N (ppm) as NO_3, NH_4 and in total in the mid-row, for 3 nitrogen treatments (control, 150 kgN.ha^{-1} topdressed (150NT) and 150 kgN.ha^{-1} mid-row banded (150NMRB)), and two water-logging treatments (dry and wet), for 2 depths of sampling (shallow (2-10cm) and deep (10-20cm)), North Dale, Moulamein, 2018.

	Dry			**Wet**		
[N] (ppm)	**Control**	**150NT**	**150MRB**	**Control**	**150NT**	**150MRB**
1st Sample (63 DAS):[2]						
NO_3–N 2-10cm	1.33a	1.23a	1.57a			
NO_3–N 10-20cm	1.01a	1.02a	1.40a			
NH_4–N 2-10cm	6.66b	2.63b	306.9a[1]			
NH_4–N 10-20cm	3.24b	2.25b	23.27a			
Total N 2-10 cm	*7.99*	*3.86*	*308.5[1]*			
Total N 10-20 cm	*4.25*	*3.27*	*24.7*			
2nd Sample (120 DAS):						
NO_3–N 2-10cm	0.70a	0.98a	1.16a	0.52a	0.49a	1.21a
NO_3–N 10-20cm	0.29a	1.24a	0.53a	0.29a	0.34a	0.23a
NH_4–N 2-10cm	7.74b	24.65b	238.8a[1]	8.34b	19.71b	144.9a[1]
NH_4–N 10-20cm	1.68a	6.88a	5.09a	1.84a	2.24a	3.36a
Total N 2-10 cm	*8.44*	*25.64*	*240.0[1]*	*8.86*	*20.20*	*146.1[1]*
Total N 10-20 cm	*1.97*	*8.12*	*5.62*	*2.13*	*2.58*	*3.59*
3rd Sample (160 DAS):						
NO_3–N 2-10cm	0.24a	2.29a	4.19a	0.75a	1.28a	6.01a
NO_3–N 10-20cm	0.21a	1.89a	1.75a	0.45a	0.87a	1.76a
NH_4–N 2-10cm	3.71b	12.21b	171.6a[1]	3.70b	11.9b	114.7a[1]
NH_4–N 10-20cm	3.21b	11.88b	52.3a	2.95b	9.40b	23.1a
Total N 2-10 cm	*3.95*	*14.50*	*175.8[1]*	*4.45*	*13.18*	*120.7[1]*
Total N 10-20 cm	*3.42*	*13.77*	*54.04[1]*	*3.40*	*10.27*	*24.84[1]*

4th Sample (Post-harvest):						
NO_3–N 2-10cm	2.21	4.61	6.52	3.07	3.42	7.35
NO_3–N 10-20cm	1.20	2.04	3.07	1.78	1.96	3.09
NH_4–N 2-10cm	1.17	4.37	47.5[1]	1.81	2.96	36.27[1]
NH_4–N 10-20cm	0.78	1.98	14.3	1.05	2.06	8.86
Total N 2-10 cm	*3.38*	*8.98*	*54.0*[1]	*4.88*	*6.38*	*43.6*[1]
Total N 10-20 cm	*1.98*	*4.02*	*17.4*	*2.83*	*4.02*	*12.0*

Row entries within the same water-logging treatment, followed by different letters, are significantly different ($P<0.05$)

[1] The value recorded is indicative of the high N concentration present within a mid-row band.

[2] This sample was taken prior to topdressing at 105DAS

It should be noted that although a decline of 27% N concentration can be seen in the topdressing treatments for the same period, topdressing did not occur until 105 DAS, 11 days after the waterlogging event occurred. Hence, topdressed N would not have been subjected to the same soil conditions as mid-row N and is less likely to have been lost via denitrification.

Photos/images

Photographer: Laura Kaylock (p) 0431236045 (e) laura.kaylock@wmlig.org

Date: 6/8/2018

Description: Waterlogging trial plots at North Dale for 11 days to measure denitrification losses in mid-row banding plots.

Photographer: Laura Kaylock (p) 0431236045 (e) laura.kaylock@wmlig.org

Date: 7/09/2018

Description: Observing the increase in pH (purple) where the concentrated mid-row band of ammonium nitrogen occurs as compared with the pH of the soil (green) at a depth 0 – 20cm.

Discussion of Results

At the Collinjen site, where yield was not grossly limited by drought effects, mid-row banded nitrogen had a similar effect on growth, yield and grain protein as top-dressed nitrogen. The mid-row banded nitrogen appeared to provide nitrogen nutrition to the crop for most of the growing season, as it increased growth and nitrogen uptake during the season and grain nitrogen at harvest.

The ANRE of the mid-row banded nitrogen was similar to that of top-dressed nitrogen at about 30%, which is comparable to that found by Angus et al. (2014). Previous experiments found a similar ANRE for both mid-row banded and top-dressed nitrogen, with the exception of a highly-efficient topdressing event before a waterlogging event in 2017 (ANRE 41%). Hence, mid-row banding seems a comparable technique to topdressing in a southern Riverina irrigated context, but not more efficient.

The mid-row banding of urea produced a band of high concentration of ammonium nitrogen that persisted for more than 2 months in a fully irrigated crop, and until after harvest in a drought-affected site. This concentrated ammonium nitrogen would have inhibited nitrification to nitrate (Wetselaar et al., 1973), hence restricted plant access until later in the growing season when nitrogen nutrition has the best effect on yield. Previous experiments showed that the wheat crop did not access the mid-row nitrogen until 84-86 DAS, after which the nitrogen was accessed by the wheat crop until around flowering.

The concentrated band of ammonium largely resisted a prolonged waterlogging event, hence preserving most of the banded nitrogen; sampling error from the effects of inundation on the soil surface may have been the cause of the apparent loss of 39% of the ammonium nitrogen. In a previous experiment in 2017, the ammonium band completely survived a similar waterlogging event.

Mid-row banding is a useful technique where yield potential is relatively high and is known with some confidence. It avoids the need for extra topdressing operations, but it does require the entire investment in nitrogen fertilizer to be made at sowing. The two drought-affected sites in 2018 show that even in a context where a higher yield potential is estimated with some confidence, extremely dry conditions in the winter especially can reduce that yield potential and the consequent return on investment in fertilizer. It also requires more fertilizer to be handled at sowing, which can slow the sowing process unless a large capacity seeder is used. Mid-row banded nitrogen does appear to survive major water-logging events, which gives more confidence to make the fertilizer investment at sowing. In 2017, ANRE of both mid-row banded and top-dressed nitrogen, after major waterlogging, was still about 20%.

Mid-row banding can be a useful nitrogen application method in southern Riverina irrigated systems, where yield potential is known with confidence, and appropriate investment is made to handle more fertilizer at sowing.

Conclusion

Mid-row banding nitrogen at 133 kgN.ha^{-1} gave a similar response to topdressing the same rate at GS31. It increased yield by 1.38 t/ha and grain N by 38 kgN.ha^{-1} to give an ANRE of 30%. Mid-row banded N created a highly-concentrated band of ammonium which appeared to mostly survive a water-logging event.

Mid-row banding N appears to be a valid application method for nitrogen in a southern Riverina irrigated context, allowing all nitrogen requirements to be placed in the soil at sowing. This is applicable where a higher yield potential is known with some confidence, and seeding equipment can handle larger amounts of fertilizer at sowing. Hence, it may also be a useful technique in higher rainfall zones, where yield potential is high and waterlogging is more common.

Implications

The mid-row banding methodology investigated in these trials appears to have little agronomic benefit on the Australian cropping industry as compared to topdressing, as yield and ANRE were statistically similar to topdressing nitrogen at GS31. It is possible that this nitrogen application method could benefit systems with low nitrogen availability, a high water-limited yield and a risk of waterlogging events during the growing season.

An economic analysis of mid-row banding nitrogen compared with topdressing nitrogen and the control can be seen below. Data for this was collected from the AWB daily grain contract prices in February 2019 and costs were based on those associated with the trial. The slightly higher yield of mid-row banded nitrogen resulted in a better net $/ha return.

This may not be the case in a non-irrigated scenario, where the flexibility of topdressing will allow for total N rate to be determined within the cropping season; while mid-row banding N rates are set at sowing and may be above requirements for the seasonal conditions. As a result, N fertiliser cost for mid-row banded treatments could be far higher than topdressed treatments, resulting in a better $/ha return from topdressing. Hence, it is important for growers to consider their water-limited yield potential prior to banding high rates of nitrogen at sowing.

Table 4: Economic comparison of the net return ($/ha) of mid-row banded nitrogen treatments in comparison with topdressing and control treatments

Treatment	***Grain Yield (t/ha)***	***Grain Protein (%)***	***Grain N (kg/ha)***	***N Fertiliser Cost ($/ha)***	***Net ($/ha)***
COLINJEN					
15N	*3.62*	*8.55*	*54.8*	*$ -*	*$ 575.05*
150T	*4.93*	*10.65*	*92.5*	*$ 147.50*	*$ 868.86*
150MRB	*5.08*	*10.70*	*95.2*	*$ 130.50*	*$ 931.47*

Recommendations

- Mid-row banding can be used for applying higher rates of nitrogen (100 $kgN.ha^{-1}$ or more) in high-yielding irrigated situations.
- Mid-row banding has a similar ANRE to topdressing, but does not require the extra topdressing events later in the season.
- Mid-row banding at sowing delays access to nitrogen until later in the growing season when it gives better yield response, and continues to supply nitrogen nutrition until around flowering.
- Mid-row banded N can resist major waterlogging events, which gives confidence in the fertilizer response in waterlogging-prone situations like rice stubble or other irrigated contexts.
- Mid-row banding does require handling more fertilizer at sowing, so is more suited to growers who have larger-capacity seeders.
- Existing seeding equipment can be adapted to mid-row banding, but specially-designed seeders would be justified once confidence is had with the technique.
- Further research to quantify losses from banded nitrogen in a persistently water-logged context would be beneficial, to determine the full potential of this method in both irrigation and high rainfall cropping regions.

Appendix A.
Appendix Title

Glossary and Acronyms

Below is a sample Abbreviations and Acronyms list.

ANRE	Apparent Nitrogen Recovery Efficiency
N	nitrogen
DAS	Days after sowing
NH_4	Ammonium nitrogen
NO_3	Nitrate nitrogen
NDVI	Normalized Difference Vegetation Index
NDRE	Normalized Difference Red Edge
CCCI	Canopy Chlorophyll Content Index
SPAD	Soil Plant Analysis Development
DAP	Diammonium Phosphate
GS31	Growth stage 31 (zadock's scale)

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    b. *Facebook text: "Have you considered mid-row banding nitrogen to improve nitrogen uptake within your crop? Trials in the southern Riverina have found banding to be as efficient as topdressing in a range of irrigation systems. The advantage of banding nitrogen is being able to apply the total N requirement of your crop upfront, reducing the risk of volatilisation. It may also help reduce your nitrogen losses during situations of waterlogging! For more information on how this could suit your system, follow the link below."*
    c. *Twitter text: "Have you considered mid-row banding N to improve uptake within your crop? Trials in NSW have found banding to be as efficient as topdressing in a range of irrigation systems. For more information follow the link below."*