Mid-row banding for reliable nitrogen supply in post-rice crops

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ABSTRACT
In the Australian Riverina, winter crops following rice can achieve a high water-limited yield of around 5 $t.ha^{-1}$ for wheat. This system is an important element of improved rice system water productivity. Yield is most commonly limited by nitrogen supply and/or water-logging. Residual soil nitrogen levels are generally very low, so nitrogen fertilization is required from early in the season to achieve water-limited yield potential. Water-logging from excess winter rainfall can allow early applications of nitrogen to be lost from denitrification, and conversely in dry winters there can be insufficient rainfall for reliable uptake of top-dressed nitrogen.

We undertook two experiments banding N (as urea) in between rows of wheat after rice. This technique aimed to allow high rates of N to be banded without seedling damage, delay early access to N so that availability was in line with uptake demands and to inhibit nitrification of banded N, reducing the risk of denitrification.

Mid-row banded N was available from 11-12 weeks after seeding, avoided gross denitrification from water-logged periods in both seasons, and high N rates were available until after flowering. Apparent nitrogen recovery efficiency was similar to that of similar mid-row banding and topdressing trials. Post-harvest soil tests showed that high levels of N may remain in the soil for the next crop. Further research to refine N recovery methods would indicate if nitrogen use efficiency (NUE) is improved with this system. However, currently our experiments strongly suggest that mid-row banding shows potential for efficient supply of N to crops after rice.

Key words
Mid-row, nitrogen, post-rice, wheat

1. Introduction
Post-rice crops have access to stored moisture accumulated during the period of inundation during the rice season. Hence, even in a year with only 150-200 mm GSR, post-rice crops have a reliable water-limited yield approaching 5 $t.ha^{-1}$. This may be due to the dis-continuous soil porosity within our sodic clay subsoil; the prolonged period of inundation fills these small poorly-connected pores. Similarly, the water in these pores is difficult to access, ensuring that this component of soil water is not fully utilized until later in the season.

Rice stubbles are invariably low in N fertility and are often subject to P tie-up. The latter is easily addressed with P fertilizer at seeding but a high rate of N is necessary to achieve high yields. In the authors' on-farm experience, only 20-40 $kgN.ha^{-1}$ is available from the soil at seeding, with another 20-30 $kgN.ha^{-1}$ mineralizing during the season. This makes 40-70 $kgN.ha^{-1}$ available from the soil during the season. If 200 $kgN.ha^{-1}$ is required to reach 5 $t.ha^{-1}$ grain yield, 130-160 $kgN.ha^{-1}$ needs to be applied during the season.

With an increasing incidence of dry winters in the Riverina, top-dressed N may not be washed into the soil far enough for reliable root access, and some can be lost from volatilization; more than 10 mm of rainfall is required within a few days after a topdressing event for the N to be properly accessible to crop roots, especially on a clay soil with large amounts of decomposing OM tying applied N (Angus et al., 2014). Nitrogen losses in this situation can reach 40% (Fowler & Bryndon, 1989). Hence, response to top-dressed N can vary greatly with rainfall (Angus et al., 2014).

Conversely, even with the increasing incidence of dry winters in the NSW Riverina, the saturated soil profile of a post-rice crop increases the risk of prolonged periods of water-logging in winter from relatively modest rainfall events. When N is in the nitrate form, in a water-logged soil it can quickly be converted to nitrogen gas and a large proportion of it lost to the crop (Zerulla et al., 2001)

Double-shooting allows high rates of N to be safely applied at seeding. However N at seeding needs to be moderated to limit early vegetative growth which leads to a low harvest index, as well as increased lodging and disease risk, so additional top-dressed N is usually required.

Mid-row banding follows a similar concept but allows more separation between N and the seed. The increased distance delays access to the applied N, as it takes time for crop roots to reach the band (Passioura & Wetselaar, 1972). The authors' on-farm experience with mid-row banding in rice stubble suggests that the crop is capable of accessing applied N about 6-8 weeks after seeding. Mid-row banding urea or ammonia provides a high concentration of ammonium, which can reduce nitrification rates by inhibiting microbial activity within the vicinity of the banded N (Wetselaar et al., 1973). Hence, mid-row banding can reduce the risk of N leaching and denitrification if the soil becomes waterlogged, as only limited amounts of nitrate are present at any point in time (Zerulla, 2001). There is also potential for an increase in assimilation efficiency because N uptake by wheat in the form of ammonium can occur when high concentrations are present (Haynes & Goh, 1978). The assimilation of nitrate requires 20ATP mol¯1, whereas ammonium requires 5ATPmol¯1 (Salsac et al., 1987), which could lead to increased NUE. Hence, mid-row banding should be able to reliably supply high rates of N, without the need of the extra time and expense to topdress, in a wide range of seasonal conditions.

These experiments aim to measure the response of wheat after rice to N applied entirely at seeding by mid-row banding.

2. Methodology

The experiment was conducted in a burnt rice stubble at Moulamein, NSW. Modern dryland wheat varieties were used, as they have a yield potential of 6 $t.ha^{-1}$, and a short growing season that should not require irrigation. Table 1 shows details of the experiments. In every third seeding row no wheat was seeded. Rather, urea (46%N) was placed in this row, as mid-row fertilizer.

The experiments were a randomized complete-block design, with 4 replicates. Each plot was 19 m wide, 60 m long in 2015 and 150 m long in 2016. A variable rate seeder was used, so that mid-row fertilizer rate could be changed during the seeding process without stopping the machine. Each plot had 10 m border zones at each end, to allow for the seeder rate to equilibrate after changing the rate between plots. The harvest width was 12.0 m.

Table 1: The experiment details from 2015 and 2016.

Year	2015	2016
Wheat variety	Yitpi	Mace
Sowing date	May 23rd	May 22nd

Sowing rate (kg.ha^{-1})	100	100
Seeder row spacing (cm)	26	18
Mid-row band spacing* (cm)	78	54
Fertilizer with seed	160 kg.ha^{-1} Granulock 10Z**	100 kg.ha^{-1} Granulock 10Z** + 50 kg.ha^{-1} urea
Fertilizer in mid-row (kg.ha^{-1} urea)	0, 125, 250 and 375	0, 125 and 250
Total N rates (kgN.ha^{-1})	16, 76, 136 and 196	30, 90 and 150

* Every third row of the seeder was blocked to seed, and only urea applied in that row.
**Granulock 10Z contains 11%N, 21.8%P, 4%S and 1% Zn

From 40 days after seeding (DAS), until after flowering, the chlorophyll content of the youngest fully-expanded leaf was measured with a SPAD (N Tester©) meter twice a week in 2015, and once a week in 2016. 30 plants were measured in each plot. Plant number, tiller number and head number were measured. At harvest total grain weight, moisture, protein and 1000-grain weight were measured. Total soil nitrogen was measured at seeding, and total soil nitrogen in the mid-row was measured at harvest.

All statistics were analyzed using the Statistix software package.

3. Results
Water-logging (as indicated by surface water) occurred for approximately four weeks in each season; one event in 2015 and three separate events in 2016 (Figure 1). Significant crop damage and some plant death occurred in 2016, from the combination of selective herbicide (Tralkoxydim) and water-logging. The wheat accessed the mid-row N 84 DAS in 2015 and 86 DAS in 2016 (Figure 1).
The 60N treatment in the mid-row maintained a chlorophyll content equivalent to the highest N rate until 98 DAS in 2015 and 111 DAS in 2016. The 120N treatment, maintained a chlorophyll content equivalent to the highest N rate until 142 DAS in 2015.

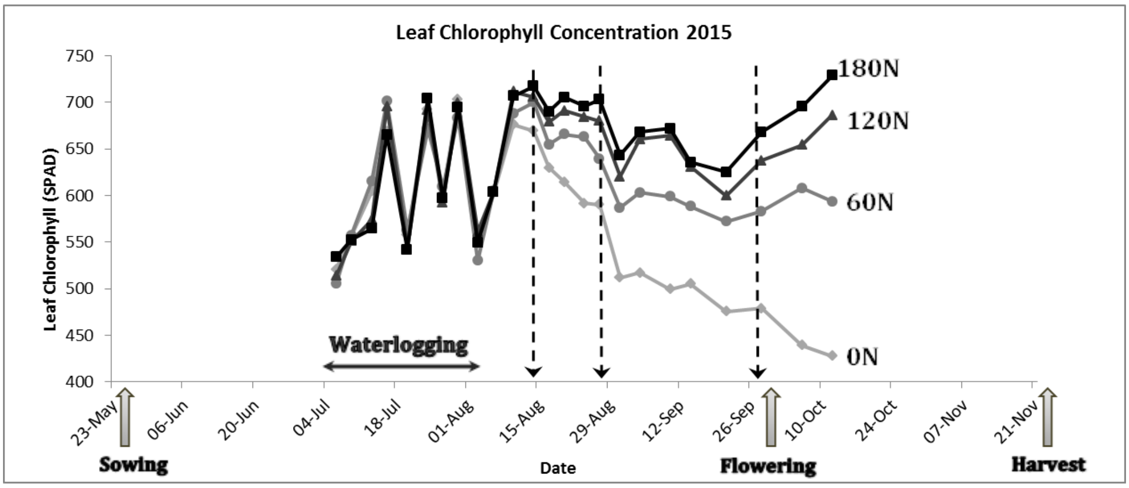

Figure 1a: N Tester© (SPAD) measurements leaf chlorophyll concentration for four mid-row nitrogen treatments (0N, 60N, 120N & 180N) during the 2015 growing season for wheat. Arrows with dotted lines indicate the time when chlorophyll concentration became significantly less than the higher N rates for 0N, 60N and 120N respectively.

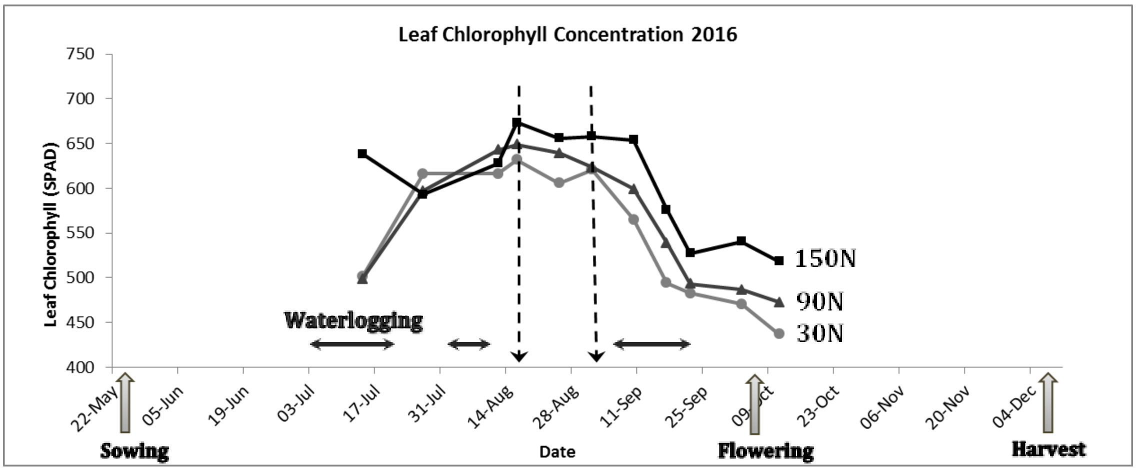

Figure 1b: N Tester© (SPAD) measurements leaf chlorophyll concentration for four mid-row nitrogen treatments (0N, 60N, 120N & 180N) during the 2016 growing season for wheat. Arrows with dotted lines indicate the time when chlorophyll concentration became significantly less than the higher N rates for 0N and 60N respectively.

Mid-row N increased grain yield a similar amount in both seasons; 120 kgN.ha^{-1} increased yield by 1.2-1.3 t.ha^{-1} compared with 0N (Table 2). Mid-row N only increased grain protein in 2015. Consequently, grain N responded more to mid-row N in 2015 than in 2016. The apparent nitrogen recovery efficiency (ANRE) in the grain was greater in 2015 (maximum of 28-30%) than in 2016 (maximum of 17%).

Table 2**:** The mid-row N rate (kgN.ha^{-1}), total fertilizer N rate (kgN.ha^{-1}), grain yield (mt.ha^{-1}) and grain protein content (%), grain N (kgN.ha^{-1}) and ANRE (%), for four mid-row N treatments in 2015 (0, 60, 120 and 180 kgN.ha^{-1}) and three mid-row N treatments in 2016 (0, 60 and 120 kgN.ha^{-1}), North Dale, Moulamein.

Year	Mid-row N (kg.ha^{-1})	Total N (kg.ha^{-1})	Grain yield (mt.ha^{-1})	Grain protein (%)	Grain number (grains.m^{-2})	1000 grain weight (g)	Grain N (kg.ha^{-1})	ANRE (%)
2015	0	16	1.85c	8.5d	4,410c	43a	28c	-
	60	76	2.73b	9.6c	7,170b	40a	46b	30
	120	136	3.14a	11.3b	9,000a	36b	62a	28
	180	196	2.95ab	12.2a	9,310a	33b	63a	19
2016	0	30	2.95c	8.2c	7,190c	41a	42b	-
	60	90	3.55b	7.8b	8,880b	40a	48b	10
	120	150	4.12a	8.4a	10,300a	40a	62a	17

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

4. Discussion

Mid-row N was accessed by the wheat crop from 84-86 DAS, with the 120-180kgN.ha^{-1} treatments delivering N until after flowering. At that point the SPAD meter was no longer capable of measuring leaf chlorophyll content, due to a lack of actively growing leaf tissue to sample. When the wheat first accessed the mid-row N, it was at the mid-tillering stage. This is compatible with achieving high yields in the Riverina, because limited N access moderated early vegetative growth.

The grain yield response to mid-row N was similar in both years; 0.6-0.9 t.ha^{-1} for 60 kgN.ha^{-1} in the mid-row and 1.2-1.3 t.ha^{-1} for 120 kgN.ha^{-1}. Grain protein only responded to mid-row N in 2015. Consequently the response of grain N and thus ANRE, was greater in 2015. The protein response can be attributed to a much drier spring in 2015 spring than 2016, only receiving 20 mm of rainfall in September and October compared to 119 mm in 2016. There was also a week of unseasonably hot weather just after flowering, with temperature ranging from 21-33°C. Gibson & Paulson (1999) reported a 3-5% reduction in yield for every one degree increase in average daily temperature above 15°C. 1000-grain weight did not decline with increased mid-row N in 2016 as it did in 2015, but the yield response was similar to 2015. If other yield components had responded similarly to that in 2015, the yield response should have been greater in 2016, but grain number (the product of head number and grains per head) did not respond as much to mid-row N in 2016.. This may have been due to the crop damage from combined herbicide and water-logging that occurred in 2016.

The measured ANRE of 17-30% was similar to that for mid-row N of 21-28% in an Australian high rainfall environment (Angus et al., 2014) and 24-31% in south-east China (Chen, 2016), although it was much lower than the 40-100% found by Hartmann et al. (2015) in a maize-wheat system in northern China. It was also similar to ANRE of top-dressed N in the above experiments of 20% in Australia and 27-30% in south-east China. It is lower than the global estimate of 34% by Ladha et al. (2005).

Although detailed soil N measurements were not taken, the ANRE estimates suggest a substantial proportion of the mid-row N survived the water-logging events. This may have been due to the high concentration of N in the mid-row band inhibiting nitrification of ammonium to nitrate (which is then vulnerable to denitrification in a water-logged soil), such as described by Wetselaar et al. (1973) and Zerulla et al. (2001).

Further research is needed to achieve a better understanding of ANRE of mid-row banded N. It would be useful to compare ANRE of mid-row banded N and the conventional practice of top-dressed N on a range of soil types and degrees of water-logging.

5. Conclusions

Mid-row banded N increased yield in wheat after rice, despite significant water-logging in both seasons. The response of grain protein, grain N, and consequent ANRE, was greater in 2015 than in 2016; perhaps due to crop damage limiting grain yield response in 2016. ANRE to mid-row banded N was similar to that found in other studies and similar to results for top-dressed urea in a similar environment.

SPAD measurements indicated that most mid-row banded N survived the substantial water-logging events in both seasons, with wheat still accessing N after flowering. This may make it a helpful technique for situations with an elevated water-logging risk, such as crops after rice.

6. References

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