

Building an understanding of normalised difference vegetation index (NDVI), through the comparison of nitrogen products, nitrogen application timing and rate in wheat and barley

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Key points

- A wet winter and spring during 2016 meant that nitrogen (N) applied at sowing was inefficient in meeting crop requirements during the season, due to high losses through leaching and denitrification.
- Application of nitrogen at first node (GS31) and third node (GS33) improved crop uptake, and was reflected as increased 'greenness' in wheat towards the end of the season, as measured by normalised difference vegetation index (NDVI).
- Using the Greenseeker® to measure NDVI in-crop was useful to determine crop responses to fertiliser treatments, and aligned well with final yield results.
- Determining crop nitrogen requirements based on in-crop NDVI readings improved the efficiency of nitrogen supply, as nitrogen was only added as needed, reducing input costs
- For both wheat and barley there was no difference between urea and Easy N® in terms of tiller and head numbers, dry matter (DM) production, yield or grain quality parameters when comparable nitrogen application rates and timings were used.

Background

In order to improve the efficiency and cost-effectiveness of nitrogen applications, there are three key aspects that can be manipulated: product type (solid urea vs liquid nitrogen), application timing and application rate.

While any differences in these parameters can influence final yield, being able to measure in-crop performance allows greater flexibility in modifying the in-season fertiliser strategy, while appreciating how seasonal conditions have influenced the crop response to fertiliser product, timing and rate.

The use of normalised difference vegetation index (NDVI) to measure and monitor crop 'greenness' and better understand variance in crop vigour and biomass (dry matter — DM) production is becoming more generally accepted. Growers and advisors can measure NDVI using either satellite imagery, or via a hand-held sensor, such as a Greenseeker. A hand-held Greenseeker was used in this trial to evaluate the extent and rate with which the crop responded to the different fertiliser treatments, and additionally, if the form in which the nitrogen was applied (solid vs liquid) resulted in a different rate or intensity of crop response.

The intent of this trial was to understand if wheat and barley would respond to the applied nitrogen treatments differently and if the responses would result in comparable changes in NDVI values.

Riverine Plains Inc funded this trial through member and sponsor support and the trial was located at the *Riverine Research Centre*: a partnership between Riverine Plains Inc and FAR Australia.

Aims

The specific aims of this trial were to:

- understand if the crop responded differently to urea compared with Easy N (liquid nitrogen)
- define the sensitivity with which the NDVI method can detect differences in timing and rate of nitrogen application
- determine if wheat and barley respond comparatively to nitrogen type (product), timing and rate, as measured by NDVI
- quantify how the use of different nitrogen types, timing and rates influence grain yield and quality.

Trial site: Riverine Research Centre, Yarrawonga, Victoria

Location: Telewonga Pty Ltd
Sowing date: 17 May 2016
Rotation: First wheat and barley after canola
Variety: Wheat: Trojan, Barley: Latrobe
Stubble: Canola unburnt, one pass with a Kelly chain
Rainfall:
GSR: 604mm (April–October)
Summer rainfall: 125mm
Soil mineral nitrogen: 50kg N/ha (0–60cm)

Method

A range of nitrogen treatments was applied in a randomised complete block design across replicated small plots of wheat or barley.

Two products were used: granular urea (42% N w/w) and liquid Easy N (50% urea, 25% ammonium, 25% nitrate — total 42.5% N w/v). While the maximum nitrogen application rate with urea was 150kg N/ha, there was a fluid application limit of 100kg N/ha with Easy N due to concentration restrictions.

Statistical analysis was carried out using analysis of variance (ANOVA), with statistical significance determined at 5% variance. Measures of least significant difference (LSD) were used to determine which, if any, treatments were significantly different.

Due to the large number of treatments across both wheat and barley, the results will be discussed separately for each crop type.

Wheat results

The range of nitrogen treatments applied to wheat is shown in Table 1.

The nitrogen application rates for the NDVI treatments (treatment 8: NDVI1 – 171kg N/ha and treatment 9: NDVI2 – 133kgN/ha)) were based on the NDVI 'response index' from representative plots. The method was based on a rate of change of NDVI during early stem elongation (GS30–33), which determined the amount of nitrogen required for the crop to reach either full yield potential or three-quarters of the yield potential. In order to respond to that change, a later nitrogen application was required at third node (GS33).

i) Establishment and crop structure

Plant establishment

The key differences in wheat establishment and development are shown in Table 2.

At the three-leaf to one-tiller stages there was no clear nitrogen response on plant numbers, with the control (nil N applied) having comparable plant numbers to Treatment 4 (50kg N/ha applied at sowing) (data not shown).

In addition, there was no benefit of using Easy N (Treatment 2) in terms of early plant establishment compared with urea (Treatment 4), when applied at comparable rates and timings.

Tiller numbers

As tiller numbers were assessed immediately *prior* to the third node (GS33) nitrogen applications, the final nitrogen applications for Treatments 6, 8, 9 and 10 had not yet been applied. This means the results shown in Table 2 for Treatment 4 (50kg N/ha @ sowing, 50kg N/ha @ GS31) and Treatment 6 (50kg N/ha @ sowing, 50kg N/ha @ GS31, 50kg N/ha @ GS33) are both comparable to those for Treatment 2 (Easy N 50kg N/ha @ sowing, 50kg N/ha @GS31).

TABLE 1 Nitrogen treatments applied to wheat, Riverine Research Centre, 2016

Treatment	Total N applied (kg N/ha)	Sowing (GS00) (kg N/ha)	First node (GS31) (kg N/ha)	Third node (GS33) (kg Nha)
1 Control	Nil nitrogen			
2 Easy N	100	50	50	
3 Urea	100	100		
4 Urea	100	50	50	
5 Urea	100		100	
6 Urea	150	50	50	50
7 Urea	150	50	100	
8 Urea: NDVI 1	171	50	115	6
9 Urea: NDVI 2	133	50	79	4
10 Urea: N budget	204	50	100	54



TABLE 2 Plant counts 16 May 2016, three leaf–one tiller (GS13–21); tiller counts 25 August 2016, third node (GS33) and head counts 1 December 2016, harvest (GS99)

Treatment	Nitrogen treatments				Plant counts		
	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	Plants/m^2 (GS13–21)	Tillers/m^2 (GS33)	Heads/m^2 (GS99)
1 Control	Nil nitrogen				157^{ab}	320^{c}	198^{c}
2 Easy N	100	50	50		144^{b}	350^{bc}	272^{ab}
3 Urea	100	100			143^{b}	372^{b}	203^{c}
4 Urea	100	50	50		163^{a}	362^{bc}	263^{abc}
5 Urea	100		100			352^{bc}	277^{ab}
6 Urea	150	50	50	50		444^{a}	289^{ab}
7 Urea	150	50	100			384^{b}	253^{bc}
8 Urea: NDVI 1	171	50	115	6		379^{b}	322^{a}
9 Urea: NDVI 2	133	50	79	4		379^{b}	270^{ab}
10 Urea: N budget	204	50	100	54		368^{bc}	294^{ab}
Mean					**152**	**371**	**264**
LSD					15	50	65

Figures followed by different letters are regarded as statistically significant.

While some significant differences in tiller numbers were measured between treatments, there are no clear messages, as comparable treatments behaved differently. For example, while the control (nil N applied) had the least number of tillers, this was not statistically different to Treatment 2 (Easy N 50kg N/ha @ sowing, 50kg N/ha @GS31) or Treatments 4, 5 or 10, which had between 100 and 150kg N/ha added. The highest number of tillers was measured in Treatment 6, in which 100kg N/ha had been applied by the GS33 assessment (which was equivalent to Treatment 4 at GS33), with the remainder of the treatments falling in between.

Head numbers

The key result from the head number assessment is that the control (nil N applied) and Treatment 3 (100kg N/ha @ sowing) were significantly lower than the Easy N treatment (Treatment 2), and Treatments 5, 6, 8, 9 and 10, all of which had a large proportion of their nitrogen allocation applied at first and third node (GS31, GS33). This result was likely due to the wet winter and spring of 2016, with nitrogen applied at sowing being subject to higher losses through leaching and denitrification.

ii) Dry matter production and nitrogen uptake

Dry matter

The differences in DM production are shown in Table 3. Measures of DM were taken early in the season, at mid-tillering (GS23), when the average DM was 0.61t/ha, and also at stem elongation (GS30), when the average DM was 0.86 t/ha. However, as there were no significant differences in DM at these times, the results are not shown in the table.

The DM production across the different treatments shows a clear trend when measured at flag leaf–start of booting (GS39–43) and at harvest (GS99). The control (nil N applied) performed as expected, producing less DM compared with the fertilised treatments. However Treatment 3 (100kg N/ha @ sowing) also performed poorly and was statistically comparable to the control, following the trend in head numbers, whereby high rates of nitrogen applied at sowing did not translate into DM production.

Nitrogen uptake

Nitrogen uptake of the crop under different fertiliser regimes is shown in Table 4. Measures of nitrogen uptake were taken early in the season at mid-tillering (GS23) and stem elongation (GS30). However, as there were no significant differences in DM at these times, the results are not shown.

Due to variation across treatments at each growth stage, nitrogen uptake across flag leaf–start of booting (GS39–45) and the start of flowering (GS61) are considered together. The treatments with consistently high nitrogen uptake are Treatment 7 (50kg N/ha @ sowing, 100kg N/ha @ GS31), Treatment 8 (NDVI1 100% yield potential: 171kg N/ha) and Treatment 10 (N budget: 204kg N/ha). The common theme across these treatments is the high rates of nitrogen applied at first node (GS31). Other treatments with high nitrogen at GS31 (Treatments 5 and 9) also showed high nitrogen uptake by the start of flowering (GS61) assessment.

TABLE 3 Dry matter 25 August 2016, third node (GS33); 15 September 2016, flag leaf fully emerged/start of booting (GS39/43); 6 October 2016, start of flowering (GS61) and 1 December, harvest (GS99)

Treatment	Nitrogen treatments				Dry matter (t/ha)			
	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	GS33	GS39–45	GS61	GS99
1 Control	Nil nitrogen				1.90	3.44^{c}	6.08	6.95^{c}
2 Easy N	100	50	50		2.40	4.32^{ab}	5.95	10.22^{a}
3 Urea	100	100			2.60	3.96^{abc}	6.99	7.37^{bc}
4 Urea	100	50	50		2.20	4.33^{a}	7.58	10.10^{a}
5 Urea	100		100		2.00	3.52^{bc}	6.46	9.71^{ab}
6 Urea	150	50	50	50	2.20	4.47^{a}	6.01	11.19^{a}
7 Urea	150	50	100		2.00	4.33^{a}	6.36	9.37^{abc}
8 Urea: NDVI 1	171	50	115	6	2.00	4.62^{a}	6.92	10.42^{a}
9 Urea: NDVI 2	133	50	79	4	2.60	4.58^{a}	7.34	10.69^{a}
10 Urea: N budget	204	50	100	54	2.50	4.62^{a}	7.34	9.69^{ab}
Mean					**2.24**	**4.22**	**6.70**	**9.57**
LSD					n.s.	0.80	n.s.	2.47

Figures followed by different letters are regarded as statistically significant.

TABLE 4 Nitrogen uptake in wheat 25 August 2016, third node (GS33); 15 September 2016, flag leaf fully emerged–start of booting (GS39–43); 6 October 2016, start of flowering (GS61) and 1 December, harvest (GS99)

Treatment	Nitrogen treatments				Nitrogen uptake in crop (kg N/ha)			
	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	GS33	GS39–45	GS61	GS99
1 Control	Nil nitrogen				34^{e}	58^{d}	57^{c}	35^{e}
2 Easy N	100	50	50		64^{abc}	78^{c}	76^{c}	46^{e}
3 Urea	100	100			53^{bcd}	69^{cd}	77^{c}	34^{e}
4 Urea	100	50	50		50^{cd}	75^{cd}	112^{b}	67^{bcd}
5 Urea	100		100		49^{cd}	97^{b}	129^{ab}	70^{bcd}
6 Urea	150	50	50	50	55^{bcd}	99^{b}	72^{c}	52de
7 Urea	150	50	100		66^{ab}	132^{a}	127^{ab}	86^{b}
8 Urea: NDVI 1	171	50	115	6	57^{a-d}	131^{a}	150^{a}	66^{cd}
9 Urea: NDVI 2	133	50	79	4	71^{a}	99^{b}	141^{ab}	116^{a}
10 Urea: N budget	204	50	100	54	47de	127^{a}	153^{a}	72^{bc}
Mean					**55**	**96**	**110**	**64**
LSD					15	18	31	19

Figures followed by different letters are regarded as statistically significant.

iii) Green leaf retention differences (NDVI)

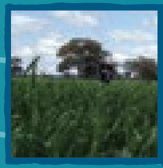
There were eight NDVI readings carried out, using the hand-held Greenseeker, between 18 July and 6 October. These were done in order to understand the key timings where differences in treatments might be detected due to differences in plant green leaf retention. When all treatments are combined it is difficult to identify key differences (Figure 1).

As such, it may be of more value to focus on different sets of treatments in order to address specific questions.

In all of the following results, the control (nil N applied) results are shown to provide a benchmark to compare against.

Q1. ***Are there differences in NDVI between Easy N and urea, when applied at the same rate and timing in wheat?***

The wheat crop was significantly 'greener' in the Easy N fertiliser treatment than the wheat treated with granular urea when the NDVI was measured at 18 and 24 August 2016, and 29 September 2016 (Figure 2).



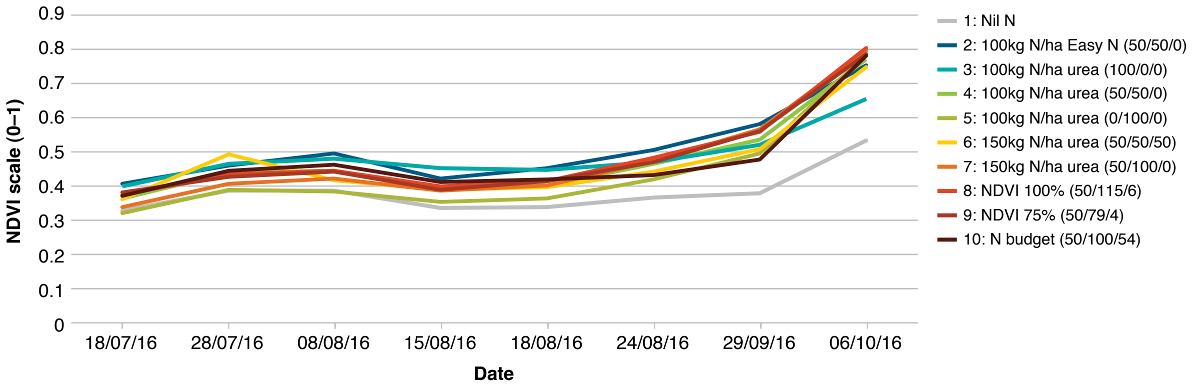


FIGURE 1 Influence of applied nitrogen timing and rate on NDVI in wheat, showing all treatments

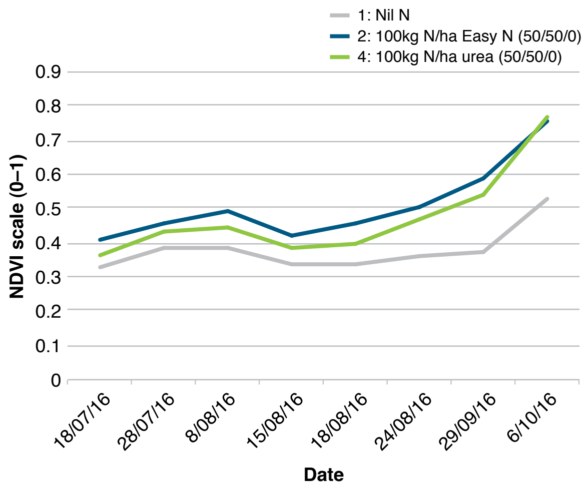


FIGURE 2 Influence of liquid Easy N compared with granular urea on NDVI in wheat*

*The first node (GS31) nitrogen was applied on 15 August 2016.

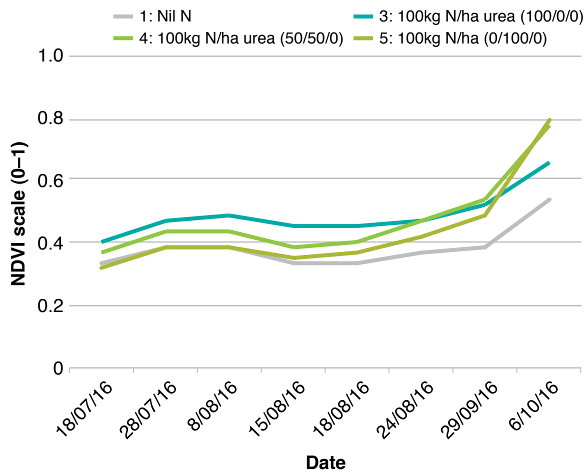


FIGURE 3 Influence of timing of urea on NDVI in wheat, showing treatments with the same total rate (100kg N/ha), at different timings*

*The first node (GS31) nitrogen was applied on 15 August 2016.

Q2. *Can NDVI pick up differences in the timing of nitrogen application in wheat, with the same total amounts applied?*

At the first NDVI reading (18 July 2016) Treatment 3 (100kg N/ha @ sowing) was significantly 'greener' than the other treatments (Figure 3). On 8 August 2016 both Treatment 3 (100kg N/ha @ sowing) and Treatment 4 (50kg N/ha @ sowing, 50 kg N/ha @ GS31) were greater than Treatment 5 (100kg N/ha @ GS31), which had not yet received any fertiliser.

Treatment 3 continued to measure significantly greater NDVI values on 15 and 18 August 2016, with Treatment 3 and 4 again 'greener' than Treatment 5 on 24 August 2016. However, at the 6 October reading Treatments 4 and 5 were significantly 'greener' than Treatment 3.

It is likely much of the applied nitrogen at sowing was lost through denitrification and leaching during the wet winter, resulting in reduced nitrogen supply to the crop through spring. Splitting the nitrogen application between sowing and first node (Treatment 4) gave a consistent plant response, while reducing the magnitude of nitrogen loss through the wet winter.

Q3. *Can NDVI pick up differences in rates of urea applied at the same timings in wheat?*

There were no differences between NDVI measurements when 100kg N/ha was applied compared to the 150kg N/ha rate (when applied at the same timings) until the final reading on 6 October 2016. At the final assessment, Treatment 7 (50kg N/ha @sowing, 100kg N/ha @GS31) had a small but significantly higher NDVI reading than Treatment 4 (50kg N/ha @ sowing, 50kg N/ha @GS31) (Figure 4).

These results suggest that plant nitrogen requirements were met with the lower application rate until late spring.

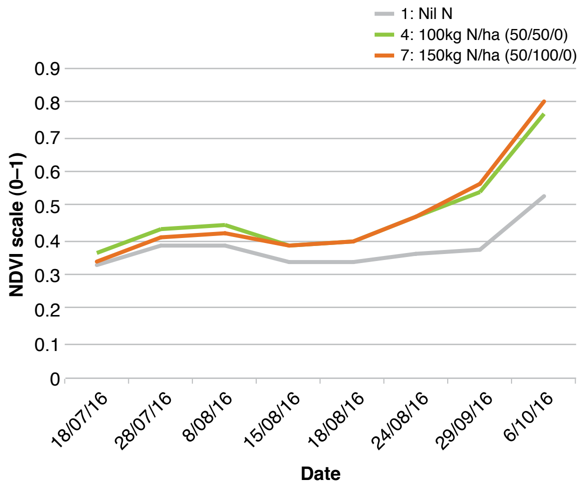


FIGURE 4 Influence of rates of urea on NDVI in wheat, showing treatments with different total rates (100 vs 150kg N/ha), at the same timings*

*The first node (GS31) nitrogen was applied on 15 August 2016. The application targeted for third node (GS33) was delayed by very wet conditions and was applied on 15 September 2016 when the crop was at the flag leaf fully emerged/start of booting (GS39/43) stage.

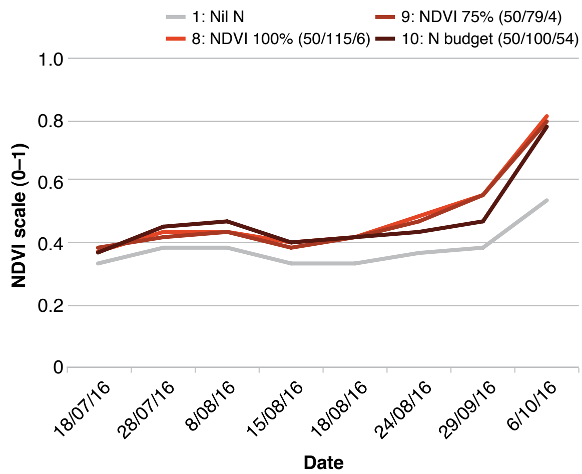


FIGURE 5 Influence of method of determining nitrogen application in wheat, showing the two NDVI-derived treatments (100% yield potential, 75% yield potential) and the nitrogen budgeting method*

*The first node (GS31) nitrogen was applied on 15 August 2016. The application targeted for third node (GS33) was delayed by very wet conditions and was applied on 15 September 2016 when the crop was at the flag leaf fully emerged/start of booting (GS39/43) stage.

***Q4.** Are there any differences in the 'alternative methods' of determining nitrogen application rates; using NDVI to determine rates required for 100% and 75% potential yield, and the highest rates applied through a nitrogen budget approach in wheat?*

The three treatments shown in Figure 5 vary in total nitrogen application from 133kg N/ha to 204kg N/ha. However, there are only limited differences in their NDVI readings. On 28 August Treatment 8 (NDVI1 100% yield potential: 171kg N/Ha), had an NDVI reading significantly higher than Treatment 10 (nitrogen budget: 204kg N/ha), while on 29 September 2016 both Treatments 8 and 9 (NDVI1 and NDVI2) had higher readings than the nitrogen budget method.

These results clearly demonstrate the value of using in-crop NDVI measurements (or satellite derived NDVI) when calculating the crop nitrogen requirements to reduce over-supply, which is further supported by the following yield data.

iv) Yield and grain quality

Yield

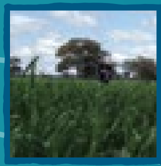
The lowest-yielding treatments were the control (nil N applied) and Treatment 3 (100kg N/ha@ sowing) (Table 5), both of which also had the lowest head counts (Table 2).

Due to the wet winter and spring, nitrogen losses through denitrification and leaching would likely have been high, particularly for nitrogen applied early in the season.

TABLE 5 Wheat yield, protein, test weight and screenings 11 December 2016, at harvest (GS99)

	Nitrogen treatments				Yield and quality			
Treatment	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)
1 Control	Nil nitrogen				3.11^{g}	7.5^{f}	82.1^{ab}	1.0^{ab}
2 Easy N	100	50	50		4.53^{bcd}	7.8^{ef}	82.5^{a}	0.9^{ab}
3 Urea	100	100			3.55^{fg}	7.7^{ef}	82.6^{a}	1.0^{ab}
4 Urea	100	50	50		4.31^{cde}	8.6^{def}	82.1^{ab}	1.0^{ab}
5 Urea	100		100		3.85^{ef}	10.8^{bc}	81.0^{cd}	1.2^{a}
6 Urea	150	50	50	50	4.16^{de}	9.2^{de}	82.2^{ab}	0.9^{ab}
7 Urea	150	50	100		4.07^{def}	10.7^{bc}	81.2^{cd}	1.1^{a}
8 Urea: NDVI 1	171	50	115	6	4.72^{bc}	11.9^{ab}	80.9^{de}	0.9^{ab}
9 Urea: NDVI 2	133	50	79	4	5.37^{a}	10.0^{cd}	81.6^{bc}	0.8^{b}
10 Urea: N budget	204	50	100	54	4.87^{ab}	13.0^{a}	80.2^{e}	0.8^{b}
Mean					**4.25**	**9.7**	**81.6**	**1.0**
LSD					0.54	1.5	0.7	0.4

Figures followed by different letters are regarded as statistically significant.



While the other treatments would have also suffered considerable losses, having a spread of application timings (sowing, GS31 and GS33) would ensure there was recently-applied nitrogen available as the crop needed it. In comparison, applying all the nitrogen up-front means there is no further opportunity to replace nitrogen lost from the system.

The top four yielding treatments were: Treatment 8 (NDVI 1: 100% yield potential, 171kg N/ha), Treatment 9 (NDVI 2: 75% yield potential, 133kg N/ha), Treatment 10 (N budget: 204kg N/ha) and Treatment 2 (Easy N, 100kg N/ha), with Treatment 9 (NDVI 2: 75% yield potential, 133kg N/h) yielding significantly more than all others (Table 5). While the Easy N treatment yielded well, it was not significantly higher yielding than the solid urea treatment at the same rates and timings.

Protein

Treatment 10 (N budget: 204kg/ha) received 154kg N/ha between the first and third node growth stages (GS31 and GS33) and as expected, had significantly higher protein levels than all other treatments (Table 5).

The top four treatments in terms of protein levels (Treatments 5, 7, 8, 10) all had at least 100kg N/ha applied at first node (GS31).

Test weight and screenings

While significant differences were measured between the treatments for test weights and screenings, the range of values between treatments is low (Table 5).

Barley

The list of nitrogen treatments applied to barley is shown in Table 6. The treatments for barley are the same as for wheat, except for those dependent upon NDVI readings (Treatments 8 and 9), which have less total nitrogen applied compared with the wheat trial.

i) Establishment and crop structure

Plant establishment and tiller numbers

There were no differences in plant establishment or tiller number between treatments (Table 7). While there may be trends, the high variance across each replicate and within each treatment, means there is as much variability within each treatment as there is between treatments. This was likely due to the excessively wet conditions during the 2016 season.

Head numbers

The only differences in barley plant development between treatments were measured at harvest (GS99) (Table 7). Treatment 5 (100kg N/ha N @ GS31), which received all nitrogen at first node (GS31) had significantly more head numbers than all other treatments, while the lowest number of heads was measured in the control (nil N applied) and Treatment 3 (100kg N/ha @ sowing).

Due to the wet season, it is likely much of the nitrogen applied at sowing was lost through leaching or denitrification before the plant required it.

ii) Dry matter production and nitrogen uptake

Dry matter

The amount of DM produced with each nitrogen fertiliser strategy is shown in Table 8. Measures of DM were also taken earlier in the season at tillering–stem elongation (GS24–30) and again at stem elongation–first node (GS30–31), with mean values of 0.78t/ha and 0.96t/ha respectively. There were no significant differences between treatments and these results are not shown in Table 8.

There were no significant differences in DM production between each treatment due to the high variability within treatments.

TABLE 6 Nitrogen treatments applied to barley, Riverine Research Centre, 2016

Treatment no.	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)
1 Control	Nil nitrogen			
2 Easy N	100	50	50	
3 Urea	100	100		
4 Urea	100	50	50	
5 Urea	100		100	
6 Urea	150	50	50	50
7 Urea	150	50	100	
8 Urea: NDVI 1	140	50	85	5
9 Urea: NDVI 2	117	50	63	4
10 Urea: N budget	204	50	100	54

TABLE 7 Plant counts 16 May 2016, three leaf – one tiller (GS13–21); tiller counts 25 August 2016, third node (GS33) and head counts 1 December 2016, harvest (GS99)

Treatment	Nitrogen treatments				Plant counts		
	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	Plants/m² (GS13–21)	Tillers/m² (GS33)	Heads/m² (GS99)
1 Control	Nil nitrogen				124	573	428[d]
2 Easy N	100	50	50		112	580	521[bcd]
3 Urea	100	100			115	496	442[d]
4 Urea	100	50	50		124	630	558[bcd]
5 Urea	100		100			611	728[a]
6 Urea	150	50	50	50		570	501[cd]
7 Urea	150	50	100			502	682[ab]
8 Urea: NDVI 1	140	50	85	5		534	611[abc]
9 Urea: NDVI 2	117	50	63	4		613	654[abc]
10 Urea: N budget	204	50	100	54		529	554[bcd]
Mean					**119**	**564**	**568**
LSD					n.s.	n.s.	168

TABLE 8 Dry matter 25 August 2016, third node (GS33); 15 September 2016, mid-booting (GS45); 6 October 2016, start of grain fill (GS71) and 1 December, harvest (GS99)

Treatment	Nitrogen treatments				Dry matter (t/ha)			
	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	GS33	GS45	GS71	GS99
1 Control	Nil nitrogen				2.50	3.94	6.10	9.04
2 Easy N	100	50	50		2.90	5.00	8.61	10.94
3 Urea	100	100			2.80	4.57	8.44	9.72
4 Urea	100	50	50		3.30	3.93	9.19	10.54
5 Urea	100		100		2.40	3.66	8.00	8.26
6 Urea	150	50	50	50	3.10	4.57	9.93	10.56
7 Urea	150	50	100		2.80	3.84	8.62	9.56
8 Urea: NDVI 1	140	50	85	5	2.80	4.27	9.67	10.38
9 Urea: NDVI 2	117	50	63	4	3.10	4.61	8.76	11.69
10 Urea: N budget	204	50	100	54	3.50	4.87	11.37	9.75
Mean					**2.93**	**4.33**	**8.87**	**10.04**
LSD					n.s.	n.s.	n.s.	n.s.

Nitrogen uptake

Nitrogen uptake at mid-booting (GS45) was statistically similar in Treatments 5–10 (Table 9). However, by the start of grain fill (GS71), Treatments 8 (NDVI 1) and 10 (N budget) had the highest nitrogen uptake values, while the control (nil N applied) and Treatment 3 (100kg N/ha @sowing) had the lowest uptake values. The total nitrogen uptake values across the treatments had dropped by harvest (GS99), with NDVI 1, NDVI 2 and the N budget treatment (Treatments 8–10) having the highest values.

iii) Green leaf retention differences (NDVI)

There were eight NDVI readings carried out, using the hand-held Greenseeker, taken between 18 July and 6 October. This was done in order to understand the key timings where differences in treatments might be detected, due to differences in plant green leaf retention. When all treatments are combined it is difficult to pick out key differences (Figure 6).

Of interest is that the range of NDVI readings is less for barley than for wheat. While the wheat measurements ranged from 0.32–0.81 with a total range of 0.49, the barley measurements ranged from 0.39–0.73 with a total range of 0.34. The barley NDVI measurements also do not show the sharp rise in NDVI values on 29 September that is seen in the wheat.

The smaller range of NDVI values in barley suggests that either plant requirements were met with a number of

Table 9 Crop nitrogen uptake 25 August 2016, third node (GS33); 15 September 2016, mid-booting (GS45); 6 October 2016, start of grain fill (GS71) and 1 December, harvest (GS99)

Treatment	Nitrogen treatments				Nitrogen uptake in crop (kg N/ha)			
	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	GS33	GS45	GS71	GS99
1 Control	Nil nitrogen				46^{d}	66^{c}	57^{g}	39^{f}
2 Easy N	100	50	50		79^{abc}	90^{bc}	111^{ef}	70^{cde}
3 Urea	100	100			57^{cd}	79^{c}	93^{fg}	47^{ef}
4 Urea	100	50	50		75^{abc}	68^{c}	136^{c-f}	71^{cde}
5 Urea	100		100		59^{cd}	101^{abc}	160^{b-e}	55^{ef}
6 Urea	150	50	50	50	77^{abc}	102^{abc}	119^{def}	64^{def}
7 Urea	150	50	100		93^{a}	117^{ab}	172^{bc}	87^{bcd}
8 Urea: NDVI 1	140	50	85	5	77^{abc}	121^{ab}	209^{ab}	100^{ab}
9 Urea: NDVI 2	117	50	63	4	85^{ab}	99^{abc}	169^{bcd}	94^{abc}
10 Urea: N budget	204	50	100	54	66^{bcd}	134^{a}	237^{a}	115^{a}
Mean					**71**	**98**	**146**	**74**
LSD					23	37	52	27

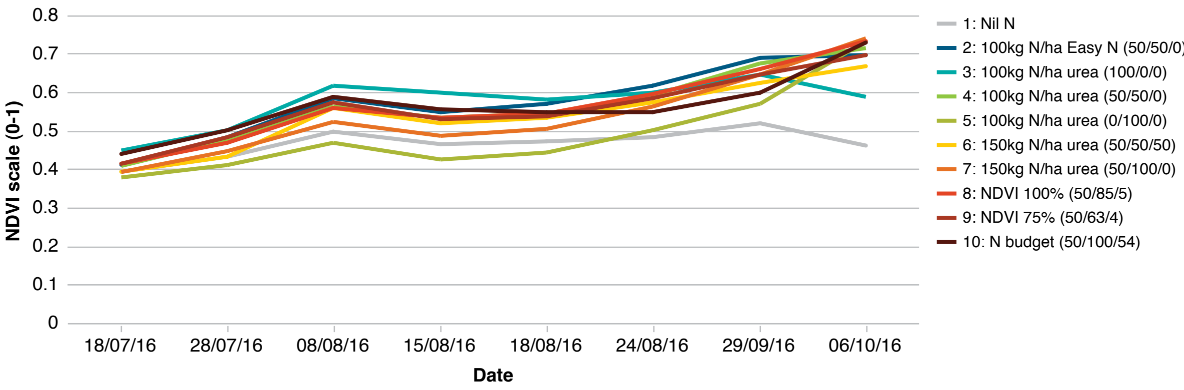


FIGURE 6 Influence of applied nitrogen timing and rate on NDVI in barley, showing all treatments
*The first node (GS31) nitrogen was applied on 15 August 2016. The nitrogen N application targeted for GS33 was delayed by very wet conditions and was applied 15 September 2016 when the crop was at mid-booting stage (GS45).

different treatments, or that the greenness of the barley plant is not as sensitive to nitrogen supply, as is the wheat plant.

As in the wheat trials, it may be of more value to focus on different sets of treatments in order to address specific questions. In all of the results shown below, the control (nil N applied) results are shown to provide a benchmark to compare against.

Q1. *Are there differences in NDVI between Easy N and urea, when applied at the same rate and timing in barley? How does this compare to wheat?*

As shown in Figure 7, there were no significant differences in green leaf retention between Easy N and urea in barley. In comparison, the Easy N treatment showed an increase in NDVI values at three measurement points in wheat, compared with urea.

Q2. *Can NDVI pick up differences in the timing of nitrogen application, with the same total amounts applied? Is this different to wheat?*

At the first NDVI measurement taken 18 July 2016 there was a significantly higher NDVI reading for Treatment 3 (100kg N/ha @ sowing) compared with Treatment 5 (100kg N/ha @ GS31), which is expected as Treatment 5 had not yet had nitrogen applied (Figure 8).

Treatments 3 (100kg N/ha @ sowing) and 4 (50kg N/ha @ sowing, 50kg N/ha @ GS31) were significantly 'greener' than Treatment 5 (100kg N/ha @ GS31) at 28 July 2016 and at 8 August 2016. On 15 August 2016 Treatment 3 (100kg N/ha @ sowing) had a significantly higher NDVI reading than Treatment 4 (50kg N/ha @ sowing, 50kg N/ha @ GS31), which was higher than Treatment 5 (100kg N/ha at GS31). From 18 to 29 August 2016, readings from Treatments 3 and 4 were significantly higher than

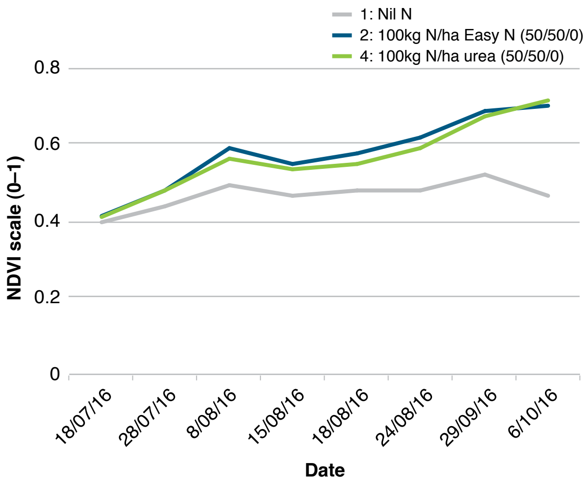


FIGURE 7 Influence of liquid Easy N compared with granular urea on NDVI in barley*

*The first node (GS31) nitrogen was applied on 15 August 2016.

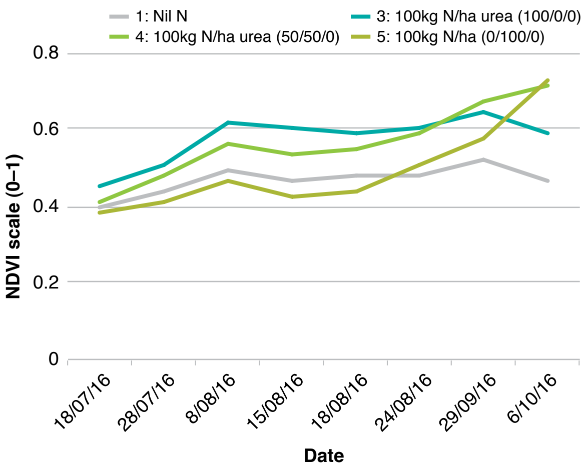


FIGURE 8 Influence of timing of urea on NDVI in barley, showing treatments with the same total rate (100kg N/ha), at different timings*

*The first node (GS31) nitrogen was applied on 15 August 2016.

Treatment 5, while at the final reading on 6 October the NDVI readings for Treatment 3 were lower than the other treatments.

These results demonstrate that the NDVI method can pick up differences in plant response to the timing of nitrogen applications in barley, as in wheat. Splitting the nitrogen between sowing and first node (GS31) gave the most consistent plant response to NDVI (Treatment 4), compared to putting all nitrogen up front at sowing (Treatment 3) and delaying application until first node (Treatment 5).

3. *Can NDVI pick up differences in rates of urea applied at the same timings?*

There were no significant differences in NDVI readings when urea was applied to barley at 50kg N/ha at sowing, and 50 or 100kg N/ha applied at first node (Figure 9). This may be due to barley nitrogen requirements being met at 100kg N/ha, with the added 50kg N/ha in Treatment 7 being above requirements.

This result is similar to that in wheat, in which the increased rate of nitrogen only showed a significant increase in NDVI at the last reading on 6 October.

Q4. *Are there any differences in the 'alternative methods' of determining nitrogen application; using NDVI to determine rates required for 100% and 75% potential yield, and the highest rates applied through a nitrogen budget approach? How does this compare to wheat?*

There were no differences in NDVI between the 100% crop potential NDVI treatment (Treatment 8) and the 75% crop potential NDVI treatment (Treatment 9). The only difference in NDVI readings between the two NDVI-derived treatments and the nitrogen budget treatment (Treatment 10), was on 29 August when the 100% NDVI treatment was significantly 'greener' than the nitrogen budget treatment. This suggests that all of these treatments added surplus nitrogen beyond what was required for plant growth (Figure 10).

The wheat and barley NDVI results were similar when comparing the alternative methods of determining nitrogen application rates, with no added plant response from the large rate in the nitrogen budget treatment.

A key finding from the results (Figure 10) is that using the NDVI hand-held Greenseeker sensor to guide decisions on plant-nitrogen requirements provided the barley crop

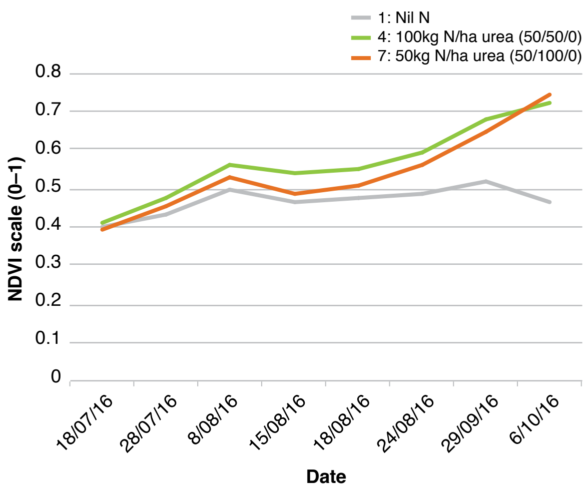


FIGURE 9 Influence of rates of urea on NDVI in barley, showing treatments with different total rates (100 vs 150kg N/ha), at the same timings*

*The first node (GS31) nitrogen was applied on 15 August 2016. The N application targeted for GS33 was delayed by very wet conditions and was applied 15 September 2016 when the crop was at mid-booting stage (GS45).



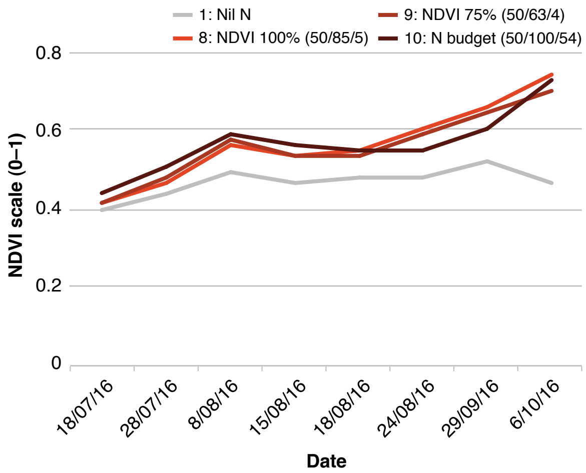


FIGURE 10. Influence of method of determining nitrogen application in barley, showing the two NDVI-derived treatments (100% yield potential, 75% yield potential) and the nitrogen budgeting method*

*The first node (GS31) nitrogen was applied on 15 August 2016. The N application targeted for GS33 was delayed by very wet conditions and was applied 15 September 2016 when the crop was at mid-booting stage (GS45)

with adequate nutrition. This was achieved at a lower rate per hectare than if nitrogen was applied following the nitrogen budget scenario. This is also supported in the yield results.

iii) Lodging

Lodging of the barley was assessed on 1 December 2016, just before harvest. While there was a range of lodging scores measured, from 9–64 (severity x per cent of plot), the high variability meant there were no significant treatment effects (data not shown).

iv) Yield and grain quality

Yield

Most of the treatments had comparable yields (Table 10). The control (nil N applied) treatment yielded significantly less than all the other treatments, with Treatment 3 (100kg N/ha @ sowing) having the next lowest yields.

The yield data largely matches the comparisons made in NDVI measurements; where the NDVI readings showed no significant differences, the yield data showed the same result.

Protein

The protein results were strongly driven by nitrogen splits with high levels of fertiliser applied from first node (Table 10). The highest protein levels were measured in treatments where 50kg N/ha was applied at sowing, which were then followed up with large (85–100kg N/ha) applications at first node (Treatments 7, 8, 10).

The protein levels in the nitrogen budget treatment (Treatment 10), were significantly higher than all others, which is somewhat expected as a total of 204kg N/ha was applied, with 154kg N/ha applied from first to third node (GS31–33).

The lowest protein levels were measured in Treatments 1–4, which had either nil or 100kg N/ha applied, with at least half of the nitrogen applied at sowing.

Test weight and screening

While the range in test weights was low (4.1kg/hL), screenings were significantly higher when more than 50kg N/ha was applied at first node (GS31) (Table 10).

TABLE 10 Barley yield, protein, test weight and screenings 11 December 2016, at harvest (GS99)

	Nitrogen treatments				Yield and quality			
Treatment	Total N applied (kg N/ha)	Sowing (GS00)	First node (GS31)	Third node (GS33)	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)
1 Control	Nil nitrogen				3.55[c]	8.0[e]	64.3[ab]	2.5[c]
2 Easy N	100	50	50		5.27[a]	8.5[de]	64.1[ab]	5.5[bc]
3 Urea	100	100			4.33[b]	8.4[de]	65.3[a]	4.3[bc]
4 Urea	100	50	50		5.18[a]	8.6[de]	65.7[a]	5.8[bc]
5 Urea	100		100		5.13[a]	9.6[c]	63.5[ab]	9.9[a]
6 Urea	150	50	50	50	4.85[ab]	9.2[cd]	63.7[ab]	4.3[bc]
7 Urea	150	50	100		5.18[a]	10.7[ab]	63.2[ab]	10.0[a]
8 Urea: NDVI 1	140	50	85	5	5.23[a]	10.6[b]	63.0[ab]	9.6[a]
9 Urea: NDVI 2	117	50	63	4	5.21[a]	9.2[cd]	62.1[b]	7.4[ab]
10 Urea: N budget	204	50	100	54	5.37[a]	11.5[a]	61.6[b]	11.0[a]
Mean					**4.93**	**9.4**	**63.7**	**7.1**
LSD					0.73	0.8	2.9	3.7

Figures followed by different letters are regarded as statistically significant.

Conclusions

The extremely wet winter and spring of 2016 led to transient waterlogging at the trial site. While this was a statistically designed, replicated trial, waterlogging varied randomly across the site, following the microtopography. This explains the relatively high LSD (least significant difference) values across the site, and why some nitrogen treatments did not behave consistently.

Therefore, rather than one particular treatment being considered the best, it is more the general strategy which is more useful to consider.

In both wheat and barley, the timing of the fertiliser application was important in achieving a greater crop response in most parameters, including NDVI and yield.

There was little difference in plant performance between the liquid Easy N and comparable urea rate. While an increase in plant greenness was detected with the Easy N at several NDVI measurement points in wheat, this did not correspond to any increase in final DM or yield.

As the greatest protein responses for both wheat and barley were seen with Treatment 10 (nitrogen budget approach), it is difficult to know if this is due more to the total rate of nitrogen applied (204kg N/ha), or if the 54kg N/ha applied at third node (GS33) was the key factor.

The NDVI method of assessing nitrogen status in-crop, and using these numbers to determine the rate and timing of nitrogen applied (Treatment 8 and 9) aligned well with final yield responses in both wheat and barley. This indicates the total amount of nitrogen applied could be better aligned with crop requirements using this tool, which could result in cost savings. However, for this to work in-crop, a nitrogen-rich strip needs to be used in each paddock in order to provide a benchmark NDVI reading for a non-nitrogen limited crop.

This trial was run at the Riverine Research Centre (RRC), an independent and dedicated crop research site located near Yarrawonga, Victoria. The RRC is a partnership between Riverine Plains Inc and FAR Australia and is supported by RRC hosts, the Cummins family.

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