Monitoring the performance of nitrogen applied to wheat

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Key points

- At both Corowa, NSW and Dookie, Victoria, there were significant yield responses to applied nitrogen (N), with maximum yields of 6.25t/ha at Corowa and 6.21t/ha at Dookie.
- Both sites gave identical unfertilised yields, averaging 4.67t/ha.
- Yield responses were associated with significantly higher dry matter (DM) production and greater nitrogen offtake when 120kg N/ha was applied at both sites.
- The maximum nitrogen offtake in the unfertilised crops at both sites equated to about 70–80kg N/ha, which was similar to the 95kg N/ha available to the crop at the start of the season at Corowa and the 65kg N/ha available at the start of the season at Dookie.
- The normalised difference vegetation index (NDVI) response index (NDVI of fertilised:NDVI of unfertilised plots equal to 1.17) was measured at third node stage (GS33) and equated to maximum measured yield responses of 1.5–1.6t/ha to applied nitrogen.
- Applying an extra 60kg N/ha on top of the initial 60kg N/ha at Corowa (total 120kg N/ha) produced an average yield increase of 0.17t/ha (maximum 0.25t/ha), which was not cost effective (data not shown).
- At Dookie in 2016 applying 120kg N/ha gave greater returns and was economically worthwhile based on an extra 0.64t/ha for the additional 60kg N/ha applied (data not shown).

Methodology

Two trials were set up under the Riverine Plains Inc stubble project: *Maintaining Profitable Farming Systems with Retained Stubble in the Riverine Plains Region (2013–18)* at Corowa, NSW and Dookie, Victoria. They were set up in an established wheat crop, sown 2 May 2016 at Corowa and 20 May 2016 at Dookie. The trials were run according to host farmer standard paddock practice, except for nitrogen application.

Nitrogen as urea was hand spread across the plots at three rates, 0, 60 and 120kg N/ha using two split-dose strategies. The first strategy was based on 50% of the nitrogen dose targeted at tillering (GS24) and 50% at the start of stem elongation (GS30–31). The second strategy was based on timings where 50% of the nitrogen rate was applied at the start of stem elongation (GS30–31) and 50% was applied at third-node (GS33).

Although both sites received some blanket-applied nitrogen at sowing as MAP, this was before the plots were established and it is not considered in the treatment list. Therefore those plots that only received nitrogen at sowing are still referred to as the 'unfertilised' plots.

Trials were established as a split plot design with nitrogen rate as the main plot and nitrogen timing the sub plot, replicated four times. To maintain trial balance, the trial included included two untreated treatments. Data has been statistically analysed using analysis of variance (ANOVA), with means separated using unrestricted least significant difference (LSD) procedure.

Trial 1: Corowa, NSW

Sowing date: 2 May 2016
Rotation: Third wheat
Variety: Trojan
Stubble: Burnt stubble
Rainfall:
GSR: 567mm (April–October)
Summer rainfall: 80mm
Soil mineral nitrogen: 95kg N/ha (0–60cm)

The application rates and timings of nitrogen applied to the trial are presented in Table 1. Since the effectiveness of nitrogen is clearly influenced by subsequent rainfall, Table 2 presents the rainfall data for the five days following application and the next rainfall event greater than 5mm. The early stem elongation (GS30) application was the treatment most affected by dry conditions following application.

i) Establishment and crop structure

Crops receiving either a total of 60kg and 120kg N/ha post-sowing produced significantly higher tiller numbers compared with the unfertilised crop, with the 120kg N/ha



TABLE 1 Nitrogen application rates and timings at Corowa, NSW, 2016

Treatment	2 May 2016 (GS00) (kg N/ha)	1 July 2016 (GS24) (kg N/ha)	29 July 2016 (GS31) (kg N/ha)	23 August 2016 (GS33) (kg N/ha)	Total nitrogen applied (kg N/ha)
1	23	–	–	–	23
2	23	–	–	–	23
3	23	30	30	–	83
4	23	–	30	30	83
5	23	60	60	–	143
6	23	–	60	60	143

Note: To maintain trial balance the trial included two untreated treatments where 23kg N/ha was applied as part of the sowing fertiliser regime. Sowing nitrogen was 5kg N/ha as MAP plus 18kg N/ha as urea.

TABLE 2 Rainfall measured for five days following each nitrogen application

	Five-day rainfall following nitrogen application (mm)					Date of rainfall >5mm after application
Application 1: 1 July	1 July	2 July	3 July	4 July	5 July	
	13	0.4	0.8	0	0.4	1 July (0 days)
Application 2: 29 July	29 July	30 July	31 July	1 August	2 August	
	0	1.4	1.6	4	30	2 August (4 days)
Application 3: 23 August	23 August	24 August	25 August	26 August	27 August	
	0	0	0	0	0	31 August (8 days)

rate producing significantly more tillers than the 60kg N/ha rate. However, at harvest (GS99) there were no differences in the final head numbers or crop height due to the rate of nitrogen applied (Table 3).

There was no difference in tiller numbers between the two timing strategies when assessed prior to the nitrogen application at third node (GS33). This indicates little additional response to the tillering (GS24) nitrogen application over the later nitrogen application at early stem elongation (GS31).

TABLE 3 Tiller counts 18 August third node (GS33), head counts and crop height 28 November harvest (GS99)

Nitrogen rate (kg N/ha)	Crop structure		
	GS33	GS99	
	Tillers (m^2)	Heads (m^2)	Height (cm)
0	327^{c}	311^{a}	89^{b}
60	463^{b}	334^{a}	92^{a}
120	498^{a}	312^{a}	90^{ab}
Mean	**429**	**315**	**90**
LSD	29	36	2
Nitrogen timing			
GS24 and GS31	429^{a}	322^{a}	90^{a}
GS31 and GS33*	430^{a}	309^{a}	90^{a}
LSD	32	29	2

Figures followed by different letters are regarded as statistically significant.
N.B. 23kg N/ha was added to the different fertiliser treatments as a component of the basal fertiliser.
* Comparison of tiller numbers made prior to GS33 application.

ii) Dry matter production and nitrogen uptake

There were no significant differences in dry matter (DM) production between the different nitrogen treatments and the unfertilised control plots (Table 4), although there was evidence of increased nitrogen uptake in the DM analysis (Table 5).

The sharp decline in nitrogen content of the crop canopy between flowering and harvest cannot be explained and appears to be an assessment anomaly, although at this assessment, both nitrogen rates showed significantly higher nitrogen uptake into the canopy.

iii) Normalised difference vegetation index (NDVI)

Crop reflectance measurements taken with a GreenSeeker® showed significant differences in NDVI readings (crop reflectance measurement used as a surrogate for canopy greenness reading) between the two different nitrogen application timings when measured at stem elongation (GS31), flag leaf and third node (GS33) (Table 6). The early split timing (GS24 and GS31) was significantly greener (higher NDVI reading) at both stem elongation (GS31) and third node (GS33), due to more nitrogen being applied at that stage. By flowering there was no disadvantage of the later nitrogen strategy in terms of NDVI. There was a trend for the higher nitrogen rate to stay greener for longer, but this was not statistically significant (Figure 1).

TABLE 4 Dry matter 1 July, mid-tiller (GS24); 29 July, first node (GS31); 27 August, third node (GS33); 26 September start of flowering (GS61) and 28 November, harvest (GS99)

Nitrogen rate (kg N/ha)	Dry matter (t/ha)				
	GS24	GS31	GS33	GS61	GS99
0	0.8	1.6	3.8^{a}	10.2^{a}	12.5^{a}
60		1.7	3.9^{a}	10.6^{a}	14.2^{a}
120		1.8	3.8^{a}	10.3^{a}	12.6^{a}
Mean	**0.8**	**1.7**	**3.9**	**10.4**	**13.1**
LSD			0.5	0.8	2.2
Nitrogen timing					
GS24 and GS31	0.8	1.7	3.9^{a}	10.4^{a}	13.4^{a}
GS31 and GS33			3.7^{a}	10.3^{a}	12.8^{a}
LSD			0.3	0.9	0.9

Figures followed by different letters are regarded as statistically significant.
Note. No LSD values are presented for GS24 and GS31 as no nitrogen had been applied at the time of application.

TABLE 5 Nitrogen uptake 1 July, mid-tiller (GS24); 29 July, first node (GS31); 27 August, third node (GS33); 26 September start of flowering (GS61) and 28 November, harvest (GS99)

Nitrogen rate (kg N/ha)	Nitrogen uptake (kg N/ha)				
	GS24	GS31	GS33	GS61	GS99*
0	45	55	69^{c}	127^{b}	65^{b}
60		60	88^{b}	120^{b}	98^{a}
120		73	103^{a}	149^{a}	92^{a}
Mean	**45**	**63**	**87**	**132**	**85**
LSD			10	12	13
Nitrogen timing					
GS00 and GS30	45	63	97^{a}	133^{a}	78^{b}
GS30 and GS33			76^{b}	131^{a}	92^{a}
LSD			6	10	6

Figures followed by different letters are regarded as statistically significant.
Note. No LSD values are presented for GS24 and GS31 as no nitrogen had been applied at the time of application.

TABLE 6 NDVI (scale 0–1), 1 July, mid-tiller (GS24); 29 July, first node (GS31); 27 August, third node (GS33); 10 October mid-end of flowering (GS65–69) and 7 November, early dough stage (GS83)

Nitrogen rate (kg N/ha)	NDVI				
	GS24	GS31	GS33	GS65–69	GS80
0	0.47^{a}	0.56^{a}	0.64^{b}	0.60^{b}	0.26^{c}
60	0.48^{a}	0.58^{a}	0.74^{a}	0.70^{a}	0.33^{b}
120	0.48^{a}	0.59^{a}	0.75^{a}	0.75^{a}	0.38^{a}
Mean	**0.48**	**0.58**	**0.71**	**0.68**	**0.32**
LSD	0.03	0.06	0.06	0.06	0.04
Nitrogen timing					
GS24 and GS31	0.48^{a}	0.60^{a}	0.72^{a}	0.69^{a}	0.33^{a}
GS31 and GS33	0.48^{a}	0.56^{b}	0.70^{b}	0.68^{a}	0.32^{a}
LSD	0.01	0.02	0.02	0.03	0.03

Figures followed by different letters are regarded as statistically significant.



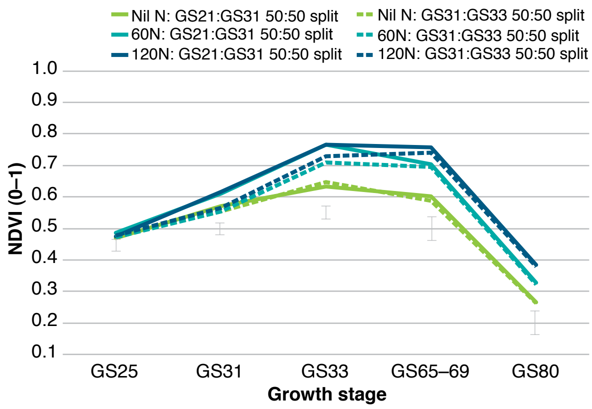

FIGURE 1 Influence of applied nitrogen timing and rate on NDVI assessments (scale 0–1)*

*The error bars are a measure of LSD

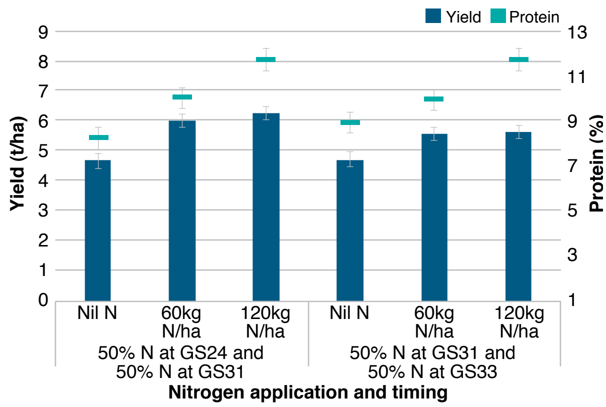

FIGURE 2 Grain yield and protein results, 10 December Corowa, NSW

The error bars for yield and protein are a measure of LSD.

iv) Yield and grain quality

Despite no significant increase in DM with additional nitrogen, the two nitrogen strategies significantly increased both yield and protein compared with the unfertilised plots, although the only difference between the 120kg N/ha treatment over the 60kg N/ha treatment was increased grain protein, with no yield advantage (11.7% protein for 120kg N/ha compared with 10% for 60kg N/ha) (Table 7, Figure 2).

There was a significant yield advantage (average of 0.34t/ha) with the earlier nitrogen timing over the later timing, despite the canopies being similar at flowering and harvest in terms of NDVI, DM and head number. There was no significant interaction between nitrogen rate and timing, as both timings showed that high levels of nitrogen increased yield and protein.

Nitrogen offtake was significantly greater at higher nitrogen rates. If 25% of the nitrogen at harvest was assumed to be present in the straw and chaff, and taking account of the 23kg N/ha applied at sowing, the offtake of nitrogen in the 60kg N/ha treatment was greater than that applied, with the unfertilised crop removing about 75kg N/ha (Table 7).

Trial 2: Dookie, Victoria

Sowing date: 20 May 2016

Rotation: First wheat after canola

Variety: Corack

Stubble: Canola unburnt

Rainfall:

GSR: 509mm (April-October)

Summer rainfall: 130mm

Soil mineral nitrogen: 65kg N/ha (0–60cm)

TABLE 7 Yield, protein, test weight, screenings and nitrogen offtake in grain at harvest (GS99), 10 December 2016

	Yield and quality				
Nitrogen rate (kg N/ha)	**Yield (t/ha)**	**Protein (%)**	**Test weight (kg/hL)**	**Screenings (%)**	**Nitrogen offtake in grain (kg N/ha)**
0	4.67[b]	8.6[c]	81.6[a]	1.7[a]	70[c]
60	5.77[a]	10.0[b]	80.4[a]	2.3[a]	101[b]
120	5.94[a]	11.7[a]	80.2[a]	1.9[a]	122[a]
Mean	**5.46**	**10.1**	**80.7**	**2.0**	**98**
LSD	0.67	0.6	1.8	0.9	12
Nitrogen timing					
GS24 and GS31	5.63[a]	10.0[a]	80.8[a]	2.0[a]	100[a]
GS31 and GS33	5.29[b]	10.2[a]	80.6[a]	2.0[a]	95[a]
LSD	0.27	0.56	0.87	0.51	8

Figures followed by different letters are regarded as statistically significant.

The application rates and timings of nitrogen applied to the Dookie trial are presented in Table 8 with the rainfall surrounding application outlined in Table 9.

i) Establishment and crop structure

The application of 60kg N/ha and 120kg N/ha significantly increased tiller production relative to the unfertilised plots, while only the 120kg N/ha treatment significantly increased final head number (Table 10). There was no difference in tiller or head number due to nitrogen timing. The height of the crop canopy at harvest (GS99) was increased by 2cm with additional nitrogen.

ii) Dry matter production and nitrogen uptake

There were clear differences in crop DM production between crops with nil nitrogen and where the crop was fertilised, with 60kg and 120kg N/ha producing significantly more DM at head emergence (GS51) and harvest (GS99) (Table 11, Figure 3).

The timing of nitrogen application did not affect DM production across any of the assessment timings.

Nitrogen uptake followed similar trends to DM production, with DM increased by applying both 60kg and 120kg N/ha, although by grain fill (GS71) only the 120kg N/ha nitrogen rate significantly increased nitrogen uptake in the plant (Table 12). The later timing strategy, at GS30 and GS33, saw lower uptake of nitrogen at harvest.

TABLE 10 Tiller counts 26 August, third node (GS33), head counts and crop height 29 November harvest (GS99)

	Crop structure		
	GS33	GS99	
Nitrogen rate (kg N/ha)	Tillers (m^2)	Heads (m^2)	Height (cm)
0	334^{c}	277^{b}	89^{b}
60	359^{b}	320^{ab}	91^{a}
120	381^{a}	338^{a}	91^{a}
Mean	**358**	**312**	**90**
LSD	21	48	2
Nitrogen timing			
GS13 and GS30	354^{a}	302^{a}	91^{a}
GS30 and GS33	361^{a}	322^{a}	90^{a}
LSD	19	34	1

Figures followed by different letters are regarded as statistically significant.

iii) Normalised difference vegetation index (NDVI)

The greenness of the crop canopy at third node (GS33) and early grain fill (GS71) (measured with a GreenSeeker®) was significantly greater where nitrogen had been applied at 120kg N/ha than where the crop was left unfertilised (Table 13). The crop treated with 120kg N/ha was the greenest throughout the assessment period.

TABLE 8 Nitrogen application rates and timings at Dookie, Victoria, 2016

Treatment	20 May (sowing) (kg N/ha)	27 June (GS13) (kg N/ha)	2 August (GS30) (kg N/ha)	26 August (GS33) (kg N/ha)	Total nitrogen applied (kg N/ha)
1	7.5	-	-	-	7.5
2	7.5	-	-	-	7.5
3	7.5	30	30	-	67.5
4	7.5	-	30	30	67.5
5	7.5	60	60	-	127.5
6	7.5	-	60	60	127.5

Note: To maintain trial balance the trial included two untreated treatments. Starting nitrogen was applied as MAP.

TABLE 9 Rainfall measured for five days following each nitrogen application

Application	Five-day rainfall following nitrogen application (mm)					Date of rainfall >5mm after application
1: 27 June	27 June	28 June	29 June	30 June	1 July	
	0	0	0	0	11	1 July (5 days)
2: 2 August	2 August	3 August	4 August	5 August	6 August	
	27.5	0	0	0	0	2 August (1 day)
3: 26 August	26 August	27 August	28 August	29 August	30 August	
	0	0	0	0	0	31 August (6 days)



TABLE 11 Dry matter 2 August, stem elongation (GS30); 26 August, third node (GS33); 19 September, start of head emergence (GS51); 17 October, grain fill (GS71) and 29 November, harvest (GS99)

Nitrogen rate (kg N/ha)	Dry matter (t/ha)				
	GS30	GS33	GS51	GS71	GS99
0	0.4	1.9[b]	4.7[b]	9.1[a]	11.5[b]
60	0.6	2.1[ab]	5.3[a]	9.4[a]	14.1[a]
120	0.6	2.3[a]	5.2[a]	9.9[a]	15.3[a]
Mean	**0.5**	**2.1**	**5.1**	**9.4**	**13.6**
LSD		0.3	0.2	1.1	1.2
Nitrogen timing					
GS13 and GS30	0.5	2.1[a]	5.0[a]	9.5[a]	13.6[a]
GS30 and GS33		2.0[a]	5.1[a]	9.4[a]	13.7[a]
LSD		0.3	0.5	0.9	1.5

Figures followed by different letters are regarded as statistically significant.
Note. Since nitrogen wasn't applied at the time of application no LSD values are presented for GS30.

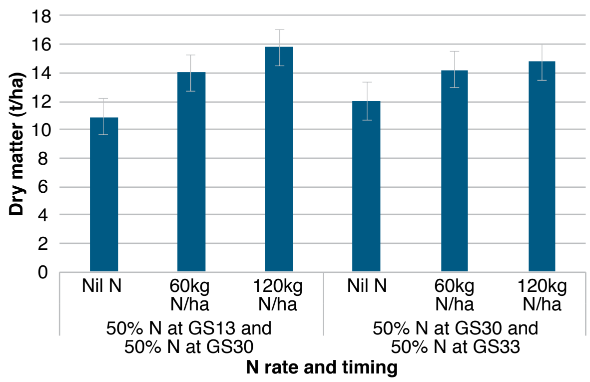

FIGURE 3 The effect of nitrogen application rate and timing on dry matter at harvest (GS99) at Dookie, 2016

TABLE 13 NDVI (scale 0–1), 2 August, stem elongation (GS30); 26 August, third node (GS33): 19 September, start of head emergence (GS51) and 17 October, start of grain fill (GS71)

Nitrogen rate (kg N/ha)	NDVI			
	GS30	GS33	GS51	GS71
0	0.44[a]	0.54[b]	0.72[a]	0.66[b]
60	0.48[a]	0.61[ab]	0.74[a]	0.70[ab]
120	0.46[a]	0.63[a]	0.76[a]	0.72[a]
Mean	**0.46**	**0.59**	**0.74**	**0.69**
LSD	0.06	0.08	0.04	0.06
Nitrogen timing				
GS13 and GS30	0.47[a]	0.61[a]	0.74[a]	0.70[a]
GS30 and GS33	0.45[a]	0.57[a]	0.74[a]	0.68[a]
LSD	0.04	0.06	0.02	0.04

Figures followed by different letters are regarded as statistically significant.

TABLE 12 Nitrogen uptake 2 August, stem elongation (GS30); 26 August, third node (GS33); 19 September, start of head emergence (GS51); 17 October, grain fill (GS71) and 29 November, harvest (GS99)

Nitrogen rate (kg N/ha)	Nitrogen uptake (kg N/ha)				
	GS30	GS33	GS51	GS71	GS99
0	21	57[b]	81[b]	91[b]	60[b]
60	32	80[a]	115[a]	91[b]	54[b]
120	37	92[a]	125[a]	116[a]	85[a]
Mean	**30**	**76**	**107**	**99**	**66**
LSD		16	16	14	10
Nitrogen timing					
GS13 and GS30	30	79[a]	105[a]	90[a]	71[a]
GS30 and GS33		73[a]	110[a]	109[a]	61[b]
LSD		13	13	22	6

Figures followed by different letters are regarded as statistically significant.
Note. Since not all the nitrogen was applied at GS30 no LSD values are presented for this.

The early split of nitrogen (GS13 and GS30) gave similar NDVI readings to the later-timed nitrogen strategy (GS30 and GS33) (Figure 4), whereas in 2015 lower NDVI readings were measured with later-applied nitrogen due to limitations on crop nitrogen uptake.

At the start of stem elongation (GS30) the difference in NDVI readings between crops fertilised with nitrogen at GS13 and the untreated crops was not significant. When all nitrogen had been applied at GS33 the NDVI readings showed greater crop canopy greenness where nitrogen was applied.

The differences in NDVI between the fertilised and unfertilised crops can be used as a guide to the background fertility of the trial site. The greater the difference in NDVI readings, the less fertile the site. This is referred to as the response index (RI). For example, at the third-node stage (GS33) applying 120kg N/ha produced an NDVI score of 0.63 compared with 0.54 for the untreated crop (Figure 4). In this case the RI at Dookie was 1.17 (0.63/0.54 = 1.17), with the same RI at Corowa (0.75/0.64 = 1.17). These calculations indicate the yield response to nitrogen at Dookie was likely to be similar to that at Corowa, but at a lower level of background fertility.

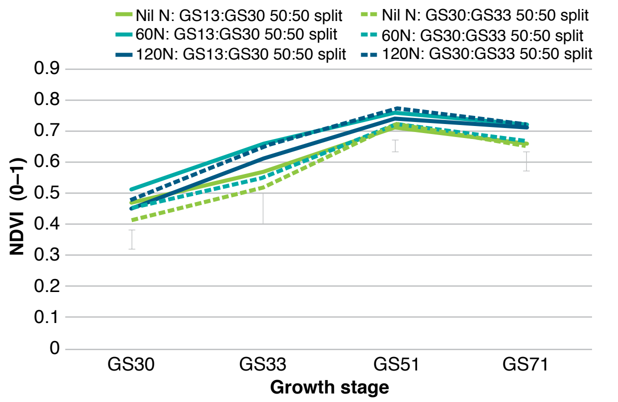

FIGURE 4 Influence of applied nitrogen timing and rate on NDVI (scale 0–1)*

*The error bars are a measure of LSD.

iv) Yield and grain quality

Applying the highest rate of nitrogen (120kg N/ha) significantly increased yield, with a 1.29t/ha yield advantage compared with the unfertilised treatment and a 0.64t/ha advantage over the 60kg N/ha treatments (Table 14, Figure 5).

There was no significant interaction between nitrogen rate and timing strategies, as both timings gave similar responses to increasing nitrogen rate. The later nitrogen timing, split at GS30 and GS33, was 0.27t/ha higher yielding than where nitrogen was split between GS13 and GS30.

Grain protein was significantly greater in the nitrogen fertilised crops compared with those where no nitrogen was applied.

Crops receiving 120kg N/ha also produced significantly higher test weights than the untreated crops, but differences were small.

There were no differences in screenings between the treatments.

The nitrogen offtake in the unfertilised plots was about 90kg N/h if we assume 25% of the nitrogen is in the crop canopy at harvest (Table 14). Where 60kg N/ha was applied, nitrogen offtake exceeded nitrogen application by about 50kg N/ha while the application of 120kg N/ha resulted in similar nitrogen offtakes to the nitrogen application rate.

TABLE 14 Yield, protein, test weight and screenings 13 December 2016, harvest (GS99)

Treatment	Grain yield and quality				
Nitrogen rate (kg N/ha)	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	Nitrogen offtake in grain (kg N/ha)
0	4.67[c]	9.7[b]	80.5[b]	0.6[a]	80[c]
60	5.32[b]	10.3[a]	81.0[ab]	0.6[a]	96[b]
120	5.96[a]	10.4[a]	81.2[a]	0.7[a]	108[a]
Mean	**5.32**	**10.2**	**80.9**	**0.7**	**95**
LSD	0.41	0.3	0.7	0.1	7
Nitrogen timing					
GS00 and GS30	5.18[b]	10.2[a]	80.9[a]	0.6[a]	93[a]
GS30 and GS33	5.45[a]	10.1[a]	80.9[a]	0.7[a]	97[a]
LSD	0.28	0.4	0.4	0.1	4

Figures followed by different letters are regarded as statistically significant.

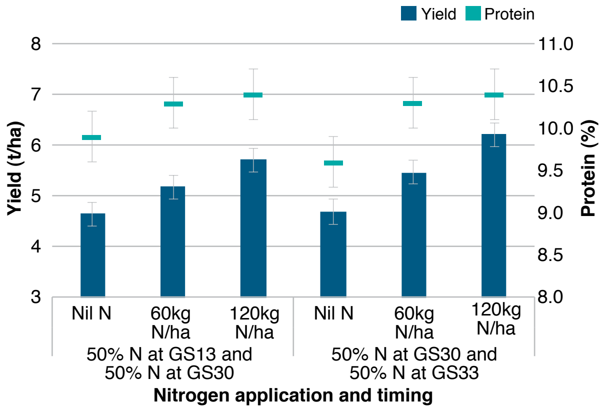

FIGURE 5 Grain yield and protein 13 December 2016, harvest (GS99)*

*The errors bars are a measure of LSD

Conclusions

At both the Corowa and Dookie sites the NDVI scores (a measurement of crop reflectance) indicated additional nitrogen would be required to maximise yield based on scores taken during early stem elongation (GS33).

There were significant DM growth responses with nitrogen application that resulted in significant yield increases at both sites (maximum nitrogen response of 1.52t/ha at Dookie and 1.6t/ha at Corowa).

In comparison, despite a higher NDVI response index in 2015, hot conditions between ear emergence (GS59) and the end of flowering (GS69) resulted in no yield advantage from additional nitrogen, with average yields about 4t/ha.

Acknowledgements

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