Nitrogen response in different electromagnetic (EM) zones of the paddock

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Key points

- Paddock variance was measured across two paddocks through EM (electromagnetic) surveys. Based on this variance, high and low EM zones were identified.
- Two small plot trials compared nitrogen (N) response in a high and low EM zone of two paddocks sown to Trojan wheat, one in Yarrawonga (sown 22 April) and the other in Dookie (sown 12 May).
- Both paddocks had high levels of nitrogen available in the soil (120–200kg N/ha 0–60cm) irrespective of zone.
- The largest response to nitrogen (1t/ha) was observed in the high EM zone at Dookie, where the highest levels of available soil nitrogen were recorded (200kg N/ha).
- Dry matter (DM) differences and normalised difference vegetation index (NDVI) readings at the Dookie site suggested the crop canopy was responding to applied nitrogen; this indicates the crop did not benefit from the high levels of soil nitrogen present (possibly as a result of later sowing or subsoil constraints).
- At the Yarrawonga site there were no significant indications from NDVI readings that a response to nitrogen fertiliser was likely; this was supported by high grain yields in the nil nitrogen plots (5.8t/ha and 6.4t/ha in the high and low EM zone respectively).
- At the Dookie low EM site, grain protein of 11.9% in the lowest-yielding treatment suggested there was sufficient soil nitrogen available to meet crop yield and protein requirements; this contrasts with in-crop NDVI measurements, which suggested the crop would respond to applied nitrogen.
- At Yarrawonga nitrogen application strategies based on NDVI readings meant nitrogen application was delayed until third node (GS33) in the high EM zone, which resulted in only limited uptake. A slightly earlier second node (GS32) application in the low EM zone resulted in an excellent response (0.39t/ha) to the NDVI-based approach.

Method

Four trials were established in 2017 under the Riverine Plains Inc stubble project: *Maintaining profitable farming systems with retained stubble in the Riverine Plains region (2013–18)*. The background to these trials is described on page 10. The four trials were carried out at two locations at Dookie, and Yarrawonga, Victoria.

Each location had two trials in the same paddock. Before the season commenced the paddocks were electromagnetically (EM) mapped and zoned. One of the two trials was placed in the high EM zone and one in the low EM zone. The trials were sown with a commercial crop and then marked out after crop emergence. The trial design was a randomised complete block and replicated four times. Nitrogen (N) applications were made as per the treatment lists in the following sections (Tables 1, 5, 10 and 14), with all other management inputs undertaken by the host farmer for the remainder of the season.

Site 1: Yarrawonga, Victoria

Sowing date: 22 April 2017
Rotation: First wheat after canola
Variety: Trojan
Stubble: Canola unburnt
Rainfall:
GSR: 270mm (April–October)
Summer rainfall: 88mm

Trial 1: High EM zone Yarrawonga, Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017 — so includes MAP at sowing)
0–10cm: 67.0kg N/ha
10–30cm: 38.5kg N/ha
30–60cm: 23.9kg N/ha
Total (0–60cm): 129.4kg N/ha

Results

i) Establishment and crop structure

The trial site averaged 102 plants/m^2.

The application of 120kg N/ha at early tillering (GS21) with the 120 N (N rich) treatment produced significantly more tillers (68–46 tillers/m^2) than the nil nitrogen and 20kg N/ha applied (only 50% of the 40 N dose had been applied at the tillering assessment) (Table 2).

TABLE 1 High EM zone treatment list, Yarrawonga, Victoria 2017

Treatment	22 April GS00 (kg N/ha[1])	30 May GS21 (kg N/ha)	20 June GS24/GS30 (kg N/ha)	11 July GS31 (kg N/ha)	25 July GS32 (kg N/ha)	7 August GS33/37 (kg N/ha)	17 August GS39 (kg N/ha)	Total (kg N/ha)
Nil N	7.5	0	0	0	0	0	0	7.5
40 N	7.5	0	20	20	0	0	0	47.5
80 N	7.5	0	40	40	0	0	0	87.5
120 N	7.5	0	60	60	0	0	0	127.5
160 N	7.5	0	80	80	0	0	0	167.5
NDVI 1* (40 N)	7.5	0	0	0	0	40	0	47.5
NDVI 2* (40 N)	7.5	0	0	0	0	0	40	47.5
120 N (N rich)	7.5	120	0	0	0	0	0	127.5

* NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots (120 N). A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 explored standard timings of nitrogen whereas NDVI 2 explored later splits of the timing of the same amount of nitrogen.

[1] GS00 nitrogen (7.5kg N/ha) was applied as 75kg MAP/ha, all other nitrogen was applied as urea (46% N).

TABLE 2 Plant counts 30 May 2017, main stem and one tiller (GS21): tiller counts 11 July 2017, first node (GS31) in the high EM zone, Yarrawonga, Victoria

Treatment	Crop growth stage	
	Plants/m^2	Tillers/m^2
	GS21	GS31
Nil N	116^{a}	328^{c}
40 N	94^{a}	350^{bc}
80 N	-	376^{ab}
120 N	-	370^{ab}
160 N	-	373^{ab}
NDVI 1 (40 N)	-	-
NDVI 2 (40 N)	-	-
120 N (N rich)	95^{a}	396^{a}
Mean	**102**	**366**
LSD	11	41

Figures followed by different letters are regarded as statistically significant.

TABLE 3 Dry matter 12 October 2017 at early grain fill (GS71) and 28 November 2017, physiological maturity (GS92), high EM zone Yarrawonga, Victoria

Treatment	Dry matter (t/ha)	
	GS71	GS92
Nil N	11.48^{b}	13.18^{c}
40 N	11.74^{ab}	14.71^{abc}
80 N	12.78^{ab}	13.21^{bc}
120 N	12.82^{ab}	15.13^{ab}
160 N	14.00^{a}	16.17^{a}
NDVI 1 (40 N)	11.85^{ab}	14.16^{bc}
NDVI 2 (40 N)	12.50^{ab}	13.71^{ac}
120 N (N rich)	12.20^{ab}	13.27^{bc}
Mean	**12.42**	**14.19**
LSD	2.42	1.93

Figures followed by different letters are regarded as statistically significant.

ii) Dry matter (DM) production

Dry matter assessments were conducted at early grain fill (GS71) and physiological maturity (GS92) (Table 3). High LSD values in both assessments indicated there were only limited differences between treatments. There was a general trend for higher rates of applied nitrogen to produce higher DM, particularly at rates of 120kg N/ha and above. The nil nitrogen DM results would suggest plants could access the high levels of nitrogen coming from the soil, as indicated by the initial soil testing (129kg N/ha).

iii) Normalised difference vegetative index (NDVI)

Crop reflectance measurements taken with the Greenseeker (handheld NDVI) showed small differences in greenness in the crop canopy with none of the treatments showing any increase in NDVI compared with the untreated control (Figure 1). This result again indicates large amounts of nitrogen being supplied by the soil.

iv) Grain yield and quality

The trial was harvested on 12 December 2017, with an average yield of 6.01t/ha and a maximum response to applied nitrogen of 0.68t/ha (Table 4).

There was a significant yield increase from applying 40kg N/ha split between tillering (GS24) and first node (GS31) (40 N treatment). There was no yield response associated with increasing nitrogen rate above 40kg N/ha, however increasing the nitrogen rate to 120kg N/ha and above significantly increased grain protein from 10.2% to 11.5%.

Applying 40kg N/ha at both third node (GS33) and flag-leaf emergence (GS39) had little or no effect, with both yield and protein results similar to the untreated control. This result is likely to be associated with the prolonged dry conditions, which would have reduced nitrogen uptake after application.

Increasing nitrogen application rates at tillering (GS21) and stem elongation (GS31) as per the 120kg N/ha and 160kg

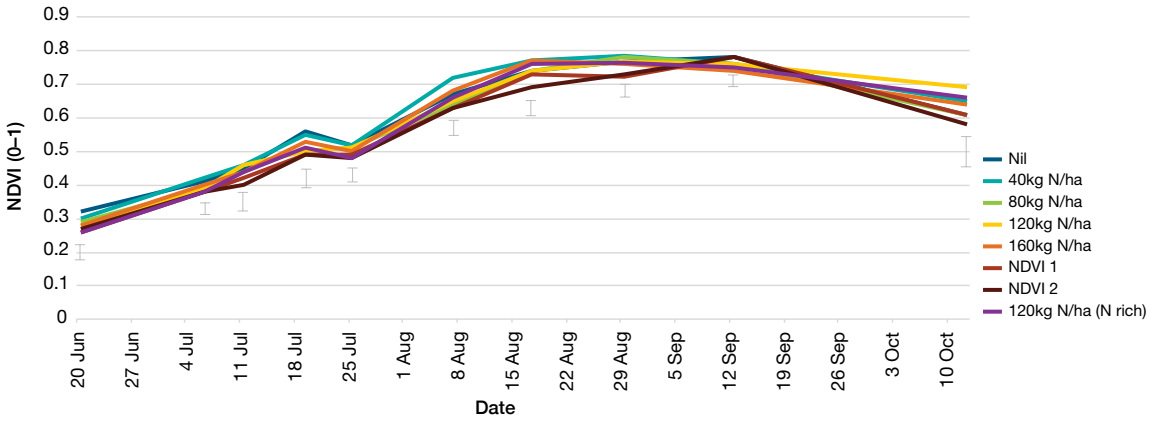


FIGURE 1 NDVI readings 20 June 2017, late tillering — start of stem elongation (GS24–30); 6 July, first node (GS31); 11 July second node (GS32); 19 July, second node (GS32); 25 July third node (GS33); 7 August third node — start of flag-leaf emergence (GS33–37); 17 August, flag leaf 75% emerged (GS37); 29 August, flag leaf fully emerged–start of booting (GS39–41); 12 September, head emergence (GS51) and 12 October, early grain fill (GS71), high EM zone, Yarrawonga, Victoria

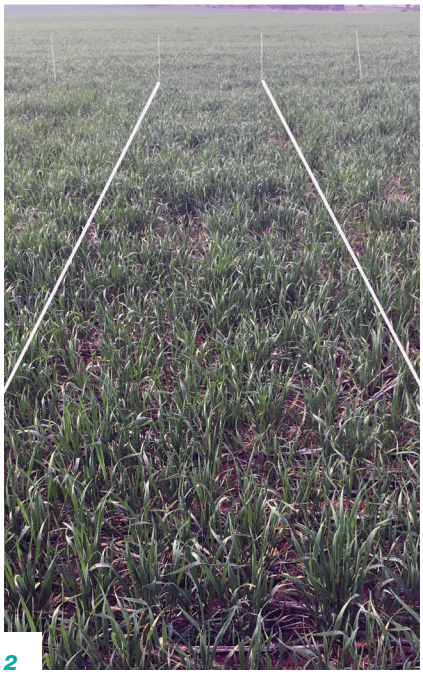
TABLE 4 Yield, protein, test weight and screenings at harvest (GS99), 12 December 2017, high EM zone, Yarrawonga, Victoria

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	5.74^{bc}	9.3^{e}	75.8^{a}	2.4^{ab}	48.9^{a}
40 N	6.42^{a}	10.2^{cd}	74.4^{ab}	2.0^{b}	45.8^{ab}
80 N	5.82^{abc}	10.5^{c}	76.0^{a}	2.1^{b}	45.2^{abc}
120 N	6.19^{ab}	11.5^{b}	75.2^{ab}	2.1^{b}	42.9^{bc}
160 N	6.29^{ab}	11.6^{b}	75.1^{ab}	2.3^{b}	42.8^{c}
NDVI 1 (40 N)	5.79^{bc}	9.5^{de}	75.8^{a}	2.2^{b}	47.5^{a}
NDVI 2 (40 N)	5.52^{c}	9.7^{de}	75.6^{a}	2.1^{b}	46.2^{a}
120 N (N rich)	6.29^{ab}	13.4^{a}	73.6^{b}	2.8^{a}	36.9^{d}
Mean	**6.01**	**10.7**	**75.2**	**2.2**	**44.2**
LSD	0.61	0.8	1.7	0.5	2.9

Figures followed by different letters are regarded as statistically significant.

N/ha treatments significantly reduced grain size, measured as thousand seed weight (TSW), however this did not increase screening levels. If 120kg N/ha was applied at early tillering (GS21) test weight was reduced, grain size was reduced still further while screenings and protein were increased, presumably as a result of increased shoot number recorded at first node (Table 2).

The only treatment achieving the APW1 grade (both 76kg/hL and 10.5% protein) was the 80kg N/ha treatment.



1 *Untreated plot at GS31, 11 July 2017*

2 *Nitrogen-rich (120 N) plot at GS31, 11 July 2017*

Trial 2: Low EM zone Yarrawonga, Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017 — so includes MAP at sowing)

- 0–10cm: 67.1kg N/ha
- 10–30cm: 29.9kg N/ha
- 30–60cm: 23.8kg N/ha
- Total (0–60cm): 120.8kg N/ha

Results

i) Establishment and crop structure

The low EM zone had a plant establishment of 103 plants/m^2, which was identical to the high EM zone site.

The application of 120kg N/ha at early tillering (GS21) produced more tillers than the nil nitrogen plots, but the difference was not statistically significant (Table 6). At the time of the first node tiller assessment (GS31) only 50% of the nitrogen had been applied for treatments receiving 80, 120 or 160 kg N/ha (excluding NDVI and nitrogen-rich treatments).

ii) Dry matter production

Dry matter production, assessed at early grain fill (GS71) and physiological maturity (GS92), produced no significant differences (Table 7). Overall, the DM contents of the crops in the low EM zone at physiological maturity were approximately 1.8t/ha less than those recorded in the high EM zone.

iii) Normalised difference vegetation index

Similarly to the high EM zone at Yarrawonga, there was no significant differences in the NDVI readings recorded in the low EM zone, indicating higher fertility in the untreated nil nitrogen plots (Figure 2). The lack of separation of the nil nitrogen plots from the nitrogen-rich plots fertilised with 120kg N/ha at GS21 indicated that yield at this site was not responsive to applied nitrogen.

TABLE 6 Plant counts 30 May 2017, one tiller (GS21), tiller counts 11 July 2017, first node (GS31), low EM zone Yarrawonga, Victoria

	Crop growth stage	
	Plants/m^2	Tillers/m^2
Treatment	GS21	GS31
Nil N	108[a]	338[a]
40 N	98[a]	352[a]
80 N	-	354[a]
120 N	-	361[a]
160 N	-	377[a]
NDVI 1 (120 N)	-	-
NDVI 2 (120 N)	-	-
120 N (N rich)	101[a]	375[a]
Mean	**103**	**360**
LSD	33	47

TABLE 7 Dry matter production 12 October 2017, early grain fill (GS71) and 28 November 2017, physiological maturity (GS92) for the low EM zone, Yarrawonga, Victoria

	Dry matter (t/ha)	
Treatment	GS71	GS92
Nil N	10.76[a]	11.95[a]
40 N	10.55[a]	11.84[a]
80 N	10.70[a]	11.88[a]
120 N	12.09[a]	12.04[a]
160 N	11.26[a]	13.82[a]
NDVI 1 (120 N)	11.49[a]	12.09[a]
NDVI 2 (120 N)	11.62[a]	12.73[a]
120 N (N rich)	11.25[a]	12.59[a]
Mean	**11.21**	**12.37**
LSD	1.98	2.56

TABLE 5 Treatment list, low EM zone Yarrawonga, Victoria

Treatment	22 April GS00 (kg N/ha[1])	30 May GS21 (kg N/ha)	20 June GS24/GS30 (kg N/ha)	11 July GS31 (kg N/ha)	25 July GS32 (kg N/ha)	7 August GS33/37 (kg N/ha)	17 August GS39 (kg N/ha)	Total (kg N/ha)
Nil N	7.5	0	0	0	0	0	0	7.5
40 N	7.5	0	20	20	0	0	0	47.5
80 N	7.5	0	40	40	0	0	0	87.5
120 N	7.5	0	60	60	0	0	0	127.5
160 N	7.5	0	80	80	0	0	0	167.5
NDVI 1* (120 N)	7.5	0	0	60	40	20	0	127.5
NDVI 2* (120 N)	7.5	0	0	60	40	0	20	127.5
120 N (N rich)	7.5	120	0	0	0	0	0	127.5

* NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots (120 N). A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 looked at standard timings of nitrogen whereas NDVI 2 looked at later splits of the timing of the same amount of nitrogen.

[1] GS00 nitrogen (7.5kg N/ha) was applied as 75kg MAP/ha, all other nitrogen *was* applied as urea (46% N).

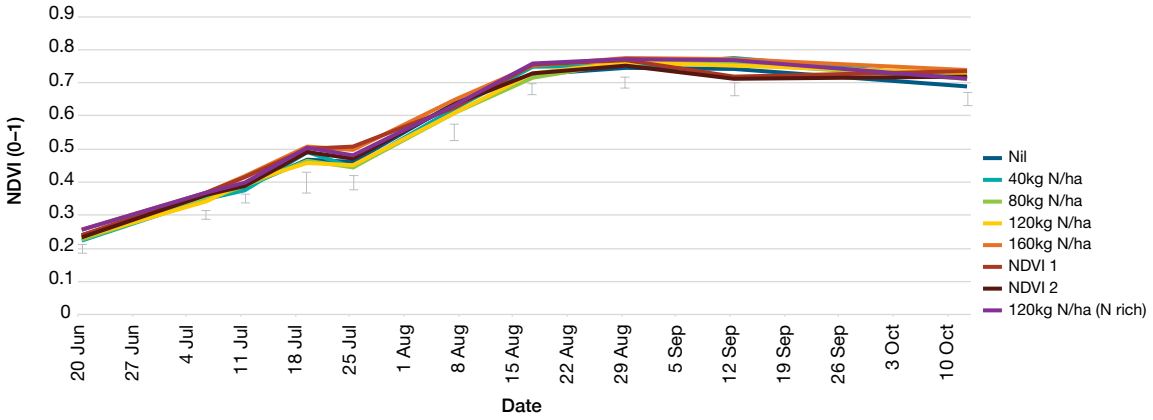


FIGURE 2 NDVI readings on 20 June, late tillering — start of stem elongation (GS24–30); 6 July, first node (GS31), 11 July second node (GS32); 19 July, second node (GS32); 25 July third node (GS33); 7 August third node–start of flag-leaf emergence (GS33–37); 17 August, flag leaf 75% emerged (GS37); 29 August, flag leaf fully emerged–start of booting (GS39–41);12 September, head emergence (GS51) and 12 October, early grain fill (GS71) for the low EM zone, Yarrawonga, Victoria

iv) Grain yield and quality

The average yield of the trial in the low EM zone was 6.74t/ha compared with 6.01t/ha in the high EM zone (Table 8). The application of 80kg N/ha and above yielded significantly higher than the nil nitrogen treatment, with a maximum yield response to nitrogen of 0.63t/ha obtained at 160kg N/ha and the economic optimum obtained at 80kg N/ha (based on $234/t and 95 cents/kg N).

The low EM zone had a similar maximum response to nitrogen as the high EM zone (0.63 vs 0.68t/ha), though yields overall were higher with a maximum of 7.01t/ha in the low EM zone compared with 6.42t/ha in the high EM zone.

The application rate of 80kg N/ha and above produced significantly higher protein than the nil nitrogen treatment.

The NDVI based treatments, which both received 120kg N/ha as 60kg N/ha at GS31, followed by 40kg N/ha at GS32, produced significantly higher proteins than the lower nitrogen rates of nil and 40kg N/ha, however the yield responses were not statistically different to the nil nitrogen plots. There were no yield, protein or quality differences between the two NDVI approaches in the low EM zone.

The high EM zone NDVI treatments received 40kg N/ha compared with 120kg N/ha in the low EM zone. The earlier application of nitrogen in the low EM zone NDVI treatments at second node (GS32 – 11 July) rather than third node (GS33 – 7 August or GS39 – 17 August) in the high EM zone was much more effective for yield and protein, presumably as a result of better uptake following application.

TABLE 8 Yield, protein, test weight and screenings at harvest (GS99), 11 December 2016, low EM zone, Yarrawonga, Victoria

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	6.38^{c}	9.4^{c}	75.5^{a}	2.4^{ab}	42.2^{ab}
40 N	6.50^{bc}	10.0^{bc}	75.7^{a}	2.9^{a}	42.7^{a}
80 N	6.87^{ab}	10.7^{ab}	75.9^{a}	2.5^{ab}	41.4^{ab}
120 N	6.86^{ab}	11.1^{a}	75.9^{a}	2.2^{ab}	42.3^{a}
160 N	7.01^{a}	11.1^{a}	75.7^{a}	2.1^{ab}	42.8^{a}
NDVI 1 (120 N)	6.77^{abc}	11.7^{a}	75.9^{a}	2.3^{ab}	39.7^{b}
NDVI 2 (120 N)	6.78^{abc}	11.8^{a}	75.6^{a}	2.5^{ab}	40.5^{ab}
120 N (N rich)	6.73^{abc}	11.1^{a}	75.5^{a}	1.9^{b}	41.4^{ab}
Mean	**6.74**	**10.8**	**75.7**	**2.2**	**41.6**
LSD	0.41	1.0	1.0	0.5	2.6

Figures followed by different letters are regarded as statistically significant.

v) Comparison of DM, yield and protein across EM zones

The slightly earlier application of nitrogen the low EM zone trial (GS32) compared with the high EM zone trial (GS33 or GS37) resulted in increased yield, presumably as a result of better uptake following application.

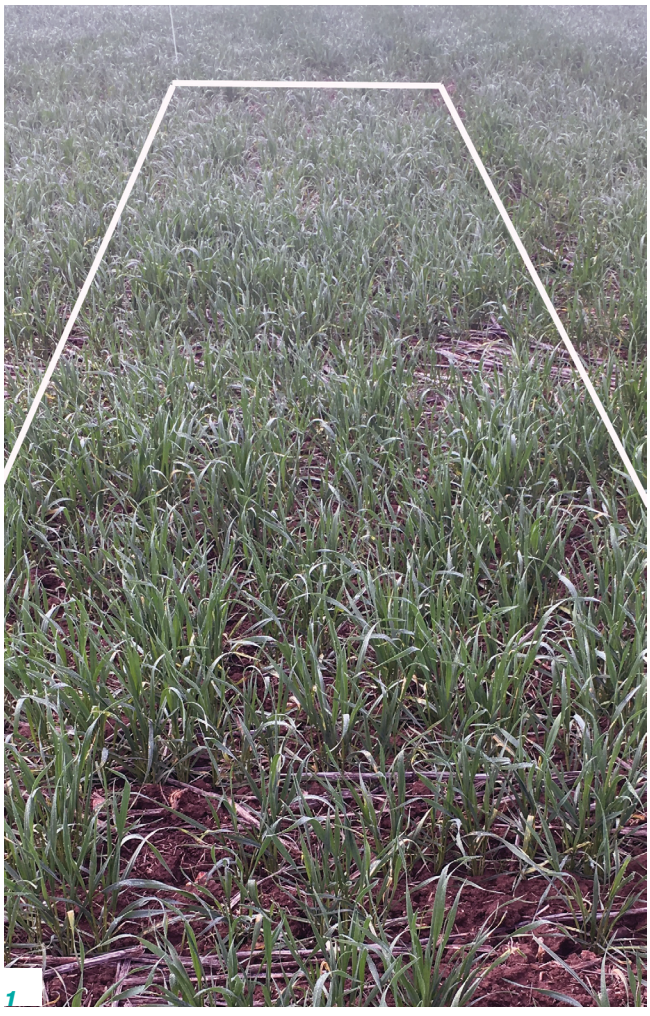
Later nitrogen applications in the low EM trial resulted in significant increases in protein, but no significant yield increases.

Crop in the low EM zone was more efficient in converting DM into yield. Harvest DM, when averaged across each zone, was 1.82t/ha greater in the high EM zone compared with the low EM zone, however average trial yields were 0.45t/ha greater in the low EM zone (Table 9).

TABLE 9 Key differences between the high and low EM zones at Yarrawonga, Victoria

	High EM zone	Low EM zone
Dry matter (t/ha)	13.2–16.2	11.9–13.8
Yield (t/ha)	5.74–6.29	6.38–7.01
Protein (%)	9.3–13.4	9.4–11.8

As the season was very dry from spring until harvest, the low EM zone can be assumed to have better water holding capacity than the high EM zone of the paddock. This can be understood by comparing yield across each zone, with higher yields in the low EM zone for the 120kg N/ha treatment (6.86t/ha) compared with the 120kg N/ha treatment yield in the high EM Zone (6.19t/ha).



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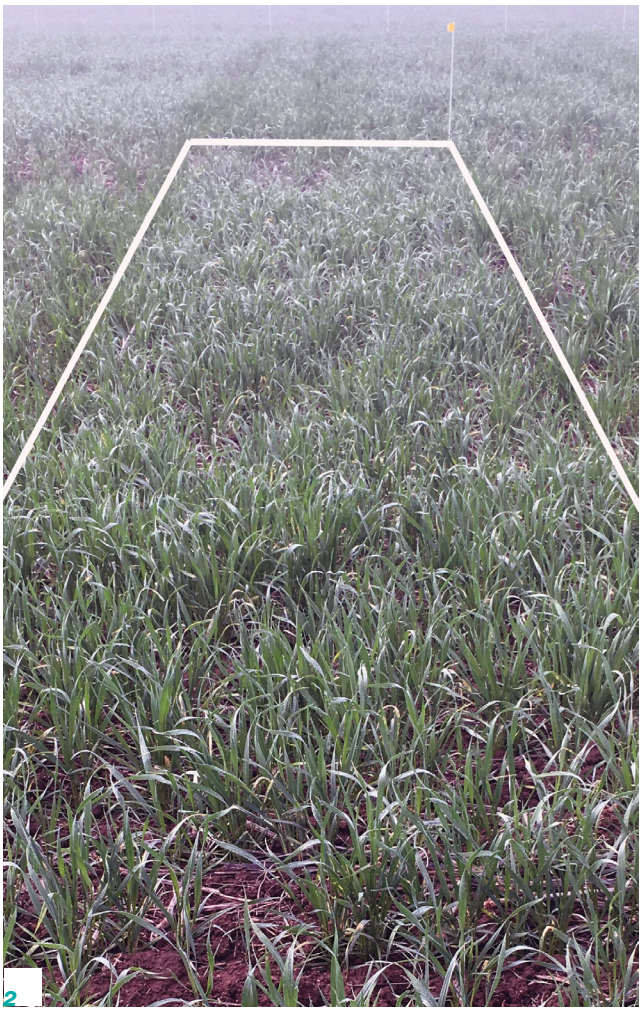

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1 Nil nitrogen treatment, GS31, 11 July 2017

2 Nitrogen rich plot (120 N) plot, GS31, 11 July 2017

Site 2: Dookie, Victoria

Sowing date: 12 May, 2017
Rotation: First wheat after canola
Variety: Trojan
Stubble: Canola unburnt
Rainfall:
GSR: 281mm (April–October)
Summer rainfall: 82mm

Trial 1: High EM zone Dookie, Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017)
0–10cm: 120.4kg N/ha
10–30cm: 46.0kg N/ha
30–60cm: 39.1kg N/ha
Total (0–60cm): 205.5kg N/ha

Results

i) Establishment and crop structure

The site averaged 162 plants/m^2, with 120kg N/ha applied at the three-leaf stage (GS13) having no effect on plant establishment numbers over the nil or 40kg N/ha treatments. Tiller numbers were only significantly different between the 80kg N/ha treatment (361 tillers/m^2) and the 160kg N/ha treatment (416 tillers/m^2). Across the rest of the treatments there was no significant difference in tiller numbers, which is likely due to high levels of available soil nitrogen (Table 11).

TABLE 11 Plant counts 6 June 2017, three leaf (GS13); tiller counts 25 July 2017, beginning of stem elongation (GS30)

Treatment	Crop growth stage	
	Plants/m^2	Tillers/m^2
	GS13	GS30
Nil N	156^{a}	378^{ab}
40 N	168^{a}	386^{ab}
80 N	-	361^{b}
120 N	-	380^{ab}
160 N	-	416^{a}
NDVI 1 (80 N)	-	-
NDVI 2 (80 N)	-	-
120 N (N rich)	163^{a}	405^{ab}
Mean	**162**	**366**
LSD	20	41

Note that only 50% of the nitrogen in the 80, 120 and 160kg N/ha and NDVI treatments had been applied at the time of the tillering assessment (GS22 – 28 June).
Figures followed by different letters are regarded as statistically significant.

ii) Dry matter production and nitrogen uptake

Dry matter assessments at the Dookie high EM site were lower than those recorded at the Yarrawonga site. When assessed at the mid-flowering stage (GS65) only the nitrogen-rich treatment (120 N) had significantly more DM than the nil nitrogen control. However, at physiological maturity (GS92) higher nitrogen rates in the 160 N and 120 N treatments resulted in significantly higher DM than the nil nitrogen control (Table 12).

iii) Normalised difference vegetation index

At this site, despite high levels of available soil nitrogen there was evidence the crop was taking up nitrogen and increasing crop canopy biomass as a result of fertiliser application. The NDVI value of the nil nitrogen plots at the mid-booting (GS45) and flowering stages (GS65) was significantly less than those plots that received 80kg N/ha or more. The difference in NDVI value between the NDVI 1 and NDVI 2 treatments is a result of the earlier timed second dose of nitrogen in NDVI 1 (GS32) compared with NDVI 2 (GS39). There was no increase in NDVI achieved by exceeding 80kg N/ha (Figure 3).

TABLE 10 High EM zone treatment list, Dookie, Victoria

Treatment	12 May GS00 (kg N/ha[1])	8 June GS13 (kg N/ha)	28 June GS22 (kg N/ha)	25 July GS30 (kg N/ha)	17 August GS32 (kg N/ha)	14 September GS39 (kg N/ha)	Total (kg N/ha)
Nil N	6	0	0	0	0	0	6
40 N	6	0	20	20	0	0	46
80 N	6	0	40	40	0	0	86
120 N	6	0	60	60	0	0	126
160 N	6	0	80	80	0	0	166
NDVI 1* (80N)	6	0	40	0	40	0	86
NDVI 2* (80 N)	6	0	40	0	0	40	86
120 N (N rich)	6	120	0	0	0	0	126

NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots (120kg N/ha). A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 looked at standard timings of nitrogen whereas NDVI 2 looked at later splits of the timing of the same amount of nitrogen.

[1] GS00 nitrogen (6kg N/ha) was applied as 60kg MAP/ha, all other nitrogen was applied as urea (46% N).

TABLE 12 Dry matter production 12 October 2017, mid-flowering (GS65) and 28 November 2017, physiological maturity (GS92) for the high EM zone, Dookie, Victoria

Treatment	Dry matter t/ha	
	GS65	GS92
Nil N	7.90[b]	9.69[b]
40 N	8.14[ab]	10.24[ab]
80 N	9.23[ab]	10.76[ab]
120 N	8.42[ab]	10.72[ab]
160 N	9.42[ab]	11.62[a]
NDVI 1 (80 N)	9.36[ab]	11.16[ab]
NDVI 2 (80 N)	9.17[ab]	10.84[ab]
120 N (N rich)	9.52[a]	11.91[a]
Mean	**8.90**	**10.78**
LSD	1.61	1.68

Figures followed by different letters are regarded as statistically significant.

iv) Grain yield and quality

The trial was harvested on 12 December 2017 and averaged 4.16t/ha (Table 13). The maximum yield response to nitrogen of 1t/ha was obtained from the split application of 120kg N/ha applied at tillering (GS22) and the start of stem elongation (GS30). Applying 120 kg N/ha in a split application of 60kg N/ha at tillering (GS22) and 60kg N/ha at the beginning of stem elongation (GS30) resulted in significantly more yield than the same dose applied at the three-leaf stage (GS13) and the 40kg N/ha treatment split into 20kg N/ha applications at GS22 and GS30. The higher yielding of the two NDVI-based treatments (NDVI 1) received 80kg N/ha split as two 40kg N/ha applications at GS22 and GS32 and produced the same yield and protein as the 120kg N/ha treatment, which received two split applications of 60kg N/ha at GS22 and GS30.

In terms of grain quality there were no differences in screenings across treatments, despite lower test weights (TSW) with higher nitrogen rates. Applying 160kg N/ha significantly reduced test weight over the nil, 40kg N/ha and NDVI treatments, however these differences were relatively small.

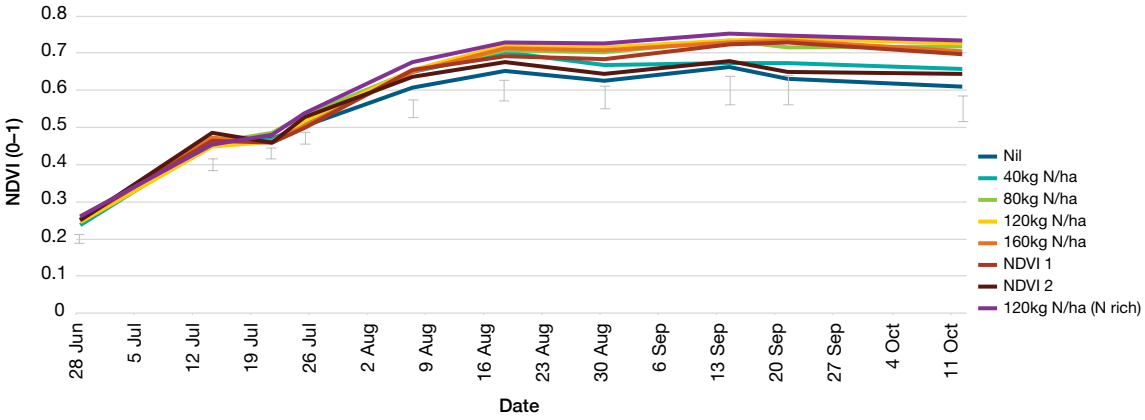

FIGURE 3 NDVI readings on 28 June, two tillers (GS22); 14 July, three tillers (GS23), 21 July, late tillering (GS24); 25 July, beginning of stem elongation (GS30); 7 August, first node (GS31); 17 August second node (GS32); 30 August, flag leaf beginning to emerge (GS37); 14 September, flag leaf fully emerged (GS39); 21 September, mid-booting (GS45) and 12 October, mid-flowering (GS65) for the high EM zone, Dookie, Victoria

TABLE 13 Yield, protein, test weight, screenings and thousand seed weight (TSW) at harvest (GS99) for the high EM zone, Dookie, 12 December 2017

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	3.59[d]	10.2[d]	78.6[a]	1.5[a]	42.2[a]
40 N	3.77[cd]	10.5[cd]	78.3[a]	1.5[a]	41.0[abc]
80 N	4.36[abc]	11.6[b]	78.2[ab]	1.3[a]	39.5[bcd]
120 N	4.59[a]	11.5[b]	78.2[ab]	1.2[a]	40.0[bcd]
160 N	4.42[abc]	12.5[a]	77.5[b]	1.4[a]	38.1[d]
NDVI 1 (80 N)	4.47[ab]	11.5[b]	78.3[a]	1.4[a]	39.3[cd]
NDVI 2 (80 N)	4.19[a-d]	11.3[bc]	78.5[a]	1.4[a]	41.3[ab]
120 N (N rich)	3.91[bcd]	10.9[bcd]	78.1[ab]	1.5[a]	39.8[bcd]
Mean	**4.16**	**11.2**	**78.2**	**1.4**	**40.2**
LSD	0.67	0.8	0.7	0.5	1.9

Figures followed by different letters are regarded as statistically significant.

1

2

3

1 *Dookie high EM zone site 9 June 2017 (GS13)*

2 *Nil nitrogen treatment at GS30, 25 July, 2017*

3 *Nitrogen rich (120 N) treatment at GS30, 25 July, 2017*

Trial 2: Low EM Zone, Dookie Victoria

Soil mineral nitrogen: (Sampled: 1 May 2017)

0–10cm: 96.7kg N/ha

10–30cm: 43.1kg N/ha

30-60cm: 41.9kg N/ha

Total (0–60cm): 181.7kg N/ha

Results

i) Establishment and crop structure

The low EM zone had an average plant population of 166 plants/m^2, with nitrogen applied at the three-leaf stage (nitrogen-rich treatment) having no effect on plant population (Table 15). In this zone there was a non-significant trend for higher tiller numbers where 120kg N/ha was applied early.

ii) Dry matter production

At mid-flowering the only significant difference in DM was where no nitrogen was applied and where 120kg N/ha (N rich) was applied at the three-leaf stage (GS13) (Table 16). However, by physiological maturity (GS92) there was a clear trend suggesting plots that received nitrogen fertiliser had higher DM than those plots where no nitrogen was applied. Significantly more DM was produced where 40, 120kg N/ha (N rich) and 160kg N/ha were applied than in the nil nitrogen treatment.

For the low EM zone, as well as for the high EM zone at this site, 120kg N/ha applied at the three-leaf stage (GS13) produced significantly higher DM than the equivalent amount of nitrogen applied at tillering and the start of stem elongation (GS30) (Table 16).

TABLE 15 Plant counts 6 June 2017, three leaf (GS13); tiller counts 25 July 2017, beginning of stem elongation (GS30), low EM zone, Dookie, Victoria

	Crop growth stage	
	Plants/m^2	Tillers/m^2
Treatment	GS13	GS30
Nil N	163^{a}	377^{a}
40 N	164^{a}	398^{a}
80 N	-	402^{a}
120 N	-	404^{a}
160 N	-	422^{a}
NDVI 1 (100 N)	-	-
NDVI 2 (100 N)	-	-
120 N (N rich)	170^{a}	427^{a}
Mean	**166**	**405**
LSD	27	51

Note that only 50% of the nitrogen in 40 N, 80 N, 120 N and 160 N treatments had been applied at the time of the tillering assessment.

TABLE 16 Dry matter production 12 October 2017, mid-flowering (GS65) and 28 November 2017, physiological maturity (GS92), low EM zone, Dookie, Victoria

	Dry matter (t/ha)	
Treatment	GS65	GS92
Nil N	5.86^{b}	7.19^{d}
40 N	6.65^{ab}	8.66^{bc}
80 N	6.46^{ab}	7.61^{cd}
120 N	6.14^{ab}	8.09^{bcd}
160 N	6.72^{ab}	8.59^{bc}
NDVI 1 (100 N)	6.39^{ab}	8.53^{bc}
NDVI 2 (100 N)	6.60^{ab}	9.22^{ab}
120 N (N rich)	7.16^{a}	9.98^{a}
Mean	**6.50**	**8.48**
LSD	1.29	1.13

Figures followed by different letters are regarded as statistically significant.

TABLE 14 Treatment list low EM zone, Dookie Victoria

	12 May GS00	8 June GS13	28 June GS22	25 July GS30	17 August GS32	14 September GS39	Total
Treatment	(kg N/ha[1])	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)	(kg N/ha)
Nil N	6	0	0	0	0	0	6
40 N	6	0	20	20	0	0	46
80 N	6	0	40	40	0	0	86
120 N	6	0	60	60	0	0	126
160 N	6	0	80	80	0	0	166
NDVI 1* (100 N)	6	0	40	0	60	0	106
NDVI 2* (100 N)	6	0	40	0	0	60	106
120 N (N rich)	6	120	0	0	0	0	126

* NDVI 1 and 2 nitrogen application rates were calculated using a response index based on the nitrogen-rich plots. A response index is the ratio of difference between the nil nitrogen plot and the nitrogen-rich plot (nitrogen-rich plot/nil nitrogen plot). When the ratio exceeded 1.05 nitrogen was applied at the rate the ratio correlated to. NDVI 1 looked at standard timings of nitrogen whereas NDVI 2 looked at later splits of the timing of the same amount of nitrogen.

[1] GS00 nitrogen (6kg N/ha) was applied as 60kg MAP/ha, all other nitrogen *was* applied as urea (46% N).

iii) Normalised difference vegetation index

Similarly to the high EM zone, and despite large quantities of available soil nitrogen, the crop canopy clearly responded to applied nitrogen fertiliser with significantly higher NDVI where nitrogen was applied (Figure 4). There was no significant difference in NDVI readings between the 40kg N/ha and 160kg N/ha treatments when nitrogen was applied at the same growth stages (GS22 and GS30), or the NDVI 1 treatment, which received 100 kg N/ha after sowing. The NDVI 2 (100 N) treatment received a later application of nitrogen (final 60kg N/ha dose applied at flag-leaf emergence — GS39) and gave consistently lower NDVI readings. This suggests the final dose at flag-leaf emergence (GS39) was too late, whereas the second node application (GS32) was well timed.

In the high EM zone, the nil nitrogen plots generated maximum NDVI values of 0.67 compared with the low EM zone where the nil nitrogen plots gave a maximum NDVI value of 0.61. The lower overall NDVI values measured through the growing season in the low EM zone also correspond to lower final DM in the low EM zone at harvest, with an average of 8.48t/ha DM compared with 10.38t/ha in the high EM zone.

iv) Grain yield and quality

The trial in the low EM zone at Dookie yielded an average 3.61t/ha compared with 4.16t/ha in the high EM zone. Although there was a trend to suggest applied nitrogen increased yield, the differences were not statistically significant across any treatments. The high grain protein levels from the nil nitrogen plots (11.9%) suggests there was sufficient nitrogen in the soil to satisfy both yield and protein requirements, given protein levels above 11% frequently indicate that nitrogen for yield has not been limiting (Table 17).

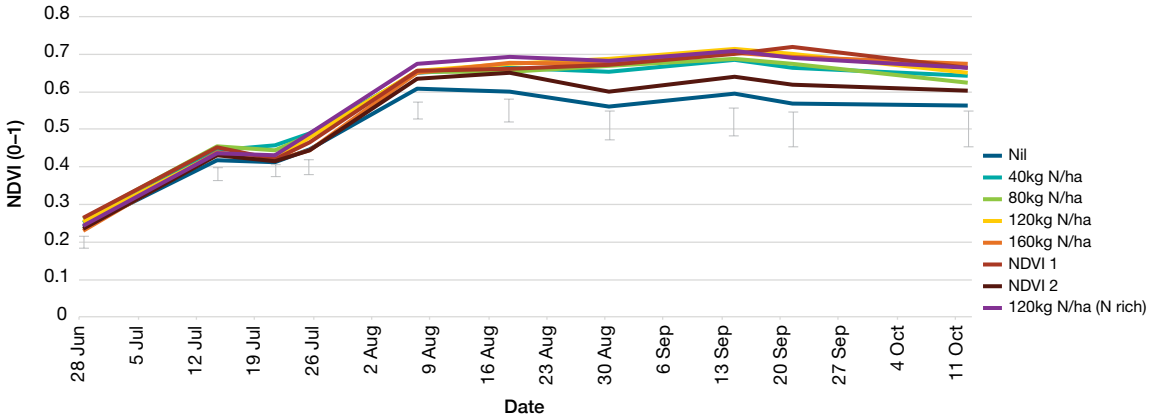

FIGURE 4 NDVI readings on 28 June, two tillers (GS22); 14 July, three tillers (GS23); 21 July, late tillering (GS24); 25 July, beginning of stem elongation (GS30); 7 August, first node (GS31); 17 August, second node (GS32); 30 August, flag leaf beginning to emerge (GS37); 14 September, flag leaf fully emerged (GS39); 21 September, mid-booting (GS45) and 12 October, mid-flowering (GS65) for the low EM zone, Dookie Victoria

TABLE 17 Yield, protein, test weight and screenings at harvest (GS99), for the low EM zone at Dookie, 12 December 2017

Treatment	Yield and quality				
	Yield (t/ha)	Protein (%)	Test weight (kg/hL)	Screenings (%)	TSW (g)
Nil N	3.31[a]	11.9[b]	76.3[a]	1.8[a]	36.4[a]
40 N	3.37[a]	13.5[ab]	73.9[ab]	2.0[a]	34.4[ab]
80 N	3.25[a]	14.0[a]	75.6[ab]	1.8[a]	34.6[ab]
120 N	3.80[a]	14.7[a]	73.4[b]	3.4[a]	30.9[b]
160 N	3.74[a]	14.1[a]	76.2[a]	2.1[a]	31.5[ab]
NDVI 1 (100 N)	3.76[a]	14.6[a]	75.4[ab]	1.9[a]	33.6[ab]
NDVI 2 (100 N)	3.85[a]	13.7[a]	75.6[ab]	1.6[a]	35.3[ab]
120 N (N rich)	3.82[a]	14.5[a]	74.8[ab]	2.3[a]	32.5[ab]
Mean	**3.61**	**13.8**	**75.1**	**2.1**	**33.7**
LSD	0.77	1.6	2.8	1.9	5.0

Figures with different letters are regarded as statistically significant.
Note: Some grain may have been lost due to hail storm at this site. High grain protein in the nil plots suggests nitrogen for this site was not limiting.

1 Dookie low EM zone site, 26 June 2017

2 Nil N treatment at GS30, 25 July 2017

3 Nitrogen rich (120 N) at GS30, 25 July 2017

v) Comparison of DM, yield and protein across EM zones

At Dookie, an NDVI treatment was the highest yielding in both EM zones and also gave the best yield response to amount of nitrogen applied.

The highest yielding treatment in the high EM Zone was NDVI 1, which had 80kg N/ha applied (40kg N/ha at GS22 and 40kg N/ha at GS32) and yielded 4.47t/ha. The highest yielding treatment in the low EM zone treatment was NDVI 2, which received 100kg N/ha (40kg N/ha at GS22 and 60kg N/ha at GS39) and yielded 3.85t/ha.

The high EM zone crop was also much more efficient at turning DM into yield. Average harvest DM in the high EM zone was 10.78t/ha, while the average yield was 4.16t/ha. In the low EM zone, average harvest dry matter was 8.48t/ha while yield was 3.61t/ha (Table 18).

High protein, which was above 11.9% for all treatments in the low EM zone, showed that adequate nitrogen was available for the crop to satisfy both yields and protein requirements. The optimum treatment for protein response in the high EM zone was 160kg N/ha, which produced grain at 12% protein.

TABLE 18 Key differences between high and low EM zones at Dookie, Victoria

	High EM zone	Low EM zone
Dry matter (t/ha)	9.69–11.91	7.19-9.98
Yield (t/ha)	3.59–4.59	3.25–3.85
Protein (%)	10.2-12.5	11.9-14.7

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