Optimising sulphur and nitrogen nutrition in canola

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Key points

- At the Howlong site, applied nitrogen gave a yield and dry matter (DM) response, however there was no sulphur response.
- The Yarrawonga site showed a clear response to applied sulphur (S) and nitrogen (N), despite high soil sulphur levels. This suggests canola roots may not be effectively exploring the soil profile to access soil sulphur.
- The Yarrawonga site had an optimum sulphur application rate of 20kg S/ha, with yield penalties measured with sulphur rates above and below this optimal rate.
- The dry finish to the season caused significant challenges during 2017. This trial will be repeated at two sites during 2018 to understand how variable the responses to sulphur are likely to be during different seasonal conditions.

Background

Following the discovery of sulphur deficiency in canola in southern NSW during the late 1980s, the application of 20–30kg S/ha was recommended when sowing canola (*GRDC Canola guide*, *2009*). Since then, the wheat–canola rotation has become established, meaning 20–30 kg S/ha is being applied as frequently as every second year. With some sulphur moving to depth, growers are questioning whether they can reduce the rate of sulphur they are applying to their canola crops.

Furthermore, a variable response to sulphur has been observed, depending on background nutrition levels, (e.g. soil nitrogen status — where nitrogen supply is sub-optimal, plant uptake of sulphur can be inhibited, leading to a confounded yield response).

The GRDC investment, *Optimising crop nutrition in canola in the southern region of NSW* is investigating the interactions between nitrogen availability and sulphur uptake, to ensure sulphur uptake is not limited by sub-optimal soil nitrogen levels.

Aims

This project aims to determine if nitrogen supply is limiting uptake of sulphur in canola crops grown in the Riverine Plains region and whether sulphur uptake and yield is increased in canola when nitrogen is available in non-limiting quantities.

The 2017 project trial assessed the response to nitrogen and sulphur in canola crops of the Riverine Plains by determining:

- the influence of nitrogen and sulphur application on canola tissue content, yield and oil
- the fluctuation in nitrogen and sulphur content and nitrogen:sulphur ratio in the plant from stem elongation (GS31) to harvest (GS99)
- the optimum available soil nitrogen level for the region's canola crops at varying sulphur application rates.

Method

Two trial sites were established at Yarrawonga, Victoria and Howlong, NSW.

A randomised block design was used with plots measuring 3m x 18m, with four replicates. The Yarrawonga trial site was sown to canola cv Roundup Ready® 44Y25 while the Howlong site was sown to canola cv Bonito.

Both sites were sown on 24 April 2017, after which combinations of nitrogen and sulphur treatments were applied.

Nitrogen (as urea) was applied in a split application at the 6–8 leaf stage (GS1.06–1.08) and green bud (GS3.3) at five rates (0, 40, 80, 120, 160 kg N/ha), with 40 kg N/ha applied at the 6–8 leaf stage, and the remainder at green bud.

Sulphur was applied as sulphate of ammonia (SOA) at four rates (0, 10, 20, 30kg S/ha), at the same time as the first application of in-crop nitrogen (GS1.06–1.08), with urea added to balance the nitrogen applied in the SOA.

Sulphur treatments were applied across the suite of nitrogen treatments to determine the interaction between nitrogen and sulphur (Table 1).

The trial site was managed as part of the surrounding commercial crop, with the exception of the sulphur and nitrogen applications.

Tissue sulphur and nitrogen testing and dry matter (DM) sampling both occurred at early flowering (GS4.1–4.2) and when seeds were black, but soft (GS6.7). Yield, oil and protein content was also measured.

TABLE 1 Sulphur and nitrogen interaction trial treatment list, 2017*

No.	Fertiliser application (kg/ha)		Total S (kg/ha)	Total N (kg/ha)
	Six-leaf stage (GS1.06)	Green bud (GS3.3)		
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	40N 0S	0	0	40
6	40N 10S	0	10	40
7	40N 20S	0	20	40
8	40N 30S	0	30	40
9	40N 0S	40N	0	80
10	40N 10S	40N	10	80
11	40N 20S	40N	20	80
12	40N 30S	40N	30	80
13	40N 0S	120N	0	160
14	40N 10S	120N	10	160
15	40N 20S	120N	20	160
16	40N 30S	120N	30	160
17	40N 0S	200N	0	240
18	40N 10S	200N	10	240
19	40N 20S	200N	20	240
20	40N 30S	200N	30	240

* Nitrogen applied as urea (46% N) and sulphur applied as ammonium sulphate (21% N and 24% S).

Treatments at six-leaf stage (GS 1.06) were applied as ammonium sulphate with residual nitrogen application applied as urea.

The first 40kg N/ha of all nitrogen treatments was applied at the six-leaf stage (GS1.06), the remainder was applied at green bud (GS3.3).

Treatment list excludes MAP applied at sowing with the commercial crop.

Trial 1: Howlong, NSW

Sowing date: 24 April 2017
Rotation: Canola after wheat
Variety: Canola, cv Bonito
Rainfall:
GSR: 272.8mm (April – October)

i) Soil sampling results

Incremented soil samples (0–30cm, 30–60cm, 60–90cm) were collected on 5 June 2017 and analysed for nitrogen and sulphur content (Table 2).

Field sites were selected based on previous cropping history and associated high levels of production and nutrient export. The soil nitrogen and sulphur levels at the Howlong site were much higher than the grower expected, with a late urea application during 2016 (to address low nitrogen availability under saturated condition) likely to have contributed to these high levels. This late application of urea would have also likely increased the movement of excess nitrogen to depth.

TABLE 2 Soil nitrogen and sulphur contents at Howlong NSW, sampled 5 June 2017

Depth (cm)	Mineral N (kg/ha)	Mineral S (kg/ha)
0–30	83.85	37.28
30–60	34.94	14.91
60–90	28.02	14.70
Total (0–90)	146.81	66.89

ii) Vigour and biomass

Due to the large number of treatments in this trial, only selected treatments (i.e. the nil sulphur and high sulphur treatments at each rate of nitrogen) received in-crop assessments.

Plant vigour assessments made at the six-leaf stage (GS1.06) showed no difference between treatments (Table 3).

The DM measurements taken at 20% flowering (GS4.2) showed the 80N:0S treatment had the greatest biomass, which was 1.49t/ha greater than the untreated controls (UTC). In comparison, measurements taken when most seeds were black but soft (GS6.7), showed that DM production aligned relatively well with the nitrogen application rate. When most seeds were black but soft (GS6.7), the greatest biomass was measured in the 240N:30S treatment, which was 4.95t/ha greater than the average of the UTC (Table 3).

iii) Plant tissue nitrogen and sulphur content

The nitrogen content of the canola at 20% flowering (GS4.2) showed uptake of nitrogen across all treatments, although the relationship was not always linear (Table 4). The greatest nitrogen uptake was measured in the 80N:0S, 160N:0S, 160N:30S and 240N:30S treatments. This suggests that at 20% flower, applications of 80N and above generally provided more nitrogen than was required.

The nitrogen response was clearer closer to maturity. When seeds were black but soft (GS6.7) there was a clear and significant trend showing increased nitrogen uptake with increased nitrogen supply (Table 4). The 80N:30S treatment showed the addition of sulphur significantly increased the uptake of nitrogen from 165kg N/ha to 207kg N/ha. Nitrogen levels at the seeds black but soft stage (GS6.7)

TABLE 3 Vigour and dry matter assessment at Howlong NSW, 2017

Treatment	21 June 2017 Vigour (1–9) Six-leaf stage (GS1.06)	18 August 2017 Dry matter (t/ha) 20% flower (GS4.2)	8 November 2017 Dry matter (t/ha) Most seed black, but soft (GS6.7)
UTC	7[a]	3.01[d]	13.23[de]
UTC	7[a]	3.00[d]	13.12[e]
40N:0S	7[a]	3.06[cd]	14.90[b-e]
40N:30S	8[a]	3.53[bcd]	13.77[cde]
80N:0S	7[a]	4.49[a]	15.13[b-e]
80N:30S	7[a]	3.93[ab]	16.08[abd]
160N:0S	7[a]	3.90[ab]	15.63[bcd]
160N:30S	7[a]	3.64[bc]	16.85[ab]
240N:0S	7[a]	3.51[bcd]	17.30[ab]
240N:30S	8[a]	3.53[bcd]	18.12[a]
Mean	**7**	**3.56**	**15.41**
LSD P=0.05	1	0.60	2.45
Treatment probability (F)	0.952	0.001	0.004
CV	8.37	11.37	10.68
SD	0.6	0.41	1.65

Figures followed by different letters are regarded as statistically different.

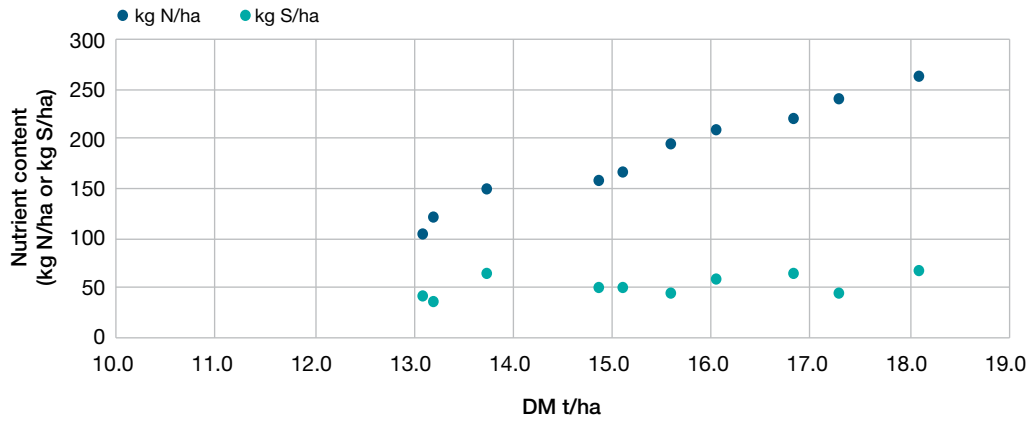


FIGURE 1 Relationship between dry matter production and nitrogen or sulphur tissue content at Howlong NSW, measured on 8 November 2017 at GS6.7

showed a strong linear relationship with the dry matter measurements taken on the same day, confirming a strong nitrogen-growth response (Figure 1).

Tissue sulphur content across treatments varied from 12–27kg S/ha at early flowering (GS4.2), with no significant differences between the nil and plus 30kg S/ha treatments. In comparison, increased tissue sulphur levels were measured at the seeds black but soft stage (GS6.7) when sulphur was added to the 40, 160 and 240kg N treatments compared with the nil treatments (Table 4). This demonstrates that added sulphur contributed to sulphur uptake by the plant. However, the lack of change in tissue sulphur levels when increasing levels of nitrogen were applied suggests that increased nitrogen supply did not facilitate increased sulphur uptake in this soil during 2017. An unclear relationship between increasing tissue sulphur levels and DM production, indicates that sulphur content was not the most limiting factor to plant growth at this site (Figure 1).

TABLE 4 Plant tissue nitrogen and sulphur contents at Howlong NSW, 2017

Treatment	Nitrogen content		Sulphur content	
	18 August 2017	8 November 2017	18 August 2017	8 November 2017
	kg N/ha	kg N/ha	kg S/ha	kg S/ha
	20% flower (GS4.2)	Most seed black, but soft (GS6.7)	20% flower (GS4.2)	Most seed black, but soft (GS6.7)
UTC	65^{d}	118^{fg}	17de	34^{d}
UTC	68^{d}	103^{g}	12^{e}	38^{cd}
40N:0S	114^{c}	156^{e}	19^{cd}	48^{bc}
40N:30S	111^{c}	148^{ef}	22^{a-d}	61^{a}
80N:0S	181^{a}	165de	27^{a}	47^{bc}
80N:30S	121^{c}	207^{c}	26^{a}	56^{ab}
160N:0S	167^{ab}	192^{cd}	25^{a}	42^{cd}
160N:30S	154^{ab}	219^{bc}	25^{ab}	63^{a}
240N:0S	151^{b}	239^{ab}	19^{bcd}	41^{cd}
240N:30S	155^{ab}	261^{a}	23^{abc}	65^{a}
Mean	**129**	**181**		**50**
LSD P=0.05	29	31	6	11
Treatment probability (F)	<0.001	<0.001	<0.001	<0.001
CV	15.39	13.35	17.61	14.35
SD	19.8	20.6	3.8	7.1

Figures followed by different letters are regarded as statistically different.

iv) Green leaf retention

There were significant treatment effects assessed as green leaf retention (GLR%) measured at 50% podset (GS5.5) + 15 days, however these results did not correlate to nitrogen or sulphur application rates. Moreover, the range in the UTC (nil) treatments was similar to that observed across the whole trial, further discounting the value of any differences in GLR% (Table 5). Similarly, there were no significant differences in GLR% when measured at 50% podset (GS5.5) + 32 days.

v) Normalised difference vegetation index (NDVI)

Normalised difference vegetation index was measured in each plot eight times throughout the season. The last measure, taken at 20% flowering (GS4.2), was the only one to show significant differences between treatments (Figure 2). While there were statistically significant differences between treatments, all of the treatments that received 80kg N/ha or above had comparable plant greenness.

vi) Yield, oil and protein

While there were significant differences in yield across the various treatments, the yield range at the Howlong site was only 2.46–3.04t/ha, with the UTC being the lowest yielding treatment and the 80N:20S being the highest yielding treatment (Table 6). The UTC, 40N:0S, 40N:30S, 160N:30S and 240N:30S treatments were all significantly lower yielding than the highest yielding treatment (80N:20S). When analysed as a factorial (when each group of factors are analysed together), the highest rate of sulphur (30kg S/ha) yielded significantly less than the 10 and 20kg S/ha application rates. There was no clear trend between nitrogen rate and yield response.

There were no significant differences in oil content across the treatments, and only limited differences in protein content, which ranged from 16.2% in an UTC to 17.1% in the 240N:0S treatment (Table 6).

TABLE 5 Green leaf retention at Howlong, NSW, 2017

Treatment	13 October 2017 GLR (%) GS5.5 +15 days	30 October 2017 GLR (%) GS5.5 +32 days
UTC	65de	40^{a}
UTC	68^{bcd}	38^{a}
UTC	61^{e}	43^{a}
UTC	70^{abc}	40^{a}
40N:0S	68^{bcd}	40^{a}
40N:10S	73^{a}	43^{a}
40N:20S	70^{abc}	45^{a}
40N:30S	70^{abc}	40^{a}
80N:0S	71^{ab}	40^{a}
80N:10S	70^{abc}	40^{a}
80N:20S	71^{ab}	43^{a}
80N:30S	70^{abc}	43^{a}
160N:0S	71^{ab}	48^{a}
160N:10S	70^{abc}	40^{a}
160N:20S	66^{cd}	45^{a}
160N:30S	70^{abc}	38^{a}
240N:0S	70^{abc}	40^{a}
240N:10S	70^{abc}	43^{a}
240N:20S	70^{abc}	45^{a}
240N:30S	69^{a-d}	38^{a}
Mean	**69.1**	**41**
LSD P=0.05	4.9	7
Treatment probability (F)	0.013	0.373
CV	5.06	12.65
SD	3.5	5.2

Figures followed by different letters are regarded as statistically different.

TABLE 6 Harvest yield and quality at Howlong NSW, 2017

Treatment	22 November 2017 Yield (t/ha) Harvest	Oil (%) Harvest	Protein (%) Harvest
UTC	2.54^{de}	48.1^{a}	16.2^{de}
UTC	2.46^{e}	47.9^{a}	16.2^{e}
UTC	2.68^{cde}	48^{a}	16.5^{b-e}
UTC	2.46^{e}	48.2^{a}	16.4^{cde}
40N:0S	2.69^{cde}	47.6^{a}	16.8^{abc}
40N:10S	2.90^{abc}	47.5^{a}	16.8^{abc}
40N:20S	2.84^{abc}	47.4^{a}	16.8^{abc}
40N:30S	2.66^{cde}	47.7^{a}	16.4^{cde}
80N:0S	2.91^{abc}	48.0^{a}	16.5^{b-e}
80N:10S	2.84^{abc}	47.6^{a}	16.9^{ab}
80N:20S	3.04^{a}	47.8^{a}	16.8^{abc}
80N:30S	2.84^{abc}	47.3^{a}	16.9^{abc}
160N:0S	2.83^{abc}	47.5^{a}	16.8^{abc}
160N:10S	3.01^{ab}	47.4^{a}	16.7^{abc}
160N:20S	2.82^{abc}	47.7^{a}	16.7^{a-d}
160N:30S	2.77^{bcd}	47.5^{a}	16.8^{abc}
240N:0S	2.77^{a-d}	47.3^{a}	17.1^{a}
240N:10S	2.90^{abc}	47.4^{a}	16.8^{abc}
240N:20S	2.99^{ab}	47.1^{a}	16.9^{ab}
240N:30S	2.75^{bcd}	47.3^{a}	16.8^{abc}
Mean	**2.79**	**47.6**	**16.67**
LSD P=0.05	0.27	0.79	0.5
Treatment probability (F)	<0.001	0.341	0.033
CV	6.81	1.17	2.13
SD	0.19	0.6	0.4

Figures followed by different letters are regarded as statistically different.

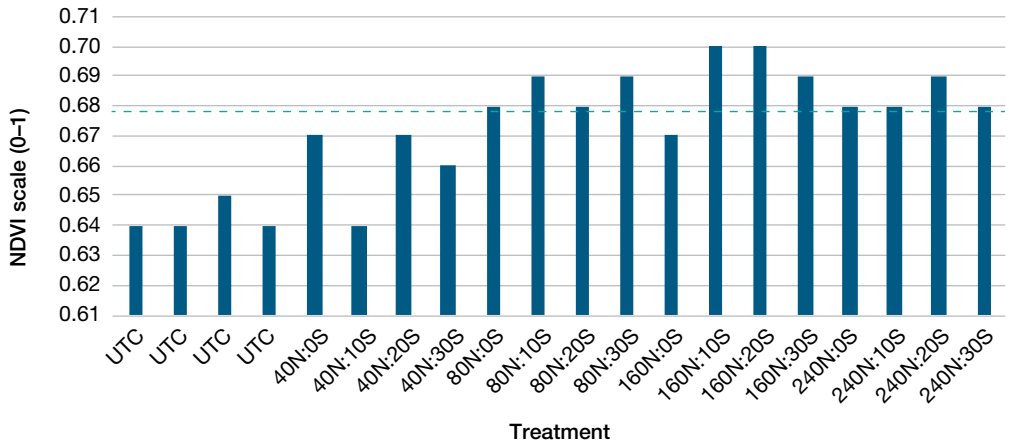


FIGURE 2 NDVI values, measured 18 August 2018, at 20% flowering (GS4.2) at Howlong, NSW

LSD = 0.02. All readings above the dotted line are statistically comparable to the highest values of 160N:10S and 160N:20S.

1 *Howlong trial site, 23 May 2017*

2 *Canola at two-leaf stage (GS1.02), 23 May 2017*

3 *Howlong trial site, 24 July 2017*

4 *Untreated control, 13 November when most seeds black, but soft (GS6.7)*

Trial 2: Yarrawonga, Victoria

Sowing date: 24 April 2017
Rotation: Canola after wheat
Variety: Canola cv 44Y25 (Round-up Ready®)
Rainfall:
GSR: 270.4mm (April – October)

i) Soil sampling results

Incremented soil samples (0–30cm, 30–60cm, 60–90cm) were collected on 5 June 2017 and analysed for nitrogen and sulphur content (Table 7).

The soil nitrogen and sulphur contents at the Yarrawonga site were almost the inverse of those measured at Howlong. The Yarrawonga site measured a mineral nitrogen value of 69.75kg N/ha and a mineral sulphur value of 140.6kg S/ha compared with 146.81kg N/ha and 66.89kg S/ha at the Howlong site. The lower nitrogen levels at depth at Yarrawonga suggest the efficient extraction of nitrogen by previous crops (Table 7). High values of sulphur were present through the profile at Yarrawonga, which is likely due to accumulation of sulphur from previous fertiliser additions and high use of gypsum as a soil ameliorant.

ii) Vigour and biomass

Similarly to the Howlong site, a large number of treatments was required at this site to understand the full interaction between nitrogen and sulphur. As such, only selected treatments received in-crop assessments (i.e. the nil-sulphur and high sulphur treatments at each rate of nitrogen).

There was no difference in plant vigour between treatments when measured at the four-leaf stage (GS1.04) (Table 8).

The DM assessment at the first flowers opened stage (GS4.1) showed a sulphur response, with the 30kg S/ha treatments showing increased biomass compared with the nil sulphur treatment (UTC) (Table 9) when 40 or 80kg N/ha was applied. The 80N:30S treatment had the highest DM production (4.68t DM/ha), which was significantly greater than the 160N:0S treatment (3.79t DM/ha).

TABLE 7 Soil nitrogen and sulphur contents at Yarrawonga, Victoria, sampled 5 June 2017

Depth (cm)	Mineral N (kg/ha)	Mineral S values (kg/ha)
0–30	57.14	42.74
30–60	8.93	66.15
60–90	3.68	31.71
Total (0-90)	69.75	140.6

TABLE 8 Vigour and dry matter assessment at Yarrawonga Victoria, 2017

Treatment	8 June 2017 Vigour (1–9) Four leaf (GS1.04)	23 August 2017 Dry matter (t/ha) 10% flower (GS4.1)	9 November 2017 Dry matter (t/ha) Most seed black, but soft (GS6. 7)
UTC	5.8^{a}	3.26^{cd}	6.72^{e}
UTC	5.0^{a}	3.16^{d}	5.58^{e}
40N:0S	5.5^{a}	2.40^{e}	8.44^{d}
40N:30S	5.3^{a}	4.17^{ab}	10.30^{bc}
80N:0S	5.3^{a}	3.89^{bc}	9.65^{cd}
80N:30S	5.3^{a}	4.68^{a}	11.50^{ab}
160N:0S	5.3^{a}	3.79^{bcd}	11.51^{ab}
160N:30S	5.0^{a}	4.20^{ab}	11.24^{abc}
240N:0S	5.3^{a}	4.40^{ab}	10.35^{bc}
240N:30S	5.0^{a}	4.37^{ab}	12.45^{a}
Mean	**5.3**	**3.83**	**9.77**
LSD P=0.05	1.1	0.65	1.61
Treatment probability (F)	0.950	<0.001	<0.001
CV	14.04	11.61	11.09
SD	0.7	0.45	1.08

Figures followed by different letters are regarded as statistically different.

The later assessment, made when seeds were black but soft (GS6.7), also showed that the high sulphur treatments had increased DM production compared with nil sulphur treatments (UTC) when 40 or 80kg N/ha was applied. The 80N:30S treatment had statistically comparable DM production to the 240N:30S treatment.

iii) Plant tissue nitrogen and sulphur content

When measured at the first flowers opened stage (GS4.1), there was a clear and statistically significant increase in tissue nitrogen content associated with increased nitrogen application rate (Table 9). There was also a significant increase in nitrogen tissue content with the addition of sulphur at the 40kg N/ha and 240kg N/ha rates.

Nitrogen content at the seeds black but soft stage (GS6.7) also reflected increases in nitrogen application rates. The increased nitrogen content evident at higher nitrogen application rates also related strongly to DM production (Figure 3), although the relationship isn't as clear as that seen at the Howlong site (Figure 1). This difference may be due to the more significant contribution of sulphur nutrition at the Yarrawonga site.

Tissue analysis at first flowers opened stage (GS4.1) showed that adding sulphur increased plant tissue sulphur levels, with all plus-sulphur treatments having significantly higher

TABLE 9 Plant tissue nitrogen and sulphur contents at Yarrawonga, Victoria, 2017

Assessment	23 August 2017 kg N/ha 10% flower (GS4.1)	9 November 2017 kg N/ha Most seed black, but soft (GS6.7)	23 August 2017 kg S/ha 10% flower (GS4.1)	9 November 2017 kg S/ha Most seed black, but soft (GS6.7)
UTC	61^{d}	42^{f}	16^{b}	18^{e}
UTC	53^{d}	41^{f}	12^{b}	24de
40N:0S	55^{d}	55^{ef}	11^{b}	25de
40N:30S	109^{c}	69^{e}	29^{a}	59^{a}
80N:0S	119^{c}	81de	13^{b}	41^{c}
80N:30S	131^{c}	97^{cd}	28^{a}	47^{bc}
160N:0S	179^{ab}	103^{cd}	13^{b}	30^{d}
160N:30S	167^{b}	119^{bc}	23^{a}	53^{ab}
240N:0S	175^{b}	130^{ab}	15^{b}	26^{d}
240N:30S	201^{a}	152^{a}	26^{a}	51^{b}
Mean	**125**	**89**	**19**	**37**
LSD P=0.05	22	26	5	8
Treatment probability (F)	<0.001	<0.001	<0.001	<0.001
CV	12.12	19.45	19.02	13.51
SD	15.1	17	3.5	5

Figures followed by different letters are regarded as statistically different.

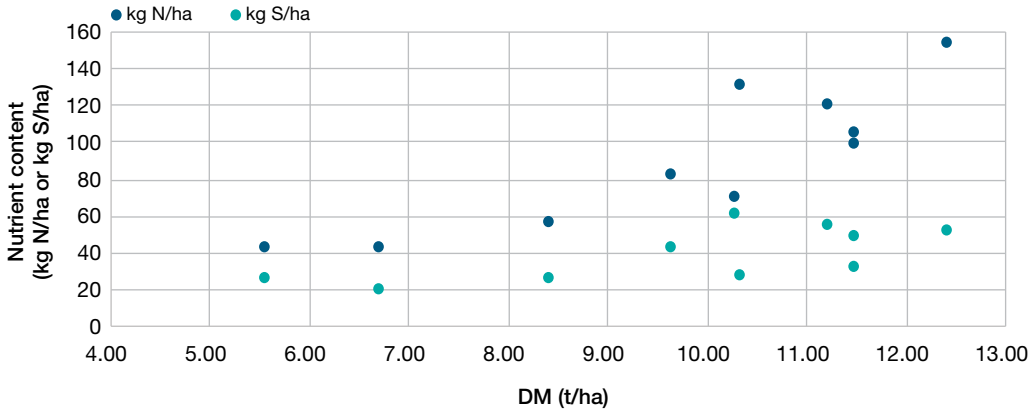


FIGURE 3 Relationship between DM production and nitrogen or sulphur tissue content at Yarrawonga, Victoria, as measured on 9 November 2017, at most seed black, but soft stage (GS6.7)

plant tissue sulphur levels compared with the nil-sulphur treatments (Table 10). There was no interaction between nitrogen supply and tissue sulphur levels at GS4.1.

A similar response was seen at the seeds black but soft stage (GS6.7) with all nitrogen treatments, except the 80kg N treatment, showing a significant increase in tissue sulphur levels compared with the nil-sulphur treatments when sulphur was added.

iv) Green leaf retention

The GLR% at the Yarrawonga site showed a nutrient response (Table 10), compared with the Howlong site, which did not show any response. When measured at both 15 and 32 days after podset (GS5.5) there was trend to increasing GLR% in all treatments from 80N:10S and above. There were no significant effects of sulphur on GLR%.

v) Normalised difference vegetation index

Of the eight NDVI measurements carried out over the life of the trial, only the last four measurements, taken during the period 27 July to 23 August 2017, showed significant differences in leaf greenness. Results from the final reading taken on 23 August are presented in Figure 4 and show a clear nutrient response, with increasing nitrogen and sulphur leading to increased NDVI measurements.

vi) Yield, oil and protein

The Yarrawonga site showed a greater yield response due to nutrition than was seen at the Howlong site, with yields ranging from 1.32t/ha in the untreated control (UTC) to 3.11t/ha in the 160N:20S treatment (Table 11). When analysed as a factorial, the addition of sulphur significantly increased yield when applied at the rate of 20kg S/ha, with

TABLE 10 Green leaf retention at Yarrawonga, Victoria, 2017

Treatment	13 October 2017 GLR (%) 50% podset (GS5.5) +15 days	6 November 2017 GLR (%) 50% podset (GS5.5) +32 days
UTC	60.0^{ef}	43.8^{cd}
UTC	57.5^{ef}	40.0^{d}
UTC	58.8^{ef}	43.8^{cd}
UTC	53.8^{f}	41.3^{cd}
40N:0S	65.0^{def}	43.8^{cd}
40N:10S	65.0^{def}	50.0^{bcd}
40N:20S	67.5^{b-e}	50.0^{bcd}
40N:30S	66.3^{cde}	43.8^{cd}
80N:0S	66.3^{cde}	42.5^{cd}
80N:10S	72.5^{a-d}	53.8^{abc}
80N:20S	73.8^{a-d}	51.3^{a-d}
80N:30S	72.5^{a-d}	47.5^{bcd}
160N:0S	81.3^{a}	60.0^{ab}
160N:10S	80.0^{a}	58.8^{ab}
160N:20S	82.5^{a}	58.8^{ab}
160N:30S	80.0^{a}	63.8^{a}
240N:0S	77.5^{abc}	57.5^{ab}
240N:10S	80.0^{a}	63.8^{a}
240N:20S	78.8^{ab}	60.0^{ab}
240N:30S	80.0^{a}	60.0^{ab}
Mean	**70.9**	**51.7**
LSD P=0.05	11.6	13.4
Treatment probability (F)	<0.001	<0.001
CV	11.59	18.25
SD	8.2	9.4

Figures followed by different letters are regarded as statistically different.

TABLE 11 Harvest yield and quality at Yarrawonga, Victoria, 2017

Treatment	22 November 2017 Yield (t/ha) Harvest	Oil (%) Harvest	Protein (%) Harvest
UTC	1.53^{gh}	47.3^{abc}	16.0^{e}
UTC	1.49^{gh}	47.1^{abc}	16.6^{cde}
UTC	1.70^{g}	47.3^{abc}	16.0^{e}
UTC	1.32^{h}	47.8^{a}	15.8^{e}
40N:0S	1.98^{f}	46.7^{a-d}	16.4^{de}
40N:10S	1.95^{f}	47.4^{ab}	16.2^{de}
40N:20S	2.16^{f}	46.1^{bcd}	16.6^{cde}
40N:30S	2.13^{f}	47.1^{abc}	16.3^{de}
80N:0S	2.45^{e}	45.5^{d}	17.9^{c}
80N:10S	2.74^{bcd}	46.1^{bcd}	17.0^{cde}
80N:20S	2.58^{de}	45.9^{cd}	17.4^{cd}
80N:30S	2.58^{de}	46.2^{bcd}	17.4^{cd}
160N:0S	2.42^{e}	42.9^{ef}	20.3^{b}
160N:10S	2.63^{cde}	43.0^{ef}	20.2^{b}
160N:20S	3.11^{a}	43.4^{e}	20.2^{b}
160N:30S	2.54^{de}	41.5^{fg}	21.2^{b}
240N:0S	2.96^{ab}	41.9^{efg}	20.8^{b}
240N:10S	2.92^{ab}	40.8^{gh}	21.4^{ab}
240N:20S	2.97^{ab}	41.7^{fg}	21.3^{b}
240N:30S	2.82^{bc}	40.0^{h}	22.6^{a}
Mean	**2.35**	**44.8**	**18.4**
LSD P=0.05	0.23	1.5	1.3
Treatment probability (F)	<0.001	<0.001	<0.001
CV	6.98	2.31	5.01
SD	0.16	1.0	0.9

Figures followed by different letters are regarded as different significant.

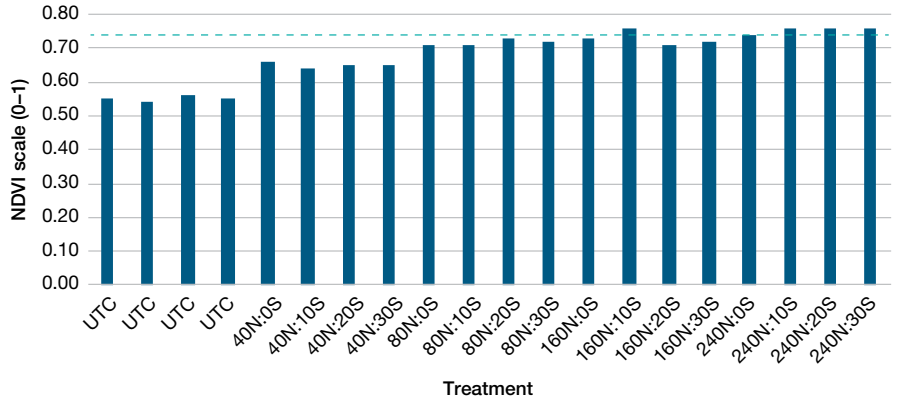


FIGURE 4 NDVI values, measured on 18 August 2018, at 20% flowering (GS4.2) at Howlong, NSW, 2017
LSD = 0.05 All the readings on and above the dotted line are statistically comparable to the highest values of 160N:10S and 240N:20S.

a yield penalty at lower and higher rates, across all nitrogen rates. There was a clear yield response to nitrogen, with an increased nitrogen application rate leading to significantly increased yield so that 240N yielded more than 80N and 160N, which yielded more than 40N.

The response of oil percentage to nitrogen was the inverse of yield so that increasing nitrogen application rate decreased oil percentage. There was no response of oil percentage to the addition of sulphur (Table 11).

Protein percentage also showed a nitrogen response, with increased nitrogen application rates causing a significant increase in protein levels. Again, protein levels showed no response to applied sulphur.

Gross margin analysis

Gross margin (GM) analyses were undertaken based on growers' input costs and included contract rates for machinery operations. Fertiliser rates were converted to combinations of urea and sulphate of ammonia, using values of $400/t for urea and $750/t for sulphate of ammonia. Grain value for the 2017–18 harvest was calculated using prices of $515/t for canola delivered Howlong and $470/t for Roundup Ready® canola delivered Yarrawonga.

A number of treatments (40N:0S, 40N:10S, 40N:20S, 80N:0S, 80N:10S, 80N:20S, 80N:30S, 160N:10S and 240N:20S) at the Howlong site were more economic than the GM of the average of the untreated control plots ($1,110/ha) (Table 12). The highest yielding treatment (80N:20S equivalent to 100kg of urea and 83kg of sulphate of ammonia) yielded 3.04t/ha and returned a GM of $1271/ha. The cost of this rate of fertiliser represented 8% of canola gross income. The second highest GM treatment (80N:0S) returned only $27/ha less and may not have been statistically different from the highest gross margin treatment. Sensitivity analysis showed that decreasing canola price by 10% or increasing fertiliser price by 10% did not change the most economic treatment outcomes.

Three of the 160kg N/ha and three of the 240kg N/ha treatments had lower GM than the untreated control plots, suggesting the higher nitrogen application rates were not economic.

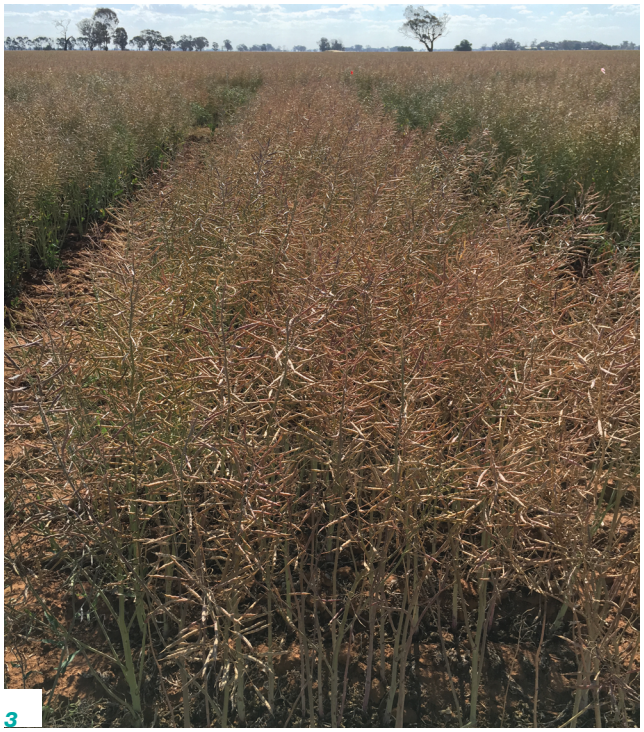
All treatments at the Yarrawonga site were more economic than the GM of the average of the untreated control plots, which returned $462/ha (Table 13). Similarly to Howlong, the highest yielding treatment (160N:20S equivalent to 200kg/ha of urea and 83kg/ha of sulphate of ammonia), which yielded 3.11t/ha, was also the most economic, returning a GM of ($1,020/ha). The cost of this rate of fertiliser represented 13.8% of canola gross income.

Sensitivity analysis showed that decreasing canola price by 10% (by $51.5/t or $164.50/ha at Howlong or by $47/t or $141/ha at Yarrawonga) had a bigger impact on canola GM than a 10% increase in fertiliser price ($40/t for urea and $75/t for sulphate of ammonia, with a combined impact of $10/ha at the Howlong site and $14 at the Yarrawonga site). Changing the canola or fertiliser price did not change which

TABLE 12 Fertiliser application rate, gross margin and sensitivity analysis for treatments at Howlong, NSW, 2017

Treatment	Urea application rate (kg/ha)	SOA application rate (kg/ha)	Gross margin ($/ha)	Gross margin# (canola price less 10%) ($/ha)	Gross margin# (fertiliser price plus 10%) ($/ha)
UTC	0	0	1110*	970	
40N:0S	87	0	1147	995	1143
40N:10S	67	42	1236	1073	1230
40N:20S	50	83	1177	1018	1169
40N:30S	30	125	1061	911	1051
80N:0S	174	0	1237	1072	1230
80N:10S	134	42	1174	1014	1165
80N:20S	100	83	1271	1099	1261
80N:30S	60	125	1134	975	1123
160N:0S	348	0	1112	953	1098
160N:10S	268	42	1209	1039	1195
160N:20S	200	83	1108	949	1094
160N:30S	120	125	1077	921	1062
240N:0S	522	0	1005	850	984
240N:10S	402	42	1095	932	1076
240N:20S	300	83	1147	980	1129
240N:30S	180	125	1037	883	1021

Gross margins not statistically analysed. The difference between the gross margins of 80N:20S and 80N:0S is therefore likely to be minimal as the yields of these treatments were not statistically different.



1 *Discolouration on older leaves 20 June 2017 caused by cold and dry conditions during June 2017*

2 *Yarrawonga trial site, 21 July 2017*

3 *Untreated control, 6 November 2017 when most seed black, but soft (GS6.7)*

4 *240N:0S treatment, 6 November 2017 when most seed black, but soft (GS6.7)*

TABLE 13 Fertiliser application rate, gross margin and sensitivity analysis for treatments at Yarrawonga, Victoria, 2017

Treatment	Urea application rate (kg/ha)	SOA application rate (kg/ha)	Gross margin ($/ha)	Gross margin# (canola price less 10%) ($/ha)	Gross margin# (fertiliser price plus 10%) ($/ha)
UTC	0	0	462*	386	
40N:0S	87	0	647	548	644
40N:10S	67	42	618	519	613
40N:20S	50	83	679	572	671
40N:30S	30	125	656	548	646
80N:0S	174	0	818	697	811
80N:10S	134	42	955	818	947
80N:20S	100	83	856	728	846
80N:30S	60	125	846	717	834
160N:0S	348	0	690	575	676
160N:10S	268	42	790	665	776
160N:20S	200	83	1020	870	1005
160N:30S	120	125	718	600	704
240N:0S	522	0	851	712	830
240N:10S	402	42	827	692	807
240N:20S	300	83	878	739	860
240N:30S	180	125	792	664	776

Gross margins not statistically analysed.

treatment was the most economic application of nitrogen and sulphur at either site.

The difference in optimum nitrogen fertiliser application rates for both sites highlighted the importance of understanding paddock history. Both the Yarrawonga and Howlong sites had maximum yields above 3t/ha, however, the Howlong site required 80kg/ha less nitrogen to achieve this yield. This was evidenced by yields in the Howlong UTC, which averaged 2.5t/ha compared with the untreated treatments at Yarrawonga, which averaged 1.5t/ha. This demonstrates how deep nitrogen testing and a knowledge of paddock history can be used to inform nitrogen decisions — in this example saving $167/ha.

Discussion

While the Yarrawonga site had only half the amount of mineral nitrogen than that measured at the Howlong site, soil mineral sulphur levels were approximately double at Yarrawonga compared with Howlong. Despite high background levels of sulphur (likely due to accumulation of sulphur from previous additions), the Yarrawonga site recorded clear sulphur responses, while these were not seen at the Howlong site. This suggests canola roots may not be effectively exploring the soil profile to access soil sulphur, or the accumulation of sulphur in the top 30cm may not supply adequate sulphur for the season.

There was a clear yield response to applied nitrogen and applied sulphur at the Yarrawonga site. The optimum level of applied sulphur at this site was 20kg/ha, with yield penalties above and below this level.

The movement of nitrogen to depth at this site is likely due to saturated soil conditions during 2016, which increased the movement of nitrogen to depth.

At the Howlong site applied nitrogen gave a yield and DM response, however there was no sulphur response.

Despite GSR being close to average for both sites during 2017, extremely dry conditions during June and September created challenges within these trials, although the absence of heat stress during pod fill and stored moisture from the 2016 season allowed canola to yield well. This trial will be repeated at two sites during 2018 to understand how variable the responses to sulphur are likely to be during different years.

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