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Assessing the benefits of using foliar N on oilseed rape

by

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CONTENTS

1. ABSTRACT

The specific objectives of this project were to:

1. understand whether late foliar N gives any yield advantage over and above optimal amounts of soil applied N such as ammonium nitrate.
2. identify the optimum timing and rate of foliar N.
3. quantify the efficiency with which foliar N is used by the crop
4. develop guidelines for the best use of late foliar N.

Field experiments were set up in 2008/09 and 2009/10 near ADAS Rosemaund, Herefordshire, and near ADAS High Mowthorpe, North Yorkshire. Each of the four experiments investigated six rates of soil applied N (ammonium nitrate) ranging from 0 to 280 or 320 kg N/ha with each treatment followed by zero or 40 kg/ha of foliar N applied as Nufol 20 (20% N) at the end of flowering. Each experiment also investigated five rates of foliar N ranging from 0 to 120 kg N/ha and five timings of foliar N from mid-flowering to two weeks after the end of flowering.

Foliar N at 40 kg N/ha increased the gross output by, on average, 0.20 t/ha across all experiments (range of 0 to 0.40 t/ha). This increase in gross output was achieved despite a reduction in the percentage oil content in the seed by an average of 0.9%. The gross output response was the same regardless of whether it followed sub-optimal or super-optimal rates of soil applied N, indicating that foliar N can increase yields over-and-above that achieved from optimal amounts of soil applied N. Similar yield responses were observed for foliar N applications between mid-flowering and two weeks after the end of flowering, which may indicate that foliar N could be combined with a fungicide spray during flowering. A foliar N rate of 40 kg/ha was found to be the maximum rate that should be used. Foliar N was usually taken up with a high efficiency of 70 to 100% and the resulting increase in post-harvest N residues was modest. It is recommended that foliar N should not be applied when the temperature is above 18°C. Yield responses were quite variable and further work is needed to identify environmental and crop factors that cause this variation. If minimal crop damage from applying foliar N is assumed then it may be concluded that, across a number of fields and seasons, applying foliar N at 40 kg N/ha will generally return a profit as long as the ratio of fertiliser cost (£ per kg of elemental N) to oilseed rape price (£/kg) is less than 3.0 when foliar N costs between £0.50 and £0.75 per kg of N, or the cost:price ratio is less than 3.5 when foliar N costs £0.80 to £1.00 per kg of N.

2. SUMMARY

2.1. Introduction

The benefits of foliar N applied to oilseed rape during flowering or early pod development as a means for increasing yield have been promoted by several sources within the agricultural industry. For example, yield responses to foliar urea applied at the end of petal fall of 0.5 to 1.6 t/ha have been reported in the popular farming press. At the time of writing this report the authors found no other independent information on the response of oilseed rape to late foliar N.

A key question is whether foliar N gives a yield benefit following optimal amounts of soil-applied N (e.g. ammonium nitrate). It is possible that the responses to foliar N that have been observed have occurred because the crops did not receive sufficient soil applied N before flowering. It is also not known at which growth stage foliar N should be applied, what the optimal rate is, or what type of crop may respond most. It will be important to understand whether foliar applied N could act as a substitute for late applications of soil applied N at yellow bud or early flowering as these can be taken up less efficiently in dry conditions and are difficult to apply to tall crops. The efficiency with which oilseed rape uses foliar N has not been measured and an understanding of this will be important for estimating the impact of foliar N use on N emissions to the air and water and its impact on the carbon footprint. Finally the impact of foliar applied N on seed protein has not been quantified which is important as it is usually inversely related to oil content.

2.1.1. Aim and objectives

Project Aim

To develop independent guidelines that describe how to make the best use of late foliar N applications on oilseed rape.

Specific Objectives

1. To understand whether late foliar N gives any yield advantage over and above optimal amounts of soil applied N such as ammonium nitrate.
2. To identify the optimum timing and rate of foliar N.
3. To quantify the efficiency with which foliar N is used by the crop
4. To develop guidelines for the best use of late foliar N.

2.2. Materials and methods

Field experiments were set up in 2008/09 and 2009/10 near ADAS Rosemaund (RM09 and RM10), Herefordshire, on a silty clay loam and near ADAS High Mowthorpe, North Yorkshire, on a silty clay loam (HM09 and HM10). The site codes (in brackets) are used in summary tables later in report. Experiments investigated six rates of soil applied N (ammonium nitrate) ranging from 0 to 280 or 320 kg N/ha, five rates of foliar N ranging from 0 to 120 kg N/ha (applied as Nufol 20, 20% N) applied at the end of flowering, five timings of foliar N from mid-flowering to two weeks after the end of flowering, and one rate of Omex Oilseed Extra (20 kg N/ha in 2008/09 and 40 kg N/ha in 2009/10). The rate of soil applied N required to achieve an optimum sized canopy at flowering was estimated using Canopy Management principles from measurements of soil mineral N and crop N in February. This soil applied N rate was either 160 or 200 kg N/ha and was followed by the foliar N rate and timing treatments. Each of the six soil applied N rates was followed by zero or 40 kg/ha of foliar N applied at the end of flowering. Foliar N was applied as Nufol 20 (20% N). A water volume of 100 l/ha was used for a foliar N rate of 20 kg N/ha, 200 l/ha for 40 kg N/ha, 400 l/ha for 80 kg N/ha and 600 l/ha for 120 kg N/ha. Soil mineral N levels and dates of fertiliser applications are described in Summary Table 1. Plots were 24m long x 3.5m wide and arranged in randomised blocks with all treatments replicated four times. Experiments were treated in spring with 75 kg/ha SO_3 as Kieserite to avoid sulphur limitation.

Measurements included: seed yield, oil content, leaf scorch, lodging, together with the biomass and N content of the seed, pod walls and stems. In 2010, thousand seed weight and seeds/m^2 were measured. Gross output was calculated to account for the combined economic effect of each treatment on seed yield and oil content using the equation below in which it is assumed that the oil bonus is 1.5% of the basic oilseed price for each additional percentage of oil content above a base level of 40%.

$$GrossOutput = 1.5\left(\frac{oilcontent - 40}{100}\right) * seedyield$$

Analysis of variance procedures within Genstat 12 (www.genstat.com) were used to calculate whether treatments were significantly different. Linear plus exponential N response curves were fitted to the seed yield and gross output data for each treatment and these were used to calculate the economic optimum N rate based on a breakeven ratio of 2.5:1.

Summary Table 1. Details of February SNS measurements, N rates and application dates for individual sites.

	HM09	RM09	HM10	RM10
Feb SMN (kg/ha)	14	19	32	24
Feb crop N (kg/ha)	65	37	50	58
Total SNS (kg/ha)	79	56	82	82
Soil appl N 1st split	16 March	05 March	23 March	11 March
Soil appl N 2nd split	7 April	19 March	21 April	30 March
Soil appl N 3rd split	21 April	08 April	11 May	19 April
Foliar N				
mid flower	10 May	22 April	19 May	14 May
mid flower +7d	21 May	29 April	27 May	21 May
end flower	4 June	24 May	11 June	2 June
end flower +7d	12 June	01 June	17 June	9 June
end flower +14d	21 June	08 June	25 June	16 June

SMN – soil mineral N, SNS – soil N supply (SMN + crop N)

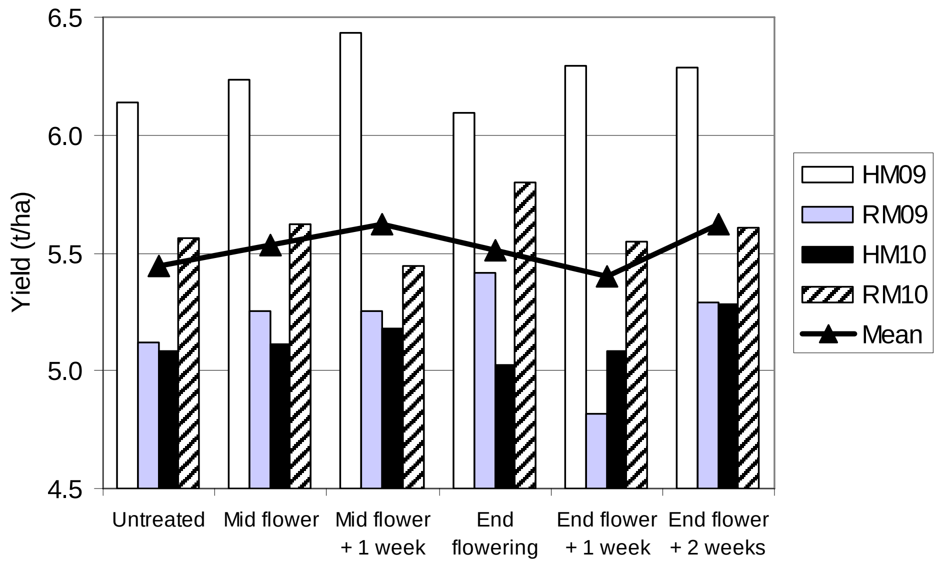
2.3. Results

2.3.1. Seed yield

The greatest yield responses resulted from increasing the soil applied N rate (ammonium nitrate) from zero to 80 or 100 kg N/ha, which increased yields by 1.42 t/ha on average. Increasing N rate by a further 80 to 100 kg N/ha increased yields by a further 0.65 t/ha on average. The economic optimum N rate for the soil applied N treatments without foliar N were 190 kg N/ha at HM09, 214 kg N/ha at RM09, 214 kg N/ha at RM10 and 174 kg N/ha at HM10. At these optimum N rates the seed yield was 6.11 t/ha at HM09, 5.12 t/ha at RM09, 5.09 t/ha at HM10 and 5.45 t/ha at RM10.

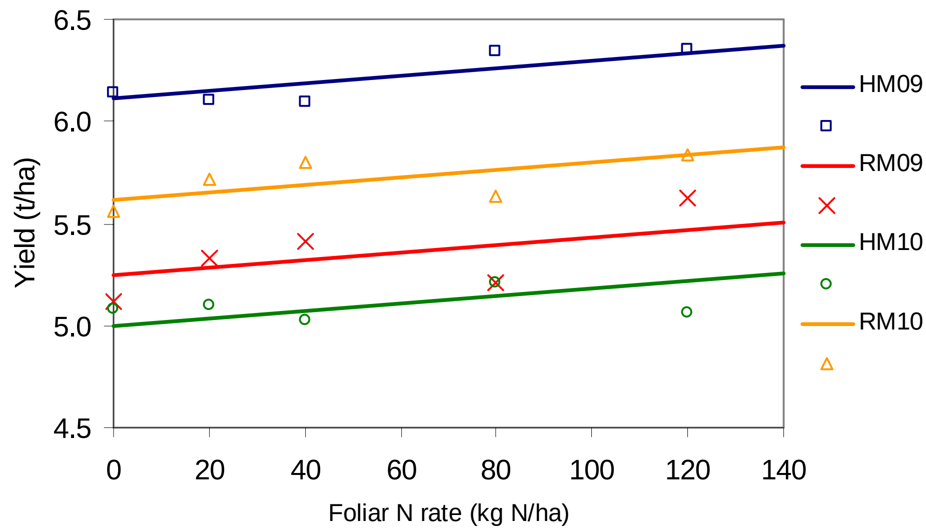
At HM09 the effect of foliar N applied at the end of flowering at 40 kg/ha interacted with the soil applied N rate ($P<0.05$) because the greatest yield increase of 0.72 t/ha was observed following a soil applied N rate of 80 kg/ha and smaller yield responses of up to 0.47 t/ha were observed following the other soil applied N rates. Foliar N increased yield by 0.24 t/ha on average across all soil applied N treatments at HM09. At RM10, a similar interaction was observed ($P=0.058$) to HM09 where the greatest yield response of 1.25 t/ha was observed in the absence of any soil applied N, with smaller yield responses of up to 0.32 t/ha following greater soil applied N rates. The average response to foliar N at RM10 was 0.41 t/ha. At RM09, there was no interaction between the soil applied and foliar N treatments and the average response to foliar N was 0.26 t/ha. At HM10, foliar N did not significantly affect yield.

The effect of foliar N timing between mid flowering and two weeks after flowering was investigated by applying a rate of 40 kg N/ha following a soil applied N rate of 160 kg N/ha at HM09, HM10 and RM10 and following 200 kg N/ha at RM09. There was no significant difference in yield response following the application of foliar N at the different timings at any site except RM09. The significant result at this site was due to a low yield following the 4th foliar N timing (7 days after end of flowering). This effect might be explained by warm weather on the day of application and the following day (max 26°C and 25°C respectively). At the same site, the other foliar N applications were applied on days with maximum temperatures no higher than 19°C. A cross site analysis revealed no consistent difference in the response of foliar N applied between mid flowering and two weeks after the end of flowering (Summary Figure 1), with an average yield response across all of the timing treatments of 0.11 t/ha.



Summary Figure 1. Effect of foliar N (40 kg N/ha) on yield, applied following soil applied N rates of 200 kg N/ha at RM09 and 160 kg N/ha at the other sites.

The effect of foliar N rate was investigated by applying rates of 0 to 120 kg N/ha at the end of flowering following a soil applied N rate of 160 kg N/ha at HM09, HM10 and RM10 and following 200 kg N/ha at RM09. At RM09, a foliar N rate of 120 kg N/ha increased yield by 0.5 t/ha ($P<0.05$), but lower foliar N rates had no significant effect. At the other sites there were no significant yield responses to foliar N applied at any rate (20 to 120 kg N/ha). A cross site analysis of variance revealed no consistent difference in the yield response to different rates of foliar N. The lack of significant effects from this dose response analysis, compared with the analysis for foliar N at 40 kg/ha, may be because the latter analysis was across several soil applied N rates which increased the amount of replication. Multiple linear regression analysis showed that the average yield increase per kg of foliar N was 0.002 t/ha and this was the same in each experiment (Summary Figure 2). Total Oilseed Extra applied at 20 kg N/ha at HM09 and RM09 and at 40 kg N/ha at HM10 and RM10 did not significantly increase yield following soil applied N rates of 160 or 200 kg N/ha; yield increases were up to 0.10 t/ha.



Summary Figure 2. Effect of foliar N rates on yield, applied at the end of flowering following soil applied N rates of 200 kg N/ha at RM09 and 160 kg N/ha at the other sites.

2.3.2. Oil content

Across all experiments increasing the soil applied N rate from 0 to 160 or 200 kg N/ha reduced oil content by 2.2% (Summary Table 2). Smaller reductions in oil content were observed when the N rate was increased above 160 or 200 kg N/ha.

Foliar N applied at the end of flowering at a rate of 40 kg N/ha significantly reduced oil content at HM09, RM09 and RM10 (Summary Table 2). At RM09 there was a significant interaction between foliar N and the soil applied N treatment because foliar N reduced oil content more at lower soil applied N rates than at high N rates. A cross site analysis showed a significant interaction between the foliar N and soil applied N treatments ($P<0.01$), and no interaction between site, foliar N and soil applied N, indicating that the interaction between foliar N and soil applied N was consistent across sites. Across sites, foliar N reduced oil content by 1.6% to 1.8% at soil applied N rates between zero and 160 to 200 kg N/ha, by 0.4% at soil applied N rates of 200 or 240 kg N/ha with no effect at greater soil applied N rates. In 2010, additional oil measurements were carried out on the foliar N rates at 20, 80 and 120 kg N/ha. These showed a negative linear relationship between increasing foliar N rate (0 to 120 kg/ha) and oil content with each additional kilogram of foliar N reducing oil percentage by 0.0324% at HM10 and by 0.0254% at RM10.

Summary Table 2. Oil content (%) for the factorially combined soil applied N and foliar N treatments.

Soil applied N rate (kg/ha)	Foliar N (kg/ha)	† Foliar N timing	HM09	RM09	HM10	RM10	Mean
0	0	0	53.0	49.0	48.5	49.3	49.9
80 or 100	0	0	52.5	48.2	46.0	48.6	48.8
160 or 200	0	0	50.3	46.4	46.5	47.4	47.6
200 or 240	0	0	49.2	46.0	44.7	46.1	46.5
240 or 280	0	0	49.1	45.1	45.0	45.6	46.2
0	40	3	51.7	47.3	46.8	47.0	48.2
80 or 100	40	3	49.8	47.2	44.4	46.7	47.0
160 or 200	40	3	50.0	45.7	43.0	45.3	46.0
200 or 240	40	3	49.7	44.7	44.8	45.4	46.2
240 or 280	40	3	48.4	46.2	45.7	45.0	46.3
Mean without Foliar N			50.8	46.9	46.2	47.4	47.8
Mean with 40 kg/ha of Foliar N			50.0	46.2	45.0	45.9	46.9
Grand Mean			50.4	46.6	45.6	46.6	47.4
	Soil appl	P Value	<0.001	<0.001	NS	<0.001	
	Soil appl	SED	0.59	0.41	1.26	0.59	
Foliar N		P Value	<0.05	<0.01	NS	<0.001	
Foliar N		SED	0.37	0.26	0.71	0.38	
Soil applied N x Foliar N		P Value	NS	<0.05	NS	NS	
Soil applied N x Foliar N		SED	0.83	0.59	1.71	0.84	

† Foliar N timings: 3 – end of flowering

2.3.3. Gross output (seed yield adjusted for oil content)

Gross output is the combined economic effect of seed yield and oil content as described in section 2.1. Increasing soil applied N increased gross output at all sites (Summary Table 3), however the increases in gross output were not as great as for seed yield because increasing soil applied N rate also reduced oil content.

Foliar N applied at the end of flowering at a rate of 40 kg N/ha significantly increased gross output at HM09, RM09 and RM10 (Summary Table 3). At RM09 and RM10 the average gross output increase to foliar N was 0.27 t/ha and 0.40 t/ha respectively. At HM09, there was a significant interaction between the foliar N and soil applied N treatments because foliar N increased yield by 0.62 t/ha at 80 kg N/ha, and by 0.44 t/ha at 200 kg N/ha, but had no effect at zero and the other soil applied N rates. Across all soil applied N rates the foliar N treatment increased gross output by 0.15 t/ha at HM09. Foliar N had no significant effect on gross output at HM10. A cross site analysis showed that the interaction between the soil applied N and foliar N treatments was not significant at the 95% level of confidence (P=0.087). A foliar N rate of 40 kg/ha applied at the end of flowering increased gross output by 0.20 t/ha across all sites and soil applied N rates of 0 to 240 or 280 kg/ha. However it should be recognised that there was also a highly significant 3-way interaction between site, soil applied N and foliar N treatments which showed that the effects of foliar N were not consistent between experiments.

Summary Table 3. Gross output (t/ha) for the factorially combined soil applied N and foliar N treatments.

Soil applied N rate (kg/ha)	Foliar N (kg/ha)	† Foliar N timing	HM09	RM09	HM10	RM10	Mean
0	0	0	5.08	2.57	3.65	4.30	3.90
80 or 100	0	0	6.11	4.62	4.91	6.00	5.41
160 or 200	0	0	7.08	5.31	5.58	6.17	6.04
200 or 240	0	0	6.93	5.34	5.46	6.09	5.96
240 or 280	0	0	7.09	5.22	5.60	6.01	5.98
0	40	3	4.86	2.89	3.73	5.57	4.26
80 or 100	40	3	6.73	5.06	5.00	6.20	5.75
160 or 200	40	3	7.01	5.52	5.25	6.26	6.01
200 or 240	40	3	7.37	5.38	5.49	6.29	6.13
240 or 280	40	3	7.09	5.57	5.68	6.24	6.14
Mean without Foliar N			6.46	4.61	5.04	5.71	5.46
Mean with 40 kg/ha of Foliar N			6.61	4.88	5.03	6.11	5.66
Grand Mean			6.47	4.66	4.96	5.88	5.49
	Soil appl	P Value	<0.001	<0.001	<0.001	<0.001	
	Soil appl	SED	0.111	0.128	0.116	0.224	
Foliar N		P Value	<0.05	<0.01	NS	<0.01	
Foliar N		SED	0.070	0.810	0.073	0.143	
Soil applied N x Foliar N		P Value	<0.01	NS	NS	0.073	
Soil applied N x Foliar N		SED	0.157	0.181	0.164	0.317	

† Foliar N timings: 3 – end of flowering

The use of foliar N did not affect the economic optimum soil applied N rate for gross output at HM09, RM09 or HM10. At HM09 and RM09 the N response data supported fitting parallel curves to the soil applied N and foliar N treatments. At HM10, a single response curve was shown to explain most variation because the foliar N treatment did not significantly affect yield at this site. At RM10, the N response data supported fitting non-parallel response curves to the soil applied N and foliar N treatments because foliar N caused a steeper response to the soil applied N treatments. The economic optimum soil applied N rates for gross output were 175 kg N/ha at HM09, 184 kg N/ha at RM09 and 237 kg N/ha at HM10. At RM10 the optimum soil applied N rate was 111 kg N/ha without foliar N and 84 kg N/ha with foliar N.

In 2010, additional measurements of oil content at the full range of foliar N doses enabled the effect of foliar N rate on gross output to be calculated. The maximum gross output occurred with a foliar N rate of 0 kg/ha at HM10 and 40 kg/ha at RM10. When the average oil response to foliar N across HM10 and RM10 was used to estimate the effect of foliar N rate on gross output across all four sites, then the greatest gross output increase occurred at a foliar N rate of 20 kg N/ha, with a smaller increase at 40 kg N/ha and reductions at 80 and 120 kg/ha.

2.3.4. N uptake

Foliar N applied at 40 kg N/ha at the end of flowering increased total N uptake by 42 kg N/ha at HM09 ($P<0.05$), 28 kg N/ha at RM09 ($P<0.001$), 37 kg N/ha at RM10, with no effect at HM10. The uptake efficiency of foliar N therefore ranged from 0 to over 100%, with an average across sites of 67%. At HM09, RM09 and RM10 foliar N increased N uptake by increasing the amount of N in the seed and pod wall (kg N/ha), which in turn resulted from increases in the biomass and N concentration of the seeds and pod walls. The reduction in the percentage of oil in the seed in response to foliar N was caused by a greater increase in protein yield (t/ha) than in oil yield (t/ha) which effectively diluted the oil content in the seed. On average, the increase in the N content of the crop residues following harvest as a result of 40 kg/ha of foliar N was 12 kg N/ha.

2.4. Discussion

Foliar N applied at the end of flowering at a rate of 40 kg N/ha increased seed yield by 0.41 t/ha at RM10, 0.26 t/ha at RM09, 0.24 t/ha at HM09 and had no significant effect at HM10. There was a tendency for foliar N to increase yield more when following nil or sub-optimal amounts of soil applied N. The economic benefits from increased seed yield from foliar N were reduced by a reduction in the percentage of oil within the seed of approximately 1%. The combined effects of foliar N on seed yield and oil concentration have been estimated in terms of the effect on gross output which takes account of the economic penalty of any reduction in oil concentration. Foliar N applied at the end of flowering at a rate of 40 kg N/ha increased gross output by 0.20 t/ha across sites, with a range of 0 to 0.40 t/ha between sites. The discovery that a similar response to foliar N occurs following a wide range of soil applied N rates, including super-optimal rates, indicates that foliar N can be used to increase yield to levels over-and-above those that can be achieved using optimal amounts of soil applied N at earlier timings.

The dose response study indicated that foliar N rates of 20 kg/ha and 40 kg/ha both gave a positive gross output response, with 80 and 120 kg N/ha giving negative responses. However, the yield responses at 20 kg/ha were not statistically significant, whereas the yield responses to 40 kg/ha were significant. Based on statistical significance this study can conclude that a foliar N rate of 40 kg/ha is the maximum rate that should be used.

This study has demonstrated that there can be quite large variation in the yield response to foliar N, particularly between sites, but also within the same field when applications were made on different days. There was no evidence that the growth stage at which foliar N was applied explained the variation and environmental or crop factors are the most likely cause of the variation. Regression analysis showed a weak negative correlation between the yield response and the air temperature at application with most yield losses occurring when the air temperature was 19^{o}C or more. Neither soil wetness, overhead conditions (sun or cloud), relative humidity nor time of day affected the size of the yield response. More research is required to quantify the effect of temperature on the yield response and to identify whether there are other environmental or crop factors which affect the yield response.

This study has indicated that late foliar N could give a greater yield response than soil applied N at yellow bud or early flowering (particularly in dry conditions). However, it should be emphasised that the foliar N yield responses also occurred following optimal or super-optimal rates of soil applied N which indicates that foliar N should be used as a treatment for increasing yields over-and-above those that can be achieved using earlier applications of soil applied N, rather than as a substitute for soil applied N. If conditions are predicted to be dry then it may be best to apply N to the soil earlier.

The unpredictable variation in yield response to foliar N means that it is difficult to carry out a reliable cost-benefit analysis. The full report describes several cost-benefit scenarios which use different assumptions about the gross output response to foliar N, the cost of foliar N, the price of oilseed rape, the cost of applying foliar N and yield losses caused by travelling through the crop. These analyses showed that the cost effectiveness of foliar N depended strongly on the assumptions used and decisions on whether it will be profitable should be calculated for each individual situation.

If an average gross output response to foliar N at 40 kg N/ha of 0.20 t/ha is assumed then the resulting cost benefit analysis is described in Summary Table 4. Yield losses from travelling through the crop are unlikely to be significant given that the majority of crops are desiccated anyway and many receive a fungicide spray during flowering. As a general guide when the fertiliser N cost is between £0.50 and £0.75 per kg of N then for foliar N to be profitable the ratio of fertiliser cost (£ per kg of elemental N): oilseed rape price (£/kg) must be less than 3.0. When the fertiliser N cost is between £0.80 and £1.00 per kg of N then for foliar N to be profitable the ratio of fertiliser cost: oilseed rape price must be less than 3.5.

Summary Table 4. Effect of foliar N cost and oilseed rape price on the gross margin over cost (£/ha) of using foliar N at 40 kg N/ha, assuming it increases gross output by 0.20 t/ha

Oilseed rape price (£/t)	**Cost of foliar N (£/kg)**					
	0.5	**0.6**	**0.7**	**0.8**	**0.9**	**1**
160	-1	-5	-9	-13	-17	-21
200	7	3	-1	-5	-9	-13
240	15	11	7	3	-1	-5
280	23	19	15	11	7	3
320	31	27	23	19	15	11
360	39	35	31	27	23	19
400	47	43	39	35	31	27
440	55	51	47	43	39	35

Cost of applying foliar N of £13/ha included within costs

2.5. Conclusions

- Guidance for using foliar N arising from this study includes:
    - When the foliar N cost is between £0.50 and £0.75 per kg of N then the ratio of fertiliser cost (£ per kg of elemental N) to oilseed rape price (£/kg) must be less than 3.0. When the foliar N cost is between £0.80 and £1.00 per kg of N then the ratio must be less than 3.5. Assuming application causes minimal crop damage.
    - Foliar N rates should not exceed 40 kg N/ha.
    - Apply any time between mid-flowering and 2 weeks after the end of flowering
    - Avoid applications when the air temperature is above 18^{o}C.
- Foliar N at 40 kg/ha significantly increased seed yield in 3 out of 4 experiments, but also significantly reduced the percentage oil content in the seed by an average of 0.9%.
- The reduction in oil content resulted in smaller responses in gross output compared with seed yield following foliar N. Gross output responses ranged from zero to 0.40 t/ha and averaged 0.20 t/ha across the experimental sites. The gross output response was the same regardless of whether it followed sub-optimal or super-optimal rates of soil applied N, indicating that foliar N can increase yields over-and-above that achieved from optimal soil applied N.
- Similar yield responses were observed for foliar N applications between mid-flowering and two weeks after the end of flowering. This indicates that foliar N could be combined with a sclerotinia spray. Further work should investigate whether foliar N could increase yield from applications at early flowering.
- Based on statistical significance this study can conclude that a foliar N rate of 40 kg/ha is the maximum rate that should be used, but further work is required to test whether it may be more economic to use less than 40 kg N/ha.
- Foliar N was taken up with an efficiency of 70 to 100% at the three sites where it increased yield significantly, with zero uptake at the unresponsive site.
- The effect of foliar N at 40 kg N/ha on post-harvest N residues was modest, giving an average increase of 12 kg N/ha.
- Variation in yield responses were observed, a modest amount of which was explained by temperature because many of the zero or negative responses occurred when foliar N was applied at 19^{o}C or more. Further work is needed to identify environmental and crop factors that cause variation in yield response.