Factsheet 08/13

Field Vegetables

Nitrogen recommendations for optimising yield and minimising nitrate levels in baby leaf salad crops

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This factsheet reports on experimental results and commercial observations from the FV 370 series of work. The aim of this work was to improve recommendations for fertiliser use in wild rocket (*Diplotaxis tenuifolia*) and baby leaf spinach (*Spinacia oleracea*). EU legislation stipulates nitrate limits for fresh produce and growers need to ensure nitrogen (N) applications do not cause crops to exceed these limits. This is particularly important for late season crops where small amounts of fertiliser may lead to high tissue nitrate concentration (TNC). Information is summarised on N requirement and the factors influencing TNC in these leafy crops. The research underlines the need to take soil mineral nitrogen (SMN) into account when determining crop fertiliser N requirements, particularly in vegetable rotations where a number of crops are grown in succession within a single season, each contributing to the build up of soil N supply to later crops.

Action points

- Follow the recommendations for N fertiliser laid out in this factsheet when determining crop N requirement.
- Pay particular attention to soil N supply based on previous cropping, and measure soil mineral N prior to drilling of each crop within the season.
- Prioritise testing for TNC on crops that are harvested late in the season (August/September), and/or when dull cloudy conditions have been experienced in the 10 days prior to harvest.
- Sample crops for TNC and SMN using representative sampling plans as you would use for collecting other plant tissue or soil samples.
- Adjust recommendations based on local circumstances, particularly if you have reliable estimates of crop N demand, and/or can reliably achieve low TNC, for example if you are on a light soil with low N supply, and can produce high yielding crops safely.
- Avoid excessive application of fertiliser on late season crops, particularly when following abandoned crops, or where following a succession of other leafy crops.

Nitrate as a contaminant

The European Commission (EC) sets maximum limits for contaminants in foodstuffs, Commission Regulation (EU) No 1258/2011 stipulates TNC for various leafy vegetables (see Information Box 1). Work has been carried out for many years on reducing TNC in traditional salad crops like lettuce. In 2012, limits were introduced for the first time for rocket which is a popular component of bagged salads, but unfortunately tends to accumulate very high levels of nitrate in the leaves. Tissue nitrate levels do not always correlate with sowing date or amount of nitrogen fertiliser applied (Table 1). However this factsheet explains how growers can exercise better control of nitrate levels, particularly through monitoring soil N supply.

Table 1. Tissue nitrate concentrations (TNC) for eight commercial wild rocket crops sampled in 2010 in the UK

County & site code	Kent 1	Norfolk 1	Sussex 1	Kent 2	Dorset 1	Wilts 1	Kent 3	Kent 4
Sowing date	27 April	03 June	21 June	15 June	12 July	12 July	22 July	13 July
Harvest date	10 June	06 July	14 July	13 July	11 August	11 August	18 August	19 August
Soil type	Brick earth	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Sandy loam	Brick earth
Applied N (kg N/ha)	116	100	98	86	146	100	90	135
Form of N fertiliser* (proportion of total N)	0.28 CS, 0.72 L	1.0 AN	1.0 CAN	1.0 CAN	0.45 CC, 0.20 CS, 0.35 CAN	1.0 L	0.33 CAN, 0.66 CS	1.0 CAN
TNC (mg/kg)	4,187	3,732	2,446	5,051	5,391	4,884	7,349	6,190

***Form of fertiliser: AN, ammonium nitrate; CAN, calcium ammonium nitrate; CS, compound solid; L, liquid/foliar; CC, calcium cyanamide (Perlka)**

Information Box 1

EU Limits for tissue nitrate concentration for various leafy vegetables, from Commission Regulation (EU) No 1258/2011

Foodstuffs	Maximum nitrate levels (mg nitrate/kg fresh weight basis)	
Fresh spinach (*Spinacia oleracea*)		3,500
Preserved, deep-frozen or frozen spinach		2,000
Fresh lettuce (*Lactuca sativa* L.) (protected and open-grown lettuce) excluding "Iceberg" types listed below	Harvested 1 October to 31 March:	
	Lettuce grown under cover	5,000
	Lettuce grown in the open air	4,000
	Harvested 1 April to 30 September:	
	Lettuce grown under cover	4,000
	Lettuce grown in the open air	3,000
"Iceberg" type lettuce	Lettuce grown under cover	2,500
	Lettuce grown in the open air	2,000
Rocket, rucola (*Eruca sativa, Diplotaxis* sp., *Brassica tenuifolia, Sisymbrium tenuifolium*)	Harvested 1 October to 31 March:	7,000
	Harvested 1 April to 30 September:	6,000

Environmental factors influencing nitrate levels in the crop

It has been shown with lettuce crops that dull conditions, particularly late in the season and in a wet summer, lead to high TNC levels. This is generally due to prolonged periods of dull weather in the 10 days prior to harvest, rather than a short term effect (up to 2 days prior to harvest are not significant). Growers should recognise that late season baby leaf crops e.g. those sown in July, will be most at risk of exceeding levels for TNC because days are getting shorter and hence light levels lower, by the time they are harvested in late August or early September. For such crops, it will be most important to test for high TNC before sending to market.

In laboratory studies it appears that there is diurnal variation in TNC, but there is little evidence for this in the field due to other confounding factors. Nevertheless, it is still a sensible approach to harvest crops early in the morning; firstly because the crop will be cool and can be stored and processed more effectively without risking deterioration and spoilage; secondly, because TNC is measured on a fresh weight basis, a well hydrated crop is less likely to have high TNC, which might otherwise be found due to wilting later in the day under hot, sunny conditions.

Achieving low soil N supply prior to drilling

Some growers routinely take SMN measurements in spring, while others assess soil N supply using the field assessment method (FAM). However, while these approaches are appropriate for the first crop grown in the season, such estimates of soil N supply become less useful for later sowings. This is because as soils warm up between February and April, soil organic matter and crop residues mineralise and supply further N to the crop. Build up of available soil N is a particular issue where there are successive sowings and fields are frequently irrigated, providing ideal conditions for continued mineralisation

into the summer. Growers should pay particular attention to ensuring low soil N supplies prior to drilling late-season crops, given the additional risk of low light levels affecting TNC in such crops. Table 2 shows how a SMN sample taken to 30 cm depth prior to drilling can be used to classify those crops which will respond to nitrogen. It shows that establishing first crops following a cereal in the previous season is helpful in minimising the risk of high TNC. Figures 1 & 2 show soil and tissue sampling equipment.

1. Soil auger for sampling

2. Equipment used for crop and soil sampling

Table 2. Gross yield responses to applied nitrogen for nine experiments conducted in commercial crops of wild rocket during 2011 and 2012 (not taking into account loss of marketable crop due to high TNC in some cases)

Location	Year	Cropping in previous season	Previous cropping in test season	SMN to 30 cm depth prior to drilling	Yield response (fresh weight of crop) to applied N fertiliser (kg N/ha)
Sites showing positive response to N					
Norfolk 2	2011	Wheat	None	52	Response to 220
Sussex 2	2011	Wheat	Rocket	63	Response to 220
Norfolk 3	2012	Wheat	None	36	Response to 120
Shropshire	2012	Wheat	Rocket	39	Response to 100
Sites showing no response to N					
Wiltshire 2	2011	Grass/clover	Rocket (2x)	182	No response
Sussex 3	2011	Wheat	None	106	No response
Dorset 2	2011	Salad crops	Lettuce	84	No response
Dorset 3	2011	Salad crops	Lettuce	205	Yield decline
Kent 5	2012	Salad crops	Spinach	143	No response

Although current advice (Factsheet 09/12) is to avoid taking SMN samples within 2 months of last fertiliser application, this is often unavoidable in leafy salad crops where multiple cropping takes place. Currently, SMN sampling is the best way of estimating the amount of available N for these crops, and the results in Table 2 show how useful these can be in predicting where there will be a yield response to N. If SMN samples cannot be taken, it is advised that SNS Index estimated by FAM should be increased by at least 1 and possibly by up to 4 index values, for the second and third crops sown within the season.

It should be noted that despite the results in Table 2 indicating yield responses at two sites at up to 220 kgN/ha, at these levels of applied N, TNC would have exceeded the limit of 6,000 mg/kg for summer-grown rocket.

Sampling for tissue nitrate concentration

There is significant spatial variability in TNC within fields. For example in 2010, one field of wild rocket contained samples which ranged between 2,428 and 5,376 mg/kg. Acceptable measures of TNC in rocket crops can be achieved from bulked samples of ten quadrats (measuring at least 25 cm x 25 cm) sampled in 'W' or 'X' shaped sampling patterns. Plants should be cut off at ground level, Figure 3 shows a crop of wild rocket being sampled. Samples should be taken from distances of at least 25 m along several different beds, and each aggregated sample should contain at least 1 kg of fresh produce. An aggregate sample of this size should also represent a block of ground of no more than 2 ha. If larger fields than this are sampled, then the field should be divided into smaller areas, and a separate aggregate sample sent to the labs, for each of those areas.

3. Sampling a wild rocket crop

Crops should be sampled early in the morning, while they are cool and well hydrated and immediately placed in a plastic bag and sealed to prevent moisture loss, before placing in a cool box or polystyrene container, with a means of keeping them cold (freezer blocks, or pre-frozen 100 ml bottles of water work well) to prevent heating. If samples are heavily contaminated with soil, they should be rinsed clean with water, and gently blotted dry before being placed in the clean plastic bag, resealed and placed in the cool box.

It is important that samples stay cool between sampling and analysis, and should not be left in a warm vehicle prior to dispatch to the lab. If samples begin to breakdown, they can give erroneous TNC readings due to the breakdown product, nitrite, interfering with the nitrate measurement. The Commission Regulation states that samples should be transported to the laboratory within 24 h of harvest. Therefore the samples should be collected by the courier on the same day as harvest, and ideally transported to the lab overnight, to increase the chance of the samples remaining cool. Further details of official sampling guidelines can be found in Commission Regulation 1882/2006.

Tissue nitrate concentrations in baby leaf crops

Tissue nitrate concentrations in wild rocket

All wild rocket crops whether they respond to N or not in terms of yield, are at risk of exceeding the limits for TNC. It can be seen that when no N is applied, TNC is always safely below the 6,000 mg/kg limit (Table 3). However as soon as fertiliser N is applied, TNC rises very quickly. For example, the crop from the Sussex 2 site in 2011 which had only 63 kg N/ha of SMN to 30 cm depth prior to drilling, and a strong response to applied N, was close to the limit for TNC at 5,682 mg/kg, with only 80 kg N/ha applied. This was principally because it was a late season crop and suffered from low light levels prior to harvest.

Table 3. Tissue nitrate concentration at three levels of applied N fertiliser for nine experiments conducted in commercial crops of wild rocket during 2011 and 2012

Location	Year	Fertiliser N rate				
		No N	Mid N		High N	
		TNC (mg/kg)	N (kg N/ha)	TNC (mg/kg)	N (kg N/ha)	TNC (mg/kg)
Norfolk 2	2011	832	80	4,444	120	5,524
Sussex 2	2011	654	80	5,682	120	6,968
Norfolk 3	2012	450	120	4,517	170	5,198
Shropshire	2012	1,392	50	3,668	100	5,431
Wiltshire 2	2011	1,200	40	3,117	120	4,426
Sussex 3	2011	2,216	40	4,783	120	6,202
Dorset 2	2011	4,252	40	5,738	120	6,206
Dorset 3	2011	5,060	40	5,413	120	5,475
Kent 5	2012	3,693	50	4,931	100	5,096

Tissue nitrate concentrations in baby leaf spinach

Up until 2011, a number of commercial UK spinach samples exceeded the limit for TNC in each season. However since the limits were relaxed in 2012 (Information Box 1), the maximum TNC set for fresh spinach is higher than it was historically, and hence the risks of exceeding the limits are substantially reduced. In 2012, at three sites where the response of baby leaf spinach to fertiliser N was examined, no samples exceeded the maximum limit for TNC set in the Regulation of 3,500 mg/kg (Table 4).

Table 4. Tissue nitrate concentration at three levels of applied N fertiliser for three experiments conducted in commercial crops of baby leaf spinach during 2012

Location	Year	Fertiliser N rate				
		No N	Mid N		High N	
		TNC (mg/kg)	N (kg N/ha)	TNC (mg/kg)	N (kg N/ha)	TNC (mg/kg)
Dorset 4	2012	78	60	537	110	1,626
N Wales	2012	213	60	1,351	110	1,900
Kent 6	2012	1,888	50	2,581	100	2,624

Fertiliser N recommendations

Based on the N response experiments over two seasons with wild rocket, the following advice can be used to guide application of fertiliser N:

- When second crops are sown in situations where the soil contains appreciable crop residues, where soil N supply prior to drilling is >100 kg/ha the N requirement is likely to be low.
- For early season crops, particularly those following cereals, or other crops which leave small residues, N requirements are likely to be greater.
- Where soil N supply is expected to be very low (<20 kg N/ha) on light soils, with low levels of soil organic matter or crop residues, applications of up to 120 kg N/ha may be justified for maximising crop yield, but there may still be a risk of exceeding the limits for TNC.

Recommendations are possible where an assessment of soil N supply is made prior to drilling. Suggestions as to how these assessments can be interpreted, are given below.

Fertiliser recommendations for wild rocket based on calculated N balance

With information on crop growth, N demand, and estimates of the proportion of soil and fertiliser N recovered by the crop, fertiliser recommendations can be devised as follows:

- **Estimating crop N demand**

  Clearly crop yields vary markedly from farm to farm, and between successive sowings. The best way of estimating crop N demand is to measure yield, by weighing the crop harvested from a known area of ground, and to send a sample for total nitrogen analysis. Maximum fresh weight yields at each site from the nine N response experiments across two seasons varied between 10 and 31 t/ha. Correspondingly N offtake varied in these experiments between 58 and 192 kgN/ha. On average across the nine sites, wild rocket had a total N offtake of around 113 kg N/ha, based on 0.56% N on a fresh weight basis (7% on a dry basis), and an average fresh weight yield of 20 t/ha.

- **Estimating soil N supply**

  As shown in Table 2, measuring SMN to 30 cm depth just prior to drilling gives a good estimate of soil supply further N will be available from the mineralisation of soil organic matter. As an estimate, the Fertiliser Manual gives a value of 22 kg N/ha mineralisable N for a crisp head lettuce crop (RB209, Appendix 10).

- **Recovery of N by the wild rocket crop**

  SMN measured to 30 cm depth was recovered on average with 89% efficiency at those sites where a positive response to N fertiliser was seen, and fertiliser N recovery was 60%, similar to other vegetable crops named in the Fertiliser Manual. However given the relatively small dataset, it is assumed here that the wild rocket crop typically can recover 100% of the available SMN in the rooting zone, as is the case for other crops.

Using these parameters, the N requirement can then be estimated as follows:

Recommended N (kg/ha) = (113 - (SMN + 22)) / 0.6

Examples are shown in Table 5.

For each of the nine N recommendations in Table 5, the nitrate level in the harvested crop would have been safely below the maximum limit for TNC of 6,000 mg/kg currently set in the EU regulations. However it should be noted that three sites exceeded 5,000 mg/kg for TNC. This is not a problem at the present time, but growers should be aware that should the limits for TNC be tightened at some point in the future, the N recommendations presented in this factsheet will need reducing.

There is one anomalous recommendation in Table 5: Dorset site 2 had a predicted fertiliser requirement of 12 kg N/ha, but gave no significant response to N in the field experiment (Table 2). This can be explained by the facts that its average yield was low (14 rather than the 20 t/ha used in the calculation, and hence its N demand was lower), and/or the soil supplied a greater amount of N than was predicted. For these reasons, the recommended N level was effectively zero for this crop. This site also had the highest TNC at the recommended N rate. This is one instance whereby the N recommendation might have been adjusted down, based on an assessment of crop growth during the season.

Table 5. Recommended fertiliser N rates calculated for nine wild rocket crops, using an average N demand (113 kg N/ha), apparent recoveries of fertiliser N (60%) and SMN (100%) measured to 30 cm depth prior to drilling, plus a fixed quantity of N (22 kg N/ha) supplied from mineralised organic matter from the studies in 2011 and 2012

Location	SMN to 30cm depth (kg N/ha)	Soil supply including 22 kg N/ha from mineralised SOM	Net requirement to be met by fertiliser (kg N/ha)	Recommended fertiliser N assuming 60% recovery (kg N/ha)	TNC (mg/kg) at recommended N rate[a]
	Sites showing a positive response to N				
Norfolk 2	52	74	39	65	4,179
Shropshire	39	61	52	87	5,072
Norfolk 3	36	58	55	92	3,321
Sussex 2	63	85	28	47	4,296
	Sites showing no response to N				
Sussex 3	106	128	0	0	2,126
Wiltshire 2	182	204	0	0	1,200
Dorset 2	84	106	7	12[b]	5,255
Dorset 3	205	227	0	0	5,060
Kent 5	143	165	0	0	3,693

[a] TNC at each level of applied N estimated by interpolating between measured values in N response experiments (FV370a and FV370b).
[b] Even though a small requirement of 12 kg N/ha is indicated, the Dorset 2 site showed no significant response to applied N in field experiments (see Table 2)

Fertiliser recommendations based on SNS Index

These guidelines can be placed broadly in the context of the soil nitrogen supply (SNS) index system as described for field vegetables in Factsheet 09/12. For first-sown crops, SNS can be estimated using the field assessment method (FAM), based on previous cropping, soil type and excess winter rainfall, or by measurement of SMN prior to drilling. However, for crops sown in the second or third position within a season, the FAM is not appropriate. SNS Indices estimated using the FAM, are likely to need adjusting by up to 4 indices higher compared to the first crop within the season (if for instance a preceding crop has been abandoned and ploughed in). In such cases SNS is best estimated by measuring SMN close to, and prior to planting.

SNS Index in the Fertiliser Manual (RB209) is based on soil mineral N to 90 cm. For field vegetable crops SNS Index can be based on soil mineral N content to rooting depth which for baby leaf salads would be 30 cm. The mineral N figures for each SNS Index in Table 6 are scaled down to the rooting depth of baby leaf salads. Figure 4 shows a nitrogen response trial in a commercial crop.

Table 6. Nitrogen recommendations[a] (kg N/ha) to maximise gross yield of the wild rocket crop, based on SNS Indices from RB209 and SMN measured to 30 cm depth

SNS Index	0	1	2	3	4	5	6
SMN (kg N/ha) to 30 cm	<20	20- 27	28-33	34-40	41-53	54-80	>80
N recommended[b]	125	115	100	90	75	40	0

[a] The recommendations in the table are based on a crop with a fresh wt yield of 20 t/ha with an N offtake of 113 kg/ha N. Mineralisation from SOM is estimated to be 22 kg/ha. Soil N recovery is 100% and Fertiliser recovery = 60% (as in the Fertiliser Manual RB209). For details see Box 4 in Factsheet 09/12.
[b] Recommendations may need to be revised down if there is a risk of exceeding TNC e.g. for late season crop grown under dull conditions.

4. Nitrogen response experiment (centre) laid out within a commercial spinach crop

Baby leaf spinach

Nitrogen responses of baby leaf spinach were studied at three sites in 2012. The guidelines devised above for wild rocket can be applied to baby leaf spinach. However if using the calculation method (Table 5), the average N demand in spinach was lower (69 kg N/ha) than that of rocket, and apparent recovery of SMN to 30 cm depth also lower (56%), which may reflect a shallower rooting depth of baby leaf spinach. Given the limited data set, it is best to assume that the recovery of fertiliser N is the same as other vegetable crops (60%). No spinach crop was in danger of exceeding the limit for TNC (3,500 mg/kg), even at the highest N rates (110 kg/ha) applied in the experiments.

Further information

HDC Project FV 370 Wild rocket: N response studies to manage and reduce nitrate levels.

HDC Project FV 370a Wild rocket: Managing and reducing nitrate levels.

HDC Project FV 370b Wild rocket and baby leaf spinach: Impacts of nitrogen and phosphorus fertiliser applications on yield and quality.

HDC Project FV 345a Soil nitrogen supply for field vegetables.

Factsheet 09/12 Soil nitrogen supply for field vegetables.

Fertiliser manual (RB209 8th Edition) Defra 2010.

EC Sampling Regulation 2006. Commission Regulation (EC) No 1882/2006 of 19 December 2006 laying down methods of sampling and analysis for the official control of the levels of nitrates in certain foodstuffs. Official Journal of the European Communities. L364:25-31.

EC Nitrates Regulation 2011. Commission Regulation (EU) No 1258/2011 of 2 December 2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for nitrates in foodstuffs. Official Journal of the European Union. L320:15-17.

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Notes

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