Project title:	Quantifying over-winter nitrogen requirements of the leek crop
Project number:	FV 350a
Project leader:	Richard Weightman, ADAS UK Ltd
Report:	Final report, November 2014
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Location of project:	ADAS Gleadthorpe, and growers holdings, North Nottinghamshire
Industry Representative:	Keith Mawer, Strawsons Ltd, Bilsthorpe, Nottinghamshire
Date project commenced:	1st April 2013
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DISCLAIMER

The results and conclusions in this report are based on an investigation conducted over a single season. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

We declare that this work was done under our supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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GROWER SUMMARY

Headline

- Up to 100 kgN/ha of supplementary N, (in addition to RB209), applied in early autumn increased marketable crop yield.
- However, 100 kgN/ha supplementary N may leave appreciable crop residues and soil mineral nitrogen after harvest, which need to be factored in before fertilising the next crop (see HDC Factsheet 09/12 Soil Nitrogen Supply for field vegetables).

Background

In recent years, our understanding of the nitrogen (N) requirements of leeks has improved because of HDC funded work. Project FV 350 broadly validated the revised fertiliser recommendation for modern F1 hybrid leeks within the 2010 version of the Fertiliser Manual (RB209). The Manual states that no more than 100 kgN/ha should be applied in the seedbed to leek crops. The remainder of the N should be applied as a top-dressing when the crop is fully established, but recognises that an additional top-dressing of 100 kgN/ha may be required on all soils except peat, depending on the appearance of the crop, to support growth and colour. This additional 100 kgN/ha would often be applied in the autumn/winter closed period for fertiliser applications.

Under NVZ rules, no N should be applied to leeks during the closed period (1st September – 15th January) unless supported by written advice from a FACTS qualified advisor. Given the increased scrutiny of N applications under NVZ rules, and the recent setting of Nmax values for vegetables, there is a need to better understand the N requirement of leeks, particularly from October through to harvest the following spring. The information from these experiments aimed to provide guidance on how to match fertiliser applications to crop N requirements of over-wintered leeks, based on assessments of crop N status, and soil mineral nitrogen (SMN) prior to application of fertiliser.

The objectives were to:

a) establish three field experiments within commercial leek crops, representing early, mid and late maturity crops,

b) study the effects of timing and rate of N applied as well as the effect of a nitrification inhibitor during the over-winter period on leek yield,

c) measure the marketable yield, biomass and total N uptake by the three leek crops in the 2013/14 winter period,

d) measure return of N to field in non-marketable crop and hence value to following crops,

e) measure residual SMN after harvest, and hence assess use of additional nitrogen applied and its potential benefit to following crops,

f) assess the usability of crop N status and SMN measurements as tools to predict the benefits from over winter applied fertiliser N.

Summary

Materials and methods

Work was carried out in three different commercial leek crops, representing early, mid and late maturing varieties in the 2013/14 season. All crops were grown on light sand land sites in North Nottinghamshire, with low soil nitrogen supply (SNS) indices in the range 0 to 2, where positive responses to N fertiliser would be expected.

Up until the end of September 2013, and before applying any supplementary N, crops were fertilised with commercial application rates (guided by RB209). Nil N areas were also retained in each field to gain a measure of SNS during the autumn and winter periods, and at the end of the experiment.

Experimental treatments assessed responses to both the rate of supplementary N (up to 100 kgN/ha for early and mid maturity crops, and up to 150 kgN/ha for the late maturity crop) and its timing (fertiliser N applied in 50 kg/ha increments) on marketable yield, non-marketable crop fractions, and total N offtake (and hence N requirements).

Immediately before each application of supplementary N, a measurement of crop N status and SMN was made, the last being in March 2014 for the late maturing crop (subsequently harvested in April 2014). At final harvest, crops were processed into marketable and unmarketable fractions according to a commercial protocol.

It should be noted that the results are based on a single mild season, in previous work (FV 350) too much N led to an increased risk of frost damage in colder winters.

Effects of the main N application

At the early and mid maturity leek sites, the main N application (the ‘control’ application for experimental purposes) by the grower increased marketable yields by 28 and 13 t/ha respectively compared to yields of the nil N areas of the crop. These observations broadly support the recommendations given in RB209.

At the late maturity site, however, there was no increase in yield in response to the main N application. With an initial SNS index of 2, a positive response to N would have been expected. Interestingly, SMN stayed about 10 kgN/ha higher in the leek rooting zone (0-60 cm depth) in the late maturity crop compared to the early and mid crops, from the end of the summer, and through the autumn and winter period. Perhaps more significantly, the late maturity crop had a much lower total N uptake in October compared with the other two crops suggesting that its slower rate of development represented a lower N requirement early in the season. Information in the literature on patterns of growth and N accumulation in different leek maturity types remains scant. Furthermore, the leek type selected for the timing of maturity scheduling is not accounted for in RB209.

Nitrogen economy of the crop

The leek crops took up appreciable quantities of N during the autumn/winter periods, based on the measured uptakes of N in the supplementary treatments. This was also the case for the late maturity crop, which showed no yield response to the main N application. Total N uptake was significantly increased by supplementary N, and was 50 kgN/ha greater in the early and late crops, and 75 kgN/ha greater than the control in the mid maturity crop. The important question however is whether this uptake is beneficial to yield or the appearance / quality of the crop, or whether it just leads to more N in crop or soil residues; this may have deleterious effects for the environment if the following crops do not make use of it.

Effects of supplementary N application on marketable yields

Taking into account the supplementary N treatments, there was only a small effect on total fresh weight yield when the effects were averaged across the different timings and N rates, but supplementary N always increased the yield of marketable plants.

When the individual supplementary N treatments were studied in more detail, timing of application appeared to affect the proportion of marketable plants. In all experiments, the main reason for the improvements in the proportions of marketable plants was a reduction in the number of undersized plants rejected (based on shaft thickness).

Across the three crops, the results can be summarised as follows with respect to supplementary N applied during autumn/winter:

- Supplementary N in October (50 kg/ha) gave a higher proportion of marketable plants than in November,
- Where 50 kg/ha N was applied in November or later, the proportion of marketable plants decreased.

- There was no significant effect of the rate of supplementary N applied, but an indication in the late crop that 100 kgN/ha or more N decreased marketability.
- Entec (100 kgN/ha) applied at the start of autumn only showed small benefits in terms of marketable yields.

NB Control treatments (figures in parentheses show Fertiliser Manual recommendations): Early site, 202 (200) kgN/ha; Mid Site, 240 (200) kgN/ha; Late Site, 183 (170) kgN/ha.

N residues left after harvest

Supplementary N increased the N offtakes by the marketable crop, but also increased the N in the unmarketable crop fractions and residues. It also increased residual SMN left after harvest. Applying 50 kgN/ha as supplementary N left on average 45, 17 and 36 kgN/ha, whereas applying 100 kgN/ha left 210, 67 and 128 kgN/ha (0-90 cm depth) for early, mid and late maturity crops respectively, compared to the control in each experiment. This is additional to the N left in crop residues and unmarketable fractions of the crop referred to above. Clearly if this N is not taken into account when making fertiliser recommendations for the following crop, then such supplementary N treatments pose a risk of diffuse pollution on these light soils in the subsequent season, if not captured by the following crop.

The following crop can benefit directly by requiring less fertiliser N itself because of a higher SNS, or after processing vegetable wastes through an anaerobic digester, with N being returned in digestate. The gap between harvesting the leeks and establishing the future crop will dictate how much N will be of benefit on these light sands (see HDC Factsheet 09/12 Soil Nitrogen Supply for field vegetables, Rahn 2012).

Measurements of crop and soil N status

Measurements of crop N status and chlorophyll concentration index (SPAD readings) were able to detect differences between nil-N and control treatments, but were not useful for discriminating between the control and supplementary N treatments. In other words, these measures were not useful in identifying those crops which might respond to supplementary N in the autumn/winter period. This might be because even where adequate N status is measured, at a single point in time, it cannot anticipate potential growth and hence predict future crop N requirement. However where CNS is consistently high, this indicates that further N may not need to be applied. To do so may increase the susceptibility of the crop to frost damage and hence appreciable economic loss.

The leek crops did appear to have a crop N requirement (based on evidence from total N uptake) but since it did not have a significant impact on total fresh weight or marketable yield, this should be considered ‘luxury’ uptake.

Conclusions

Fifty kgN/ha applied in early autumn (October/November) to the early crop increased the proportion of marketable plants. There was no evidence, however, that applying this supplementary N in late winter/early spring was beneficial for this crop. There was evidence that applying 100 kgN/ha in early autumn was beneficial to marketable FW yields (but not proportion of crop harvested) in the early crop, but at such levels of application, appreciable amounts of SMN and crop residue N were left after harvest. These residues of N would need to be taken account of when fertilising the next crop.

For the mid maturity crop, the comparable supplementary N treatment actually had 90 kgN/ha applied in total above the RB209 recommendation (40 kg/ha by the grower + 50 kgN/ha supplementary N). This was beneficial to marketable yields and did not leave excessive SMN behind after harvest. The largest responses to supplementary N were seen in the mid maturity crop. However there was no benefit of supplementary N for the late crop.

These results are in line with the guidance in the Fertiliser Manual that up to 100 kg N/ha may be beneficial in the autumn. The main N application as recommended in the Fertiliser Manual is about right, but selected cropping situations warrant further study; for example, to more effectively manage N applications for the slower growing late harvested crop.

This research underlines the fact that leek growers need to take advice before applying supplementary N in the autumn, particularly in NVZ areas.

Financial Benefits

Based on an average increase in marketable yields of 12 t/ha where a yield response to 50 kgN/ha of supplementary N was seen, a price of N at £1/kg N, and trimmed produce in trays ex-packhouse at £850/t, the financial benefit would be over £10,000/ha. However, all crops clearly took up N in the over winter period, and there is a risk that the crops could be more susceptible to frost damage in a hard winter. Excess N applied in the autumn could cause a crop loss equivalent to £21,000/ha based on an average marketable yield of 25 t/ha.

Action Points

- Follow the recommendations provided in the Fertiliser Manual (RB209) when deciding on the main N application to the leek crop,
- Leeks appear to respond to up to 100 kgN/ha of supplementary N in early autumn (October/November), which can be used to increase the proportion of marketable plants and/or marketable yields,
- There is an indication that late maturing crops may not need this N until later in their growing season, so it may be sensible to delay such applications until after the main danger of frost has passed, however in this study, late applications of N appeared to reduce the proportion of marketable plants,
- There appears to be little benefit in using an N fertiliser product containing a nitrification inhibitor to provide supplementary N, as it may not release the N quickly enough to benefit the crop in October/November,
- Measurements of crop N status appear to have some potential to identify crops with no further fertiliser N requirement, but more information is needed on CNS of different maturity types in relation to their patterns of growth before they can be used as diagnostic tests to predict the benefits of applying supplementary N,
- If applying supplementary N in the closed period then a FACTS qualified advisor must provide a written recommendation,
- Despite the potential benefits, crops over-fertilised with N can become more frost sensitive. The experiments described here were carried out in a very mild winter, with no major periods of frost or snow, but if the winter had been harsh, then marketable yields could well have been lower with supplementary N,
- Take into account the N from crop residues and unmarketable plants and any residual SMN from supplementary N applications when making fertiliser recommendations for the following crop (see HDC Factsheet 09/12 Soil Nitrogen Supply for field vegetables).

SCIENCE SECTION

Introduction

Leeks are a shallow rooted crop, and often grown on very light soils, which makes the efficient management of N a challenge. Moreover it has been suggested they have exhibit lower levels of biomass production per unit of leaf N than other than other field vegetable crops (van der Werf et al. 1996). Experiments carried out in the 1980s demonstrated favourable yield responses in leeks to very large amounts of spring applied N fertiliser (e.g. >500 kgN/ha; Goodlass et al., 1997). However, large amounts of N fertiliser are becoming increasingly difficult to justify against legislation on N use particularly in Nitrate Vulnerable Zones (NVZ).

In more recent experiments, yield responses at up to 375 kgN/ha applied have been seen (Smith et al., 2001), although the amounts applied in the UK are less than typically applied on the continent (Rahn and Lillywhite, 2011). Growers here still apply large amounts of N in the early phase of growth, with a maximum of 200 kgN/ha recommended by the Fertiliser Manual (RB209) at Soil N Supply (SNS) Index 0, albeit with the option of up to 100 kgN/ha applied during the over winter period to maintain growth and colour of the marketed crop (Defra, 2010).

Anecdotal evidence suggests that the use of a nitrification inhibitor in a product such as EnTec 26 might allow a slower release of N, such that two 50 kgN/ha doses could be replaced by a single 100 kgN/ha application, thus reducing the number of passes through the crops and hence cost; additionally there may be a reduction in nitrate leaching over winter. However there are no published data to underpin the use of such products.

In recent years, our understanding of the nitrogen (N) requirements of leeks have improved through HDC funded work. Rahn and Lillywhite (2011) broadly validated the revised fertiliser recommendation for modern F1 hybrid leeks within the 2010 version of the Fertiliser Manual (Defra 2010). The responses to additional N were variably affected by both harvest date and season.

The two seasons where FV 350 was carried out were affected by two severe winters. Results from FV 350 justified the application of additional fertiliser N in August and September, but no crop survived to the spring in the first season. It was concluded that given the increased scrutiny of N applications during the closed period under NVZ rules, there is a need to better understand the requirement of leeks for N particularly from October through to harvest the following spring.

In FV 350, measurements of crop N status and chlorophyll content were made in order to assess whether there was a method which could be used to identify whether the leek crops were over or under-fertilised. However van Geel and Radersma (2006) suggested that a mixture of measurements both on the crop (i.e. crop N status estimated using a light reflectance measurement 'Crop Scan' sensor, combined with a growth model) and the soil, would be needed to assess N status.

In the present project, three field experiments were established in the 2013/14 season, to assess the responses to both the rate of N applied (up to 150 kgN/ha) and timings (fertiliser N applied in 50 kg/ha increments) on marketable yield, non-marketable crop fractions, and total N offtake (and hence N requirements) of leeks. In addition at each site, a treatment was included in the experimental design, to examine the effect of nitrification inhibitor (applied with a rate of 100 kgN/ha). The information from these experiments was intended to provide guidance on how to match fertiliser applications to crop N requirements of over wintered leeks, based on assessments of crop N status, chlorophyll measurements, and soil mineral N prior to application of fertiliser.

Materials and methods

All work was carried out in commercial leek crops on light sandy soils in North Nottinghamshire, which were most likely to show responses to late applied N without complicating factors such as mineralization of N from soil organic matter. Prior to crop establishment, assessments were made of soil mineral nitrogen (SMN) to 90 cm depth from each trial site. Site details are summarised in Table 1.

Table 1. Growing details and sites summaries for three leek crops of contrasting maturity grown in the 2013/14 season.

	Early maturity	**Mid maturity**	**Late maturity**
Previous crop 2011	Leeks	Potatoes	Sugar beet
Previous crop 2012	Winter wheat	Winter wheat	Winter wheat
Date leek crop drilled in 2013	19th April	7th May	1st May
Variety	Lexton	Belton	Triton
SMN in spring to 90 cm depth (kgN/ha)	49 (SNS Index 0)	46 (SNS Index 0)	82 (SNS Index 2)
Total N applied by grower (kgN/ha)*	202 (200)	240 (200)	183 (170)
Date last N applied by grower in 2013	10th September	8th August	9th September
Date harvested in 2014	27th January	24th February	7th April

*, N applied by grower represents main N application; further details in individual crop descriptions below RB209 rates are shown in parenthesis.

All pesticides and other plant nutrients were applied by the host growers, based on best farm practice. At each site, experimental plots were 5m long, and the 1.8m wide (representing the width of one bed containing 4 rows of crop). In addition a length of 1m was left between treatment plots as discard, and one bed width as discard around the whole trial.

Early maturity crop

The experiment was designed to test the effects of extra N applied in the early winter period to an early spring harvested crop. Initial SMN to 90cm depth in the spring was 49 kgN/ha (SNS index 0). The grower applied N to the crop on the basis of RB209 recommendations until the end of September 2013 (Table 2).

Table 2. Main N applications applied by the host grower in 2013 to the early maturity crop prior to experimental (supplementary) applications

Date N applied*	Rate (kg N/ha)
25th May	71
25th July	80
10th September	51
Total (RB209 = 200)	202

* N applied as granular urea 46%N

The P and K indices in spring 2013 were 4 and 1 respectively. No P was applied, but the crop received 225 kg/ha of K_2O during the growing season. Note that a nitrate-N measurement was not obtained for the crop samples taken in late October prior to the first (late N) application. In these cases, organic N% has been estimated as total N x 0.99995. Experimental (supplementary N) treatments are shown in Table 3.

Table 3. Supplementary N treatment rates and timings applied after end of September 2013 to the early maturity crop

Treatment	**Timing**	**Total N applied (kg/ha)**	**Supplementary application timings and rates of N (kg/ha)**		
			30th October	**26th November**	**7th January (2014)**
1	(Control)	202	0		
2	E	252	50		
3	E	302	50	50	
4	M	252		50	
5	M/L	302		50	50
6	L	252			50
7	E	302	100 (Entec)		

<u>Notes</u>

- Treatment 6 is an additional treatment to examine effect of a single late application of 50 kgN/ha
- Number of plots = 7 treatments x 4 reps + 4 additional control plots = 32 plots.
- Within field will also be three nil N areas to estimate soil N supply

Mid maturity crop

The experiment was designed to test the effects of extra N applied in the early winter period to a mid spring harvested crop. Initial SMN to 90cm depth in the spring was 46 kgN/ha

(SNS index 0). The grower applied N to the crop on the basis of standard RB209 recommendations until the end of July 2013 and then an additional 41 kgN/ha in August (Table 4). The crop also received 135 kg/ha of K_2O. Experimental (supplementary N) treatments are show in Table 5.

Table 4. Main N applications applied by the host grower in 2013 to the mid maturity crop prior to experimental (supplementary) applications

Date N applied	Form*	Rate (kg N/ha)
1st May	6:18:30	17
7th June	AN	54
22nd June	AN	42
16th July	AS	26
18th July	AN	60
8th August	AN	41
Total (RB209 = 200)		240

*AN, ammonium nitrate; AS, ammonium sulphate

Table 5. Supplementary N treatment rates and timings applied after end of September 2013 to the mid maturity crop.

Treatment	**Timing**	**Total N applied (kg/ha)**	**Supplementary application timings and rates of N (kg/ha)**			
			31st October	**26th November**	**7th January (2014)**	**30th January**
1	(Control)	240	0			
2	E	290	50			
3	E	340	50	50		
4	M	290		50		
5	M/L	340		50	50	
6	M/L	290			50	
7	M/L	340			50	50
8	L	290				50
9	E	340	100 (Entec)			

Notes

- Treatment 8 is an additional treatment to examine effect of a single late application of 50 kgN/ha
- Number of plots = 9 treatments x 3 reps + 3 additional control plots = 30 plots.
- Within the field there were also three nil N areas to estimate soil N supply

Late maturity crop

The experiment was designed to test the effects of extra N applied in the early winter period to a mid spring harvested crop (final harvest 7th April 2014). Initial SMN to 90cm depth in the spring was 82 kgN/ha (SNS index 2). The grower applied 183 kgN/ha to the crop, close to RB209 recommendations (170 kgN/ha) until the end of September 2013 as detailed in Table 6. The crop also received 225 kg/ha of K_2O. Experimental (supplementary N) treatments are show in Table 7.

Table 6. Main N applications applied to the late maturity crop by the host grower in 2013 prior to experimental (supplementary) applications

Date N applied*	Rate (kg N/ha)
1st May	13
21 2t May	60
27th July	80
9th September	30
Total (RB209 = 170)	183

*N applied as granular urea 46%N

Table 7. Supplementary N treatment rates and timings applied after end of September 2013 to the late maturity crop.

Treatment	Timing	Total N applied (kg/ha)	Supplementary application timings and rates of N (kg/ha)				
			25th Oct	25th Nov	30th Jan (2014)	24th Feb	20th Mar
1	(Control)	183	0				
2	E	233	50				
3	E	283	50	50			
4	E	333	50	50	50		
5	M	233		50			
6	M	283		50	50		
7	M	333		50	50	50	
8	M/L	233			50		
9	M/L	283			50	50	
10	M/L	333			50	50	50
11	L	233				50	
12	E	283	100 (Entec)				

Notes

Treatment 11 was an additional treatment to examine effect of a single late application of 50 kgN/ha in the winter

Number of plots = 12 treatments x 3 reps + 3 additional control plots = 39 plots.

Within field were three nil N areas to estimate soil N supply

Measurements of crop growth and N status

Assessments over winter (Oct-March dependent on crop maturity)

At each sampling during the trial period, and prior to application of any supplementary fertiliser N by ADAS staff, assessments were made of SMN, crop colour and crop N status (see separate section on determination of crop N status below) both from the nil N areas, from both the control treatment as well as the treatment which was about to receive an extra 50 kgN/ha. Crop samples were taken from a 1m length of the two central rows in the bed, in each plot for each block. SMN samples were taken to 60cm depth in 20cm increments to gain more detailed information on N within the leek rooting zone. A minimum of 6 soil cores were taken from each experimental plot, in the specified treatments, as well as the 3 nil N areas, keeping soil separate from each depth (0-20cm, 20-40cm, 40-60cm) prior to sending to the laboratory for analysis.

Laboratory measurements made over winter

Leaf colour was recorded using a Minolta Chlorophyll Meter (SPAD-502). For each plot, 3 sets of 10 readings were taken each from separate plants, and an average of each of the 3x 10 readings recorded to give 3 readings per plot. The youngest full-size leaf was selected and the reading taken approximately three quarters of the way up from the base, avoiding the mid-rib in all cases.

On return to the lab, for each plot sample the fresh weight of the whole sample was recorded, chopped prior to washing and splitting into three subsamples, to determine: (i) dry matter by subsample fresh weight and dry weight; (ii) total N by Dumas combustion method; (iii) determination of tissue nitrate content (TNC) by cold water extraction and colorimetric analysis. All chemical analyses including SMN were carried out by NRM Laboratories.

Assessments at final harvest

A soil mineral N sample was taken from each plot at final harvest, in 3 increments to 90cm depth (0-30, 30-60, 60-90cm), thus providing consistency with standard RB209 to 90 cm. Soil mineral N and topsoil samples were sent to NRM labs for analysis. A crop sample was taken from 2m length of the two central rows in the bed.

Leeks were pulled up, and the roots trimmed close to the basal plate, discarding the roots in the field. The whole sample was weighed and the senesced outer leaves removed and weighed before discarded in the field as per commercial practice. The total number of leeks sampled from each plot was recorded, before being placed into labelled bags and transported back to the lab for analysis. Samples were kept in a cold store if necessary prior to assessment.

Laboratory measurements made at final harvest

Crop samples were processed at ADAS Gleadthorpe, where crops were oven dried at 100 ^{o}C until reaching constant weight, for determination of total biomass, and a sample sent for determination of total N (by Dumas combustion method) to NRM labs. Total biomass and total N offtake were combined to provide an estimate of crop N offtake (kg N/ha) and hence crop N requirement. Crop N status was estimated from the 'organic N' content, which was determined by measuring total N as above (see over winter sampling and measurements), and also TNC (effectively inorganic-N). Organic N was therefore calculated as total N minus nitrate N. Further details of the crop sampling protocol are as follows:

In the laboratory, each crop sample was weighed, washed to remove major soil contamination before being divided into two: 1) for determination of yield and N content of marketable and unmarketable fractions, and 2) for determination of total N offtake and TNC.

The leeks were split into marketable and unmarketable grades using the specification and guidance provided by Strawsons. The numbers of marketable and unmarketable leeks were recorded, and a sub-sample removed based on the proportion of marketable vs unmarketable leeks, for example if there were 30 marketable: 10 unmarketable, the subsample was made of 3 marketable and 1 unmarketable leek taken at random from each portion. The sub-sample was allocated as sample 2, as defined in the previous paragraph and the main sample further processed as sample 1.

Sample 1 was processed as follows: Fresh weights were recorded for both marketable and unmarketable leek fractions. Yellow/rotten/broken/unmarketable leaves were trimmed from the marketable portion, and trimmed to commercial specification, and weight of the trimmed leeks recorded. Approximately 500g of the marketable, commercially trimmed sample was placed into labelled polythene bags for total N, DM and TNC analysis by NRM. The remainder of the marketable trimmed fraction, the trimmings and the unmarketable fractions were then dried at 100 ^{o}C to constant weight, and the dry weights of each recorded.

Sample 2 was processed as follows: Fresh weights for the marketable leek and unmarketable leeks were recorded. Yellow/rotten/broken/unmarketable leaves were trimmed from the marketable portion, trim to commercial spec then weigh and the weight of the trimmed leeks recorded. The marketable and unmarketable leeks were then recombined and approximately 500 g placed into labelled polythene bags for total N and TNC analysis by NRM. The remaining sample was used for dry matter determination.

Having gained estimates of N content for the marketable crop in Sample 1, and the N content of the whole crop in sample 2, the N content of the unmarketable crop fraction and trimmings could be determined by difference.

Statistical analyses

For the data collected at final harvest, all data were first subjected to analysis of variance (ANOVA) in a fully randomised block design, with control and 7, 9 or 12 experimental treatments dependent on crop maturity type as described above. However the nil N areas were excluded from the formal ANOVA as they were not fully randomised within the experiment.

A second stage ANOVA was then carried out where only the balanced factorial treatments were analysed, and the average of the supplementary N treatments compared to the control, before then looking for differences between factorial treatments (rates or timings of addition of supplementary N). In the case of this ANOVA, the Entec treatment, and the final single application of 50 kgN/ha supplementary N in each experiment, was excluded from the formal ANOVA.

Calculation of crop N status

Crop N status was estimated using the principles developed historically at Wellesbourne (and employed in the Fertiliser manual as the basis to calculate leek crop N requirement). The calculation uses primary measurements of total crop dry weight (DW, t/ha) and organic N concentration (%). Crop N status was estimated using the following equation:

Crop N status = Actual organic N concentration / Expected organic N concentration

where;

Expected organic N (%) = Pnif*(Bo*EXP(-0.26*DW)))

and,

Pnif and Bo are constants (1.648 and 2.4587 respectively) based on the values used in HDC Fact sheet 32/12.

For further information on estimation of crop N status in leeks see FV 350 (Rahn and Lillywhite, 2011).

Results

Overall sites comparison

Before considering the effects of different rates and timings of supplementary N, the overall responses at the different trial sites are reported. Data for yields of nil N, control and supplementary N treatments are shown in Tables 8 and 9.

The main thing to note is that at the early and mid maturity sites, the crops responded well in terms of total FW and marketable yields to the main applications of N. In contrast, the late maturity site did not appear to respond to N and gave a very high yield with zero N applied.

Table 8. Effects of supplementary N compared to control treatments on total yield, and yield of marketable plants for three leek crops in the 2013/14 season.

Crop maturity type	Treatment	Total FW yield (t/ha)	Proportion of Marketable plants (%)	Marketable plants FW yield (t/ha)
Early	Nil N†	38.6	12.7	6.9
	Control	80.0	60.2	34.7
	Supplementary N	84.8	56.8	38.0
	Significance level¶	ns	ns	ns
Mid	Nil N†	44.6	22.8	7.8
	Control	63.6	40.9	20.6
	Supplementary N	74.2	54.8	29.0
	Significance level	*	*	*
Late	Nil N†	81.8	55.5	31.7
	Control	76.1	69.8	30.4
	Supplementary N	84.2	56.8	29.9
	Significance level	ns	*	ns

†, Nil N data from adjacent plots is shown for reference, but is not part of the formal statistical analysis.

¶, Significance levels indicate probability of differences between control treatment, and mean of supplementary N factorial treatments in each experiment (* $P<0.05$, ns not significant).

The lack of response to N at the late site was unexpected, because although this site had a higher initial SNS index than the other two sites, a response to the main application of N would still have been expected.

Total N uptake increased significantly in response to supplementary N (Table 9) but the data clearly show the higher level of N uptake in the nil N areas in the late maturity crop. Measurement of SMN through the winter (i.e. before each 50 kgN/ha addition of supplementary N) also showed that SMN was ca. 10 kgN/ha higher (to 60cm depth) in the late crop (Table 10).

Table 9. Effects of supplementary N compared to control treatments on N uptake for three leek crops in the 2013/14 season.

Crop maturity type	Treatment	Total N uptake (kgN/ha)	Marketable crop N offtake (kgN/ha)	N in crop residues & unmarketable crop (kgN/ha)
Early	Nil N†	105	16	89
	Control	284	102	182
	Supplementary N	323	124	199
	Significance level¶	P<0.1	P<0.1	ns
Mid	Nil N†	98	17	81
	Control	174	46	128
	Supplementary N	251	82	169
	Significance level	**	***	*
Late	Nil N†	175	56	119
	Control	204	66	137
	Supplementary N	260	69	191
	Significance level	**	ns	**

†, Nil N data from adjacent plots is shown for reference, but is not part of the formal statistical analysis.

¶, Significance levels indicate probability of differences between control treatment, and mean of supplementary N factorial treatments in each experiment (* P<0.05, ** p<0.01, *** p<0.001, ns, not significant).

Table 10. Total SMN (0-60cm depth) for nil N and control treatments during the autumn and winter periods

Crop maturity type	Treatment	SMN (kgN/ha, 0-60 cm depth)					
		Oct 13	*Nov 13*	*Early Jan 14*	*Late Jan 14*	*Feb 14*	*March 14*
Early	Nil N	11	8	3	4	-	-
	Control	28	23	26	4	-	-
Mid	Nil N	7	6	3	6	-	-
	Control	9	23	3	9	-	-
Late	Nil N	21	16	-	13	12	100
	Control	25	26	-	19	14	93

The apparent lack of overall effect of supplementary N on FW yields masks important differences between timing treatments and rates of supplementary N. Therefore the following section considers each crop maturity site separately.

Early maturity crop

- Supplementary N had relatively little overall effect on total FW yield (Table 11) although there was significant interaction with yield increasing from 76.0 to 93.6 t/ha when supplementary N increased from 50 to 100 t/ha, applied in Oct/Nov, but decreasing from 96.4 to 73.1 t/ha for supplementary N applied in Nov/Jan (yield of control treatment 80.0 t/ha),
- Supplementary N also had relatively little overall effect on fresh weight yield of marketable plants (Table 12) but with a significant interaction with yield increasing from 35.2 to 45.5 t/ha when supplementary N increased from 50 to 100 t/ha applied in Oct/Nov, but decreasing from 42.5 to 29.0 t/ha for supplementary N applied in Nov/Jan (yield of control treatment 34.8 t/ha),
- However, supplementary N appeared to increase the proportion of marketable plants (Table 13) from 60.2%, principally by reducing the number of undersized plants based on shaft thickness, with early (Oct/Nov) treatments having a greater proportion of marketable plants (63.1%) compared to Nov/Jan applications (50.6%),
- There appeared to be no benefit to the proportion of marketable plants from applying more than 50 kgN/ha as supplementary N,
- Supplementary N resulted in ca. 40 kgN/ha more N uptake compared to the control treatment (Tables 9 and 14), and there was a significant interaction within the supplementary N treatments, as for FW yield, with N uptake increasing from 293 to 368 t/ha when supplementary N increased from 50 to 100 t/ha, applied in Oct/Nov, but decreasing from 361 to 269 t/ha for supplementary N applied in Nov/Jan,
- N offtake in marketable plants was significantly greater in the supplementary N treatments than the control (124 vs 106 kgN/ha; Table 9) and was significantly greater (137 vs 111 kgN/ha) in early (Oct/Nov) compared to late (Nov/Jan) supplementary applications (Table 15),
- N (kg/ha) in the unmarketable crop and residues was not significantly different between control and supplementary treatments (183 vs 199 kgN/ha; Table 9),
- Increasing supplementary N applications from 50 to 100 kgN/ha increased the residual SMN left after harvest to 90 cm depth* by ca. 100 kgN/ha, with the highest

levels being left following late autumn/winter treatments (275 kgN/ha, Nov/Jan) and the Entec treatment (231 kgN/ha; Table 17),

* for SMN data by 30 cm depth increments see Annex Table A1,

- Despite the apparent advantages of early supplementary N, interestingly most crop growth and N uptake appeared to occur in January 2014 (Figure 1), NB for data on total DW yield at final harvest, see Table A4 in the Appendix,
- Crop N status measurements (CNS) clearly demonstrated that the nil N plots were under-fertilised with respect to control treatments (0.55 – 0.67 vs 1.39-1.59 respectively) and chlorophyll concentration index (SPAD) being 10 units lower in nil N crop (Tables 18 to 20),
- The main (control) application based on an RB209 recommendation appeared to be sufficient to maintain CNS above 1, and hence avoid N deficiency in the crop,
- Through the winter and up until the last interim harvest, the CNS of the control treatment initially fell but remained above 1, being largely matched by soil supply. Those treatments which had already had supplementary N applied at the time of sampling maintained a high CNS around 1.6 (i.e. treatment 3, Table 19 and treatment 5, Table 20; Figure 2),
- CNS increased between the last interim harvest and the final harvest in January 2014 (Figure 2) by between 0. 14 and 0.25 CNS units,
- These results appear inconclusive in providing a guide for crop sampling to guide late N applications,
- Soil sampling in late November indicated that most of the N applied in October (treatment 3) was available in the rooting zone (118 kgN/ha at 0-20cm depth; Table 19), and similarly, sampling in January showed that most of the N applied in November (treatment 5) was available in the rooting zone (109 kgN/ha at 20-40cm depth; Table 20),

Table 11. Total fresh weight yield for early maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Total FW (t/ha)				Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		38.6				
Control		80.0†				Control vs individual means in table, ns
Factorial design:	Oct/Nov		76.0	93.6	*84.8*	Timing, ns
	Nov/Jan		96.4	73.1	*84.7*	Rate, ns
	N Rate means		*86.2*	*83.3*		Timing x rate interaction, *** (6.19)

Additional treatments: 100 kgN/ha as Entec = 78.6; Single N application 50 kgN/ha in January = 83.3

Other treatment comparisons *** (12.01)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 12. Marketable plants FW yield for early maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**Marketable plants FW yield (t/ha)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		6.9				
Control		34.8[†]				Control vs individual means in table, ns
Factorial design:	Oct/Nov		35.2	45.5	*40.3*	Timing, ns)
	Nov/Jan		42.5	29.0	*35.7*	Rate, ns
	N Rate means		*38.8*	*37.2*		Timing x rate interaction, ** (10.19)

Additional treatments: 100 kgN/ha as Entec = 32.0; Single N application 50 kgN/ha in January = 35.1

Other treatment comparisons * (9.35)

[†], For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 13. Proportion of marketable plants for early maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**Proportion of marketable plants (%)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		12.7				
Control		60.2†				Control vs individual means in table, * (11.01)
Factorial design:	Oct/Nov		62.3	63.9	*63.1*	Timing, * (10.27)
	Nov/Jan		57.5	43.6	*50.6*	Rate, ns
	N Rate means		*59.9*	*53.8*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 50.8; Single N application 50 kgN/ha in January = 52.6

Other treatment comparisons * (12.7)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 14. Total N uptake for early maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**Total N uptake (kgN/ha)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		105				
Control		284[†]				Control vs individual means in table, ns
Factorial design:	Oct/Nov		293	368	*330*	Timing, ns
	Nov/Jan		361	269	*315*	Rate, ns
	N Rate means		*327*	*319*		Timing x rate interaction, ** (73.6)
Additional treatments: 100 kgN/ha as Entec = 321; Single N application 50 kgN/ha in January = 287						
						Other treatment comparisons * (65.3)

[†], For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 15. N offtake in marketable plants for early maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		N offtake (kgN/ha)				Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		16				
Control		106†				Control vs individual means in table, ns
Factorial design:	Oct/Nov		123	151	*137*	Timing, * (22.9)
	Nov/Jan		129	92	*111*	Rate, ns
	N Rate means		*126*	*121*		Timing x rate interaction, ** (32.4)
Additional treatments: 100 kgN/ha as Entec = 115; Single N application 50 kgN/ha in January = 111						
						Other treatment comparisons * (61.9)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 16. N in unmarketable crop and crop residues for early maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**N in unmarketable crop and residues (kgN/ha)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		*89*				
Control		183†				Control vs individual means in table, ns
Factorial design:	Oct/Nov		170	217	*194*	Timing, ns
	Nov/Jan		232	177	*205*	Rate, ns
	N Rate means		*201*	*197*		Timing x rate interaction, p=0.05 (71.9)

Additional treatments: 100 kgN/ha as Entec = 206; Single N application 50 kgN/ha in January = 176

Other treatment comparisons, ns

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 17 Total SMN to 90 cm depth at final harvest in 2014 for early maturity leek crop with supplementary N applied in autumn/winter period (data for individual 30 cm depth increments can be found in Appendix Table A1).

Treatments	**Total SMN (kgN/ha)**			
Supplementary N application rates:	*0*	*50*	*100*	*Timing means*
Nil N	13			
Control	34			
Oct/Nov		89	209	*149*
Nov/Jan		68	275	*172*
Autumn applications, N Rate means		*79*	*242*	
Single application Jan		146	-	
Entec		-	231	

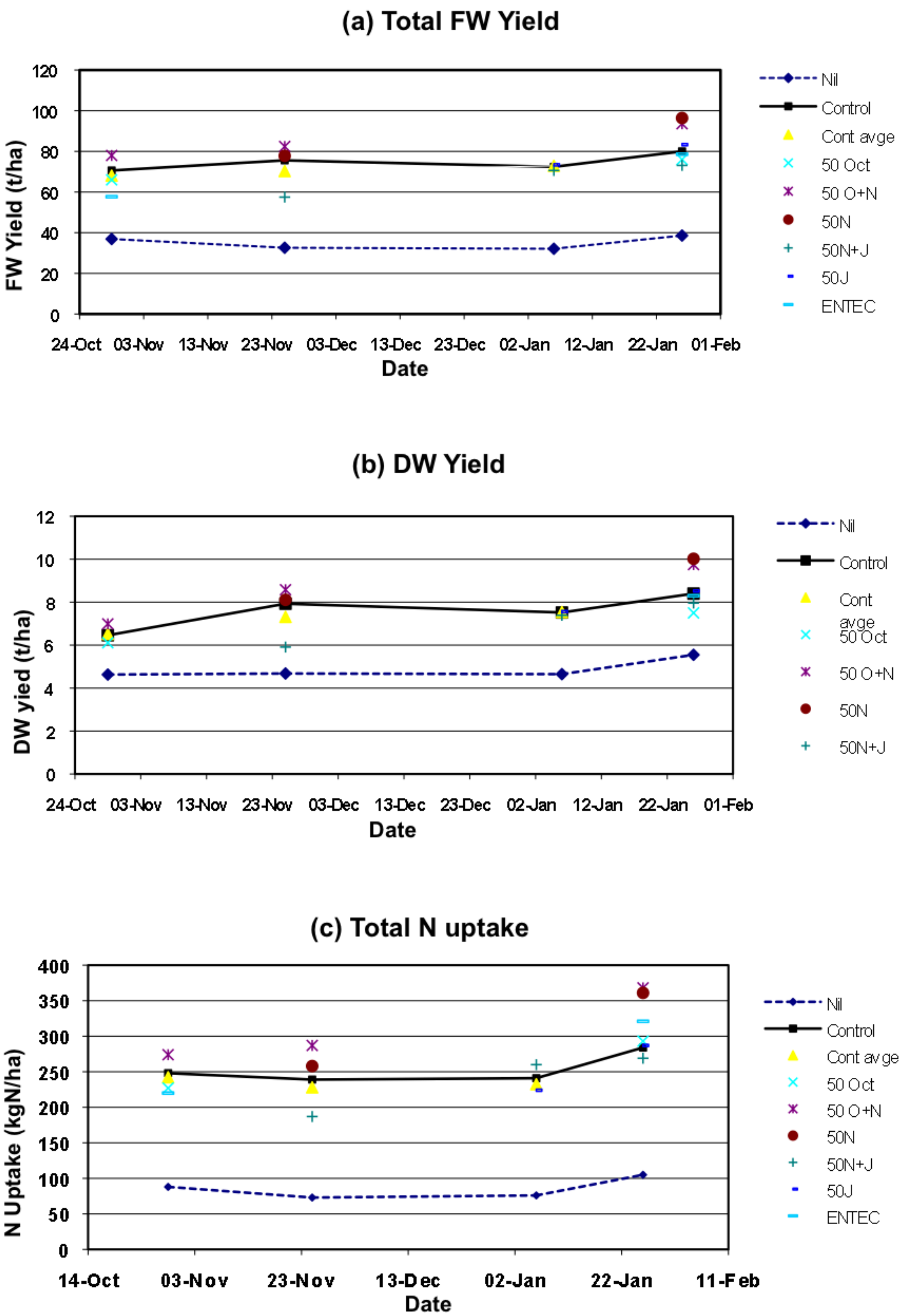

Figure 1. Growth characteristics during the autumn and winter period for the early maturity leek crop (last sampling point represents final harvest). NB 'Cont avge' represents average of all those treatments which had received no supplementary N at the time of sampling.

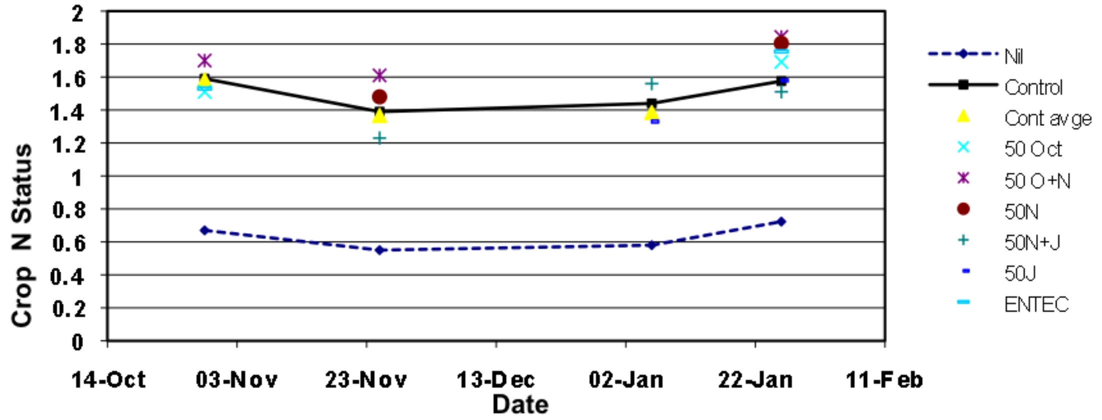

Figure 2. Crop N status during the autumn and winter period for the early maturity leek crop (last sampling point represents final harvest).

Table 18. Early maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) on selected treatments - assessment on 30th Oct 2013 before late October N application.

Treatment	Nil N	1 RB209 control	2 50kg/ha late Oct	3 50 kg/ha late Oct + 50 kg/ha late Nov	7 100 kg/ha Entec
*Crop N status**	0.67	1.59	1.51	1.70	1.53
SPAD	73.7	81.3	-	-	83.0
SMN (kg N/ha)					
0-20 cm	3.2	11.0	17.9	17.9	16.9
20-40 cm	3.8	10.5	16.2	17.3	12.4
40-60 cm	3.8	6.9	24.0	21.7	27.6
Total 0-60 cm	10.9	28.3	58.1	56.9	56.8

*, Crop N status based on total N*0.99995.

Table 19. Early maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) - assessment on 26th Nov 2013 before late November N application.

Treatment	**Nil N**	**1** RB209 control	**3** 50 kg/ha late Oct + 50 kg/ha late Nov	**4** 50 kg/ha late Nov	**5** 50 kg/ha late Nov + 50 kg/ha early Jan
Crop N status	0.55	1.39	1.61	1.48	1.23
SPAD	72.1	82.4	82.9	-	83.9
SMN (kg N/ha)					
0-20 cm	2.6	5.9	118.2	6.6	5.8
20-40 cm	3.0	6.1	36.1	6.3	6.2
40-60 cm	2.2	11.0	15.4	4.7	9.1
Total 0-60 cm	7.8	23.0	169.7	17.6	21.1

Table 20. Early maturity crop; crop N status, SMN to 60cm depth and chlorophyll concentration index (SPAD readings) on selected treatments - assessment on 7th Jan 2014 before early Jan application.

Treatment	**Nil N**	**1** RB209 control	**5** 50 kg/ha late Nov + 50 kg/ha early Jan	**6** 50 kg/ha early Jan
Crop N status	0.58	1.44	1.56	1.33
SPAD	70.3	81.4	82.1	-
SMN (kg N/ha)				
0-20 cm	0.3	2.7	57.2	8.6
20-40 cm	0.6	9.0	108.5	19.3
40-60 cm	1.8	14.4	41.3	19.3
Total 0-60 cm	2.7	26.1	206.9	47.1

Mid maturity crop

- This crop was very responsive to the main application of N, with FW yields increasing from 44.6 in nil-N plots, to 63.6 t/ha, in the control treatments (Table 8),
- Supplementary N strongly increased total FW yield (Tables 8 and 21) from 63.6 in control plots, to 74.2 t/ha, in the supplementary N treatments,
- Early autumn (Oct/Nov) applications gave the highest yields of the supplementary N treatments 79.3 vs 69.4 for Nov/Jan and 73.8 for early/late Jan. but this was not statistically significant Table 21),
- Marketable yield was higher in the supplementary N treatments compared to the control (20.6 vs 29.0 t/ha, just achieving significance at the $p<0.1$ level (Tables 8 and 22),
- Supplementary N appeared to increase the proportion of marketable plants by ca. 10% compared to the control treatment (40.9% in Table 8), and was highest in the early (Oct/Nov) treatments at 61.5% but this timing effect was not statistically significant (Table 23),
- There appeared to be no benefit to total or marketable yields from applying 50 kgN/ha as supplementary N, although it is noted that this crop had already received +40 kgN/ha above the standard RB209 recommendation as part of the main applications, pre-September 2013 (Tables 22 and 23),
- Supplementary N resulted in up to 105 kgN/ha more total N uptake compared to the control treatment (Table 24), and extra N uptake in marketable and unmarketable plants plus residues in supplementary N treatments were each 50 kgN/ha more than the control (Tables 25 and 26) however there were no significant differences in response to rate or timing of the supplementary N treatments,
- Supplementary N (50 kgN/ha) increased residual SMN left after harvest to 90 cm depth* from 7 to 24 kgN/ha; increasing supplementary N application further from 50 to 100 kgN/ha increased the residual SMN by ca. 50 kgN/ha, with the highest residues being left following late winter treatments (Jan/Feb) by ca. 60 kgN/ha (Table 27),

  * for SMN data by 30 cm depth increments see Annex Table A2,
- Despite the apparent advantages of early supplementary N, most crop growth in terms of DM accumulation occurred steadily through the winter (Figure 3b) in control and nil-N treatments, whereas most of the increase in FW and total N uptake

occurred in the supplementary N treatments, at the end of the season in the month prior to harvest (Figs. 3a and 3c), NB for data on total DW yield at final harvest, see Table A5 in the Appendix,

- Crop N status measurements (CNS) clearly demonstrated that the nil N plots were under-fertilised with respect to control treatments (0.63 – 0.79 vs 0.97 – 1.18 respectively) and chlorophyll concentration index (SPAD) being 6 - 10 units lower in the nil N crop (Tables 28 to 31),
- Through the autumn, the CNS of the control treatment declined, reaching a low in early January 2014 (Figure 4), with CNS reaching 0.97 indicating that it was borderline for deficiency, and suggesting that the crop had a demand for N in this period which was only just being met by the soil supply,
- Total SMN in the control treatments stayed low through the whole of the sampling period (Table 10),
- Where October, November or January supplementary N had been applied it was still in the root zone (measured at 0-20 cm depth) at the next sampling date e.g. 41.7 kgN/ha in treatment 3, late November 2013, Table 29; 21.7 kgN/ha in treatment 5 in early January 2014, Table 30; and 67.5 kgN/ha in treatment 7, late February 2014, Table 31.
- SPAD readings (both in nil N and control plots) were some 10 units lower than measured in the equivalent plots of the early maturity crop (see earlier section),
- As seen in the early crop, those treatments which had already had supplementary N applied at the time of sampling, maintained CNS above 1.0 (e.g. 1.19, treatment 3, Table 29; 1.15, treatment 5, Table 30, and 1.07, treatment 7, Table 31),
- Although this was the crop which responded mostly strongly to N in terms of yield (Table 8 and Tables 21 – 23) it would appear that a measurement of CNS and/or SPAD would not have been useful in predicting a requirement for supplementary N.

Table 21. Total FW yield for the mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Total FW yield (t/ha)				Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		44.6				
Control		63.6†				Control vs individual means in table, * (5.05)
	Oct/Nov		77.1	81.5	*79.3*	Timing, ns
	Nov/Jan		74.7	64.2	*69.4*	Rate, ns
	Early Jan/late Jan		74.9	72.7	*73.8*	
	N Rate means		*75.6*	*77.8*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 83.3; Single N application 50 kgN/ha in late January = 74.3

Other treatment comparisons, ns

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 22. Marketable FW yield for the mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Marketable FW yield (t/ha)				Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		7.8				
Control		20.6†				Control vs individual means in table, * (6.40)
	Oct/Nov		34.6	33.0	*33.8*	Timing, p<0.1 (7.84)
	Nov/Jan		25.2	24.9	*25.0*	Rate, ns
	Early Jan/late Jan		25.2	31.1	*28.1*	
	N Rate means		*28.3*	*29.6*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 32.8; Single N application 50 kgN/ha in late January = 29.2

Other treatment comparisons, p<0.1 (11.25)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 23. Proportion of marketable plants for mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Proportion of marketable plants (%)				Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		22.8				
Control		40.9†				Control vs individual means in table, ns
	Oct/Nov		64.2	58.9	*61.5*	Timing, ns
	Nov/Jan		47.0	54.2	*50.6*	Rate, ns
	Early Jan/late Jan		47.1	57.7	*52.4*	
	N Rate means		*52.8*	*56.9*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 59.2; Single N application 50 kgN/ha in late January = 53.3

Other treatment comparisons, p=0.13 (18.52)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 24. Total N uptake for mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**Total N uptake (kgN/ha)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		98				
Control		174†				Control vs individual means in table, *** (45.2)
	Oct/Nov		249	279	*264*	Timing, ns
	Nov/Jan		252	238	*245*	Rate, ns
	Early Jan/late Jan		251	238	*244*	
	N Rate means		*250*	*252*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 302; Single N application 50 kgN/ha in late January = 211

Other treatment comparisons, * (73.8)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 25. N offtake in marketable plants for the mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**N offtake in marketable plants (kgN/ha)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		15				
Control		46†				Control vs individual means in table, *** (8.7)
	Oct/Nov		97	95	*96*	Timing, ns
	Nov/Jan		74	77	*75*	Rate, ns
	Early Jan/late Jan		67	82	*75*	
	N Rate means		*79*	*85*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 94; Single N application 50 kgN/ha in late January = 64

Other treatment comparisons, * (31.7)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 26. N in unmarketable fraction and crop residues for the mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**N in unmarketable fraction and residues (kgN/ha)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		70				
Control		128†				Control vs individual means in table, * (16.4)
	Oct/Nov		152	184	*168*	Timing, ns
	Nov/Jan		178	162	*170*	Rate, ns
	Early Jan/late Jan		184	156	*170*	
	N Rate means		*171*	*167*		Timing x rate interaction, ns
Additional treatments: 100 kgN/ha as Entec = 208; Single N application 50 kgN/ha in late January = 147						
						Other treatment comparisons, p<0.1 (54.8)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 27. Total SMN to 90 cm depth at final harvest in 2014 for mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments	**Total SMN (kgN/ha)**			
Supplementary N application rates:	*0*	*50*	*100*	*Timing means*
Nil N	8			
Control	7			
Oct/Nov		18	41	*30*
Nov/Jan		18	38	*28*
Early/late Jan		36	143	*90*
Autumn applications, N Rate means		*24*	*74*	
Single application late Jan		56	-	
Entec		-	86	

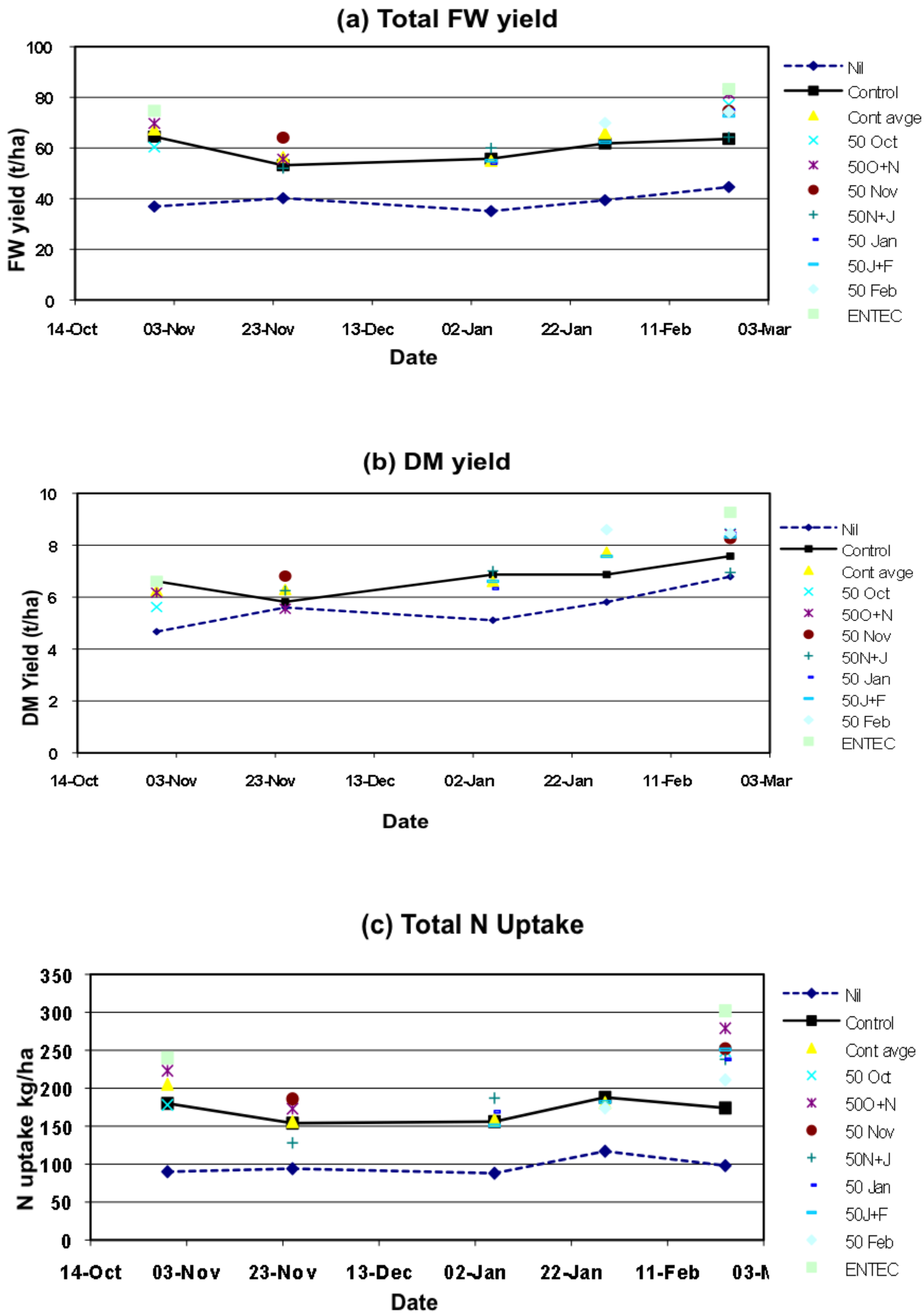

Figure 3. Growth characteristics during the autumn and winter period including final harvest, for the mid maturity leek crop. NB ‘Cont avge’ represents average of all those treatments which had received no supplementary N at the time of sampling.

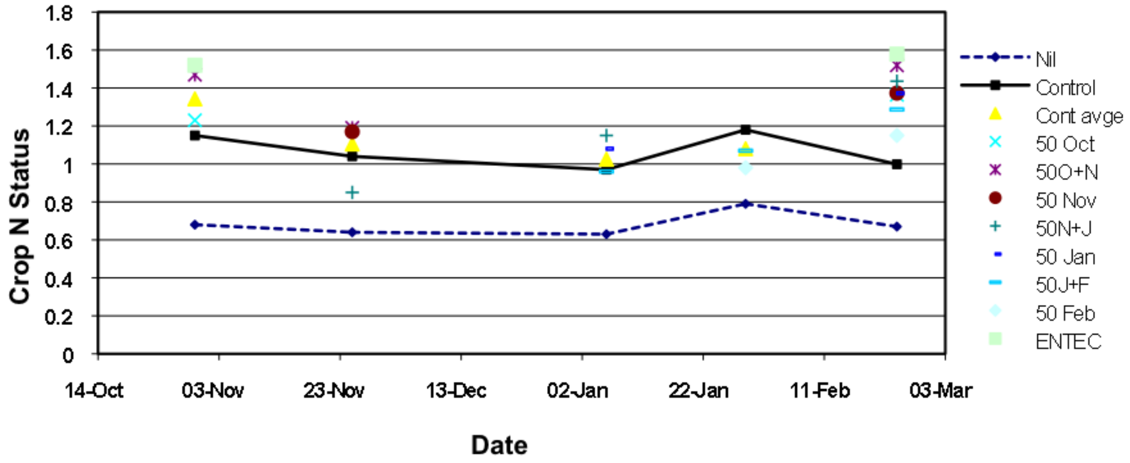

Figure 4. Crop N status during the autumn and winter period for the mid maturity leek crop (last sampling point represents final harvest).

Table 28. Mid maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) on selected treatments – assessment on 31st Oct 2013 before late October N application.

Treatment	**nil**	**1** RB209 control	**2** 50kg/ha late Oct	**3** 50 kg/ha late Oct + 50 kg/ha late Nov	**9** 100 kg/ha Entec
Crop N status	0.68	1.15	1.23	1.47	1.52
SPAD	66.8	72.1	-	-	72.4
SMN (kg/ha)					
0-20 cm	1.6	3.3	9.2	6.4	7.4
20-40 cm	1.9	3.6	8.6	12.2	10.5
40-60 cm	3.6	2.5	14.6	27.1	9.9
Total 0-60 cm	7.1	9.4	32.5	45.7	27.8

Table 29. Mid maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) on selected treatments – assessment on 26th Nov 2013 before late November N application.

Treatment	Nil N	1 RB209 control	3 50 kg/ha late Oct + 50 kg/ha late Nov	4 50 kg/ha late Nov	5 50 kg/ha late Nov + 50 kg/ha early Jan
Crop N status	0.64	1.04	1.19	1.17	0.85
SPAD	68.3	73.9	78.4	-	72.7
SMN (kg/ha)					
0-20 cm	1.6	4.6	41.7	4.8	3.3
20-40 cm	2.7	5.9	14.8	7.4	3.5
40-60 cm	2.0	12.4	12.6	4.5	2.2
Total 0-60 cm	6.3	23.0	69.1	16.7	8.9

Table 30. Mid maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) on selected treatments – assessment on 7th Jan 2014 before early January application.

Treatment	Nil N	1 RB209 control	5 50 kg/ha late Nov + 50 kg/ha early Jan	6 50 kg/ha early Jan	7 50 kg early Jan+ 50 kg late Jan
Crop N status	0.63	0.97	1.15	1.08	0.96
SPAD	67.9	72.6	72.2	-	70.6
SMN (kg/ha)					
0-20 cm	1.07	0.50	21.7	0.50	1.67
20-40 cm	1.30	1.93	19.2	1.50	2.07
40-60 cm	0.53	0.73	2.4	0.93	2.70
Total 0-60 cm	2.90	3.17	43.3	2.93	6.43

Table 31. Mid maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) on selected treatments – assessment on 30th Jan 2014 before late February application.

Treatment	**Nil N**	**1** RB209 control	**7** 50 kg/ha early Jan + 50 kg/ha late Jan	**8** 50 kg/ha late Feb
Crop N status	0.79	1.18	1.07	0.98
SPAD	66.7	75.7	70.7	-
SMN (kg/ha)				
0-20 cm	2.4	3.2	67.5	1.3
20-40 cm	1.9	3.7	13.7	1.0
40-60 cm	1.5	1.8	1.8	0.7
Total 0-60 cm	5.7	8.7	83.0	3.0

Late maturity crop

- This crop did not respond to the main N application as noted earlier (Table 8),
- Although there was no significant difference in total FW yield between control (76.1 t/ha) and supplementary N treatments (Table 8), timing had a significant effect, with early (Oct/Nov/Dec) applications having significantly higher yields (93.5 vs 74.9-84.3 t/ha) than later applications (Table 32) although no significant differences were seen in marketable yields (Table 33),
- The proportion of marketable plants was significantly lower in late supplementary N treatments (45.2 – 59.9%; Table 34) compared to the control (69.8%) and early (Oct/Nov/Jan) treatments (65.4%),
- Total N uptake was significantly greater in supplementary N treatments compared to the control (204 kgN/ha), being affected both by timing, with early autumn applications being higher, and rate, with the 150 kgN/ha rate of supplementary N in Oct/Nov giving the highest N uptake (345 kgN/ha; Table 35),
- However there was no significant effect of supplementary N on N removal in the marketable crop (Table 36), because later applications of N reduced the proportion of plants marketable which were of marketable quality, even as N uptake in the whole crop increased,
- Because of this lack of response in the marketable fraction, there was a significant effect of supplementary N on the unmarketable crop fraction and crop residues (Table 37), with the highest levels of N in these crop fractions (262 kgN/ha) found with 150 kg/ha supplementary N applied in autumn/early winter (Oct/Nov/Jan),
- Large amounts of SMN to 90 cm depth were left after harvest (Table 38) but this trial was unusual in that SMN rose markedly in the last month of the experiment. This can be seen in the March 2014 sampling (final column in Table 10) with SMN in nil N areas increasing from 12 to 100 kgN/ha, and in control plots from 14 to 93 kgN/ha; it is not known whether this was a real effect as N was mineralised from soil organic matter in the spring, or whether the trial was over spread with fertiliser N,
- The late leek crop grew slowly over autumn and winter until late February 2014, and then all growth parameters (FW, DW and N uptake) increase markedly thereafter (Figs. 5 a to c), NB for data on total DW yield at final harvest, see Table A6 in the Appendix,

- It is not known to what extent this growth pattern results from a genetic difference (late crops developing more slowly), or whether it simply reflects a response to temperature increasing in the spring,
- N uptake recorded in October (ca. 100 kgN/ha in the nil N crop, and ca. 140 kgN/ha in the control treatment) had been supplied by the soil (82 kgN/ha measured in the spring before drilling, plus continued mineralisation of N from organic matter during summer 2013), explaining the lack of response to applied N,
- Interestingly, the differential in N uptake between nil N and control plots (+40 kgN/ha) was relatively small compared that that between the same treatments in the mid (+100 kgN/ha) and early maturity crop (+150 kgN/ha), suggesting that a feature of the late maturing crop with its slower development, is lower N uptake over the summer (not currently accounted for in the Fertiliser Manual),
- Crop N status was similar between nil N and control plots (Tables 39-43) being relatively high (0.9 – 1.44) which supports the observation of a lack of response to the main N application, as well as the lack of response to supplementary N,
- Nevertheless, measurements on those plots which had previously had 50 or 100 kg/ha supplementary N applied, showed higher CNS (1.39 – 1.53) than in control treatments (i.e. treatment 3, Table 40; treatments 4, 6, 7, Table 41; treatments 7, 9 & 10, Table 42, and treatment 10, Table 43),
- As in the early and mid maturity crops, there were indications of N being left in the rooting zone at the next sampling time following supplementary N application, e.g. 119 kgN/ha at 0-20 cm depth in treatment 4 measured in early November (Table 40), and 122 and 101 kgN/ha left in treatments 7 and 9 in late February (Table 42),
- SPAD readings were also similar between plants in nil N areas and control plots (66 – 74), being similar to those measured in the mid maturity crop and lower than in the early maturity crop (70-83) noted earlier.

Table 32. Total FW yield of the late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**Total FW (t/ha)**					**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*	
Nil-N		81.8					
Control		76.1†					Control vs individual means in table, ns
Factorial treatments	Oct/Nov/Jan		83.7	91.3	105.5	*93.5*	Timing, * (15.15)
	Nov/Jan/Feb		79.9	64.0	80.8	*74.9*	Rate, ns
	Jan/Feb/Mar		74.4	90.3	88.1	*84.3*	
	N Rate means		*79.3*	*81.9*	*91.4*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 99.9; Single N application 50 kgN/ha in March = 82.4

Other treatment comparisons, ns

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 33. Marketable FW yield for late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments			Marketable yield (t/ha)				Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*	
Nil-N		31.7					
Control		30.4[†]					Control vs individual means in table, ns
Factorial treatments	Oct/Nov/Jan		34.3	35.4	34.1	*34.6*	Timing, ns
	Nov/Jan/Feb		24.3	31.8	29.1	*28.4*	Rate, ns
	Jan/Feb/Mar		23.6	29.3	26.7	*26.5*	
	N Rate means		*27.4*	*32.2*	*30.0*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 38.8; Single N application 50 kgN/ha in March = 33.2

Other treatment comparisons, ns

[†], For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 34. Proportion of marketable plants for late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Proportion of marketable plants (%)					Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*	
Nil-N		55.5					
Control		69.8					Control vs individual means in table, * (11.26)
Factorial treatments	Oct/Nov/Jan		68.6	62.7	64.9	*65.4*	Timing, ** (13.15)
	Nov/Jan/Feb		47.9	67.7	64.1	*59.9*	Rate, not sig
	Jan/Feb/Mar		38.1	51.1	46.2	*45.2*	
	N Rate means		*51.5*	*60.5*	*58.4*		Timing x rate interaction, not sig

Additional treatments: 100 kgN/ha as Entec = 61.8; Single N application 50 kgN/ha in March = 61.8

Other treatment comparisons, p<0.1 (20.08)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 8.

Table 35. Total N uptake of late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Total N uptake (kgN/ha)					Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*	
Nil-N		175					
Control		204†					Control vs individual means in table, ** (37.2)
Factorial treatments	Oct/Nov/Jan		232	271	345	*283*	Timing, p<0.01 (43.3)
	Nov/Jan/Feb		233	195	280	*236*	Rate, ** (43.4)
	Jan/Feb/Mar		218	303	264	*262*	
	N Rate means		*227*	*256*	*296*		Timing x rate interaction, * (62.3)
Additional treatments: 100 kgN/ha as Entec = 308; Single N application 50 kgN/ha in March = 260							
							Other treatment comparisons, p<0.01 (79.8)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 36. Total N offtake in marketable crop for late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**Marketable crop N offtake (kgN/ha)**					**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*	
Nil-N		59.0					
Control		66.2†					Control vs individual means in table, ns
Factorial treatments	Oct/Nov/Jan		73.4	72.5	83.3	*76.4*	Timing, ns
	Nov/Jan/Feb		53.0	80.3	73.2	*68.8*	Rate, ns
	Jan/Feb/Mar		52.9	70.8	60.6	*61.4*	
	N Rate means		*59.8*	*74.5*	*72.4*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 99.3; Single N application 50 kgN/ha in March = 72.4

Other treatment comparisons, ns

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 37. N in crop residues and unmarketable fraction for late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**N in crop residues and unmarketable crop (kgN/ha)**					**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*	
Nil-N		127					
Control		137†					Control vs individual means in table, ** (32.9)
Factorial treatments	Oct/Nov/Jan		159	199	262	*207*	Timing, P<0.1 (38.4)
	Nov/Jan/Feb		180	114	207	*167*	Rate, ** (38.4)
	Jan/Feb/Mar		165	232	203	*200*	
	N Rate means		*168*	*182*	*224*		Timing x rate interaction, * (59.5)

Additional treatments: 100 kgN/ha as Entec = 208; Single N application 50 kgN/ha in March = 188

Other treatment comparisons, ** (65.0)

†, For significance of difference between control and average of the factorial supplementary N treatments, see Table 9.

Table 38. Total SMN to 90 cm depth at final harvest in 2014 for late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments	Total SMN (kgN/ha)				
Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*
Nil N	76				
Control	103				
Oct/Nov		146	97	190	*144*
Nov/Jan		72	115	360	*182*
Early/late Jan		200	181	305	*229*
Autumn applications, N Rate means		*139*	*131*	*285*	
Single application late Jan		51	-		
Entec		-	278		

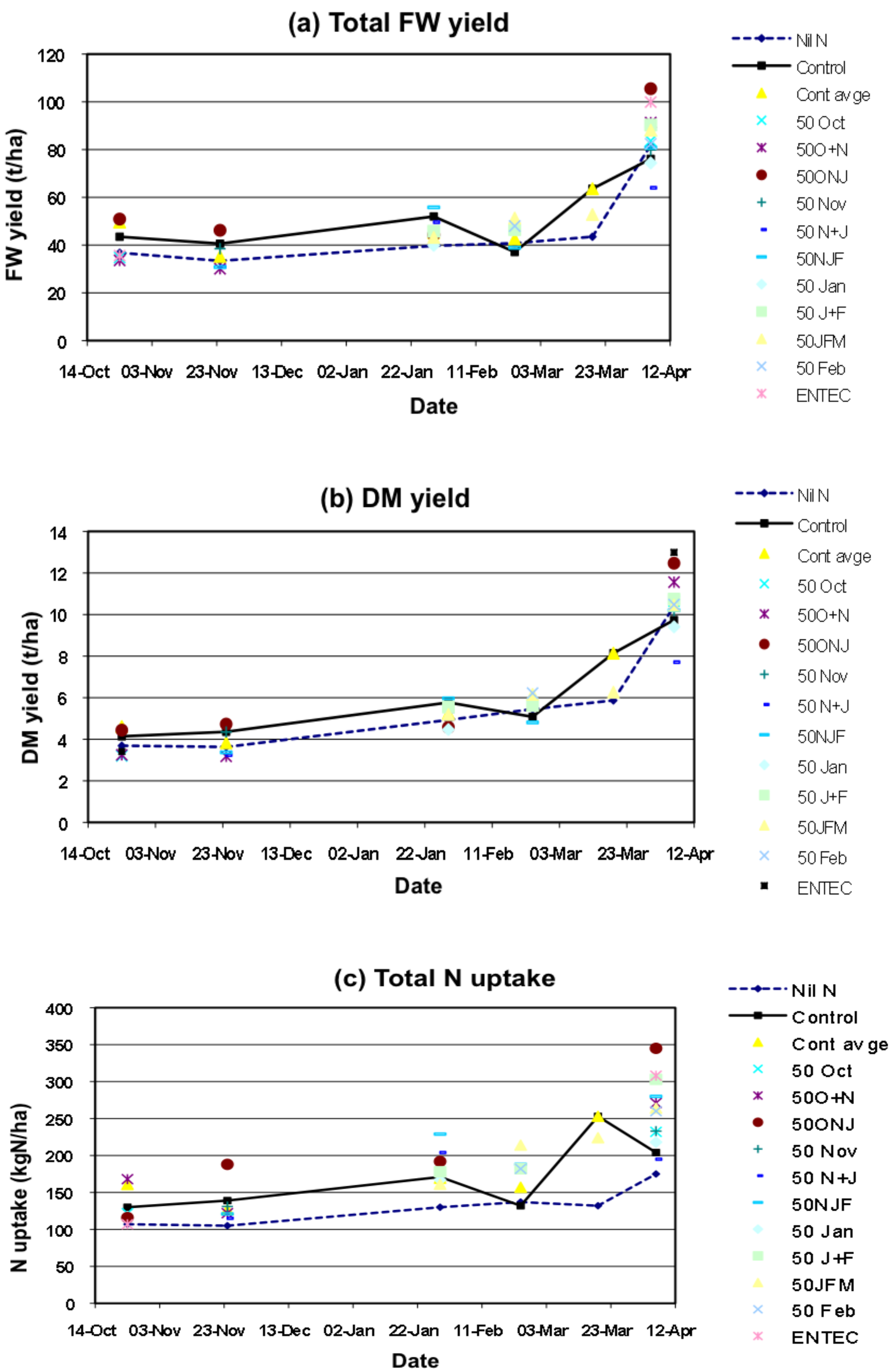

Figure 5. Growth characteristics during the autumn and winter period including final harvest, for the late maturity leek crop. NB ‘Cont avge’ represents average of all those treatments which had received no supplementary N at the time of sampling.

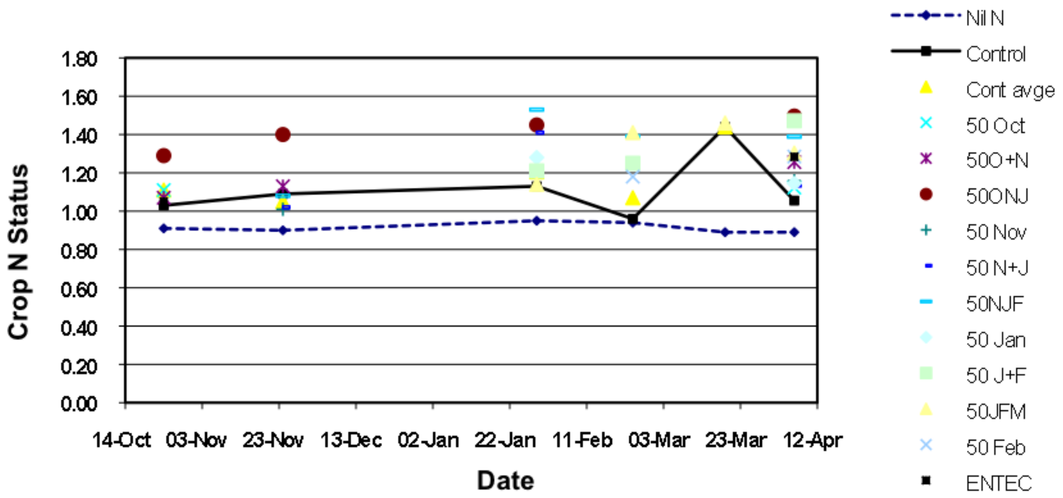

Figure 6. Crop N status during the autumn and winter period for the late maturity leek crop (last sampling point represents final harvest).

Table 39. Late maturity crop; crop N status, SMN to 60cm depth and chlorophyll concentration index (SPAD readings) on selected treatments - assessment on 25th Oct 2013 before late October N application.

Treatment	Nil N	1	2	3	4	12
		RB209 control	50kg/ha early Oct	50 kg/ha early Oct + 50 kg/ha early Nov	50 kg/ha early Oct + 50 kg/ha early Nov+ 50kg/ha late Jan	100 kg/ha Entec
Crop N status	0.91	1.03	1.11	1.07	1.29	1.05
SPAD	71.3	74.1	-	-	-	-
SMN (kg/ha)						
0-20 cm	5.2	6.7	11.4	10.4	9.8	9.8
20-40 cm	6.2	7.2	20.7	16.3	12.7	10.4
40-60 cm	9.8	11.2	27.8	13.1	17.2	20.2
Total 0-60 cm	21.3	25.1	59.8	39.8	39.7	40.4

Table 40. Late maturity crop; crop N status, SMN to 60cm depth and chlorophyll concentration index (SPAD readings) on selected treatments - assessment on 25th Nov 2013 before late November N application

Treatment	**Nil N**	**1**	**3**	**4**	**5**	**6**	**7**
		RB209 control	50 kg/ha early Oct + 50 kg/ha early Nov	50 kg/ha early Oct + 50 kg/ha early Nov+ 50 kg/ha late Jan	50 kg/ha early Nov	50 kg/ha early Nov + 50 kg/ha late Jan	50 kg/ha early Nov + 50 kg/ha late Jan + 50 kg/ha late Feb
Crop N status	0.90	1.09	1.13	1.40	1.01	1.02	1.08
SPAD	66.1	68.2	72.5	-	-	66.3	-
SMN (kg/ha)							
0-20 cm	4.6	7.4	37.7	119.2	8.1	5.8	7.4
20-40 cm	5.3	7.1	16.6	36.4	9.1	8.7	9.6
40-60 cm	6.2	11.6	15.2	17.7	11.7	8.8	7.9
Total 0-60 cm	16.1	26.1	69.5	173.3	28.8	23.2	24.9

Table 41. Late maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) on selected treatments - assessment on 30th Jan 2014 before late Jan application.

Treatment	**Nil N**	**1**	**4**	**6**	**7**	**8**	**9**	**10**
		RB209 control	50 kg/ha early Oct + 50 kg/ha early Nov+ 50 kg/ha late Jan	50 kg/ha early Nov + 50 kg/ha late Jan	50 kg/ha early Nov + 50 kg/ha late Jan + 50 kg/ha late Feb	50 kg/ha late Jan	50 kg/ha late Jan + 50 kg/ha late Feb	50 kg/ha late Jan + 50 kg/ha late Feb + 50 kg/ha March
Crop N status	0.95	1.13	1.45	1.41	1.53	1.28	1.21	1.14
SPAD	66.3	73.9	-	75.9	-	-	-	-
SMN (kg/ha)								
0-20 cm	4.8	4.8	33.7	15.4	19.0	9.0	4.6	6.0
20-40 cm	4.6	7.5	39.1	16.3	14.8	6.8	7.4	5.0
40-60 cm	3.1	6.2	31.1	12.0	11.0	9.8	4.4	3.0
Total 0-60 cm	12.5	18.5	104.0	43.7	44.8	25.6	16.4	14.1

Table 42. Late maturity crop; crop N status, SMN to 60cm depth and chlorophyll concentration index (SPAD readings) on selected treatments - assessment on 24th Feb 2014 before late February N application.

Treatment	**Nil N**	**1**	**7**	**9**	**10**	**11**
		RB209 control	50 kg/ha early Nov + 50 kg/ha late Jan + 50 kg/ha late Feb	50 kg/ha late Jan + 50 kg/ha late Feb	50 kg/ha late Jan + 50 kg/ha late Feb + 50 kg/ha March	50 kg/ha late Feb
Crop N status	0.94	0.96	1.39	1.25	1.41	1.18
SPAD	67.6	74.4	-	-	76.6	-
SMN (kg/ha)						
0-20 cm	2.6	3.4	122.2	101.4	64.5	6.0
20-40 cm	6.2	6.2	18.6	16.9	14.9	7.6
40-60 cm	2.8	4.5	11.4	6.7	6.4	3.5
Total 0-60 cm	11.6	14.1	152.2	124.9	85.8	17.1

Table 43. Late maturity crop; crop N status, SMN to 60 cm depth and chlorophyll concentration index (SPAD readings) on selected treatments - assessment on 20th Mar 2014 before March N application.

Treatment	**Nil N**	**1** RB209 control	**10** 50 kg/ha late Jan + 50 kg/ha late Feb + 50 kg/ha March
Crop N status	0.89	1.44	1.46
SPAD	73.6	80.2	82.8
SMN (kg/ha)			
0-20 cm	67.3	65.1	258.3
20-40 cm	22.8	13.2	40.5
40-60 cm	10.3	14.2	41.3
Total 0-60 cm	100.4	92.6	340.1

Discussion

Main N applications

At the early and mid maturity leek sites, the main N application (control application for experimental purposes) by the grower increased marketable yields by 28 and 13 t/ha respectively compared to yields of the nil N areas of the crop. These observations broadly support the recommendations given in the Fertiliser Manual (RB209).

However at the late maturity site, there was no increase in yield in response to the main N application. With an initial SNS index of 2, a positive response to N would have been expected. It could be that the slower growing late maturity crop actually had a lower requirement for N early in the season and this is discussed further below (see 'Patterns of crop growth' section).

Finally it should be noted that an alternative explanation to the high yields with nil N, is the possibility that N was overspread at the end of the trial, although it would be unusual to be spreading N in late February/early March. Moreover this would not have affected the observations of crop growth in October, which are discussed below.

Response to supplementary N

Taking into account the supplementary N treatments, there was only a small effect on total FW yield and marketable yield when the effects were averaged across the different timings and N rates, but supplementary N generally increased the proportion of marketable plants. In early and mid experiments, the main reason for the improvements in the proportions of marketable plants was a reduction in the number of undersized plants rejected (based on shaft thickness). When the individual supplementary N treatments were studied in more detail, timing of supplementary N applications appeared to affect the proportion of marketable plants.

The results with respect to supplementary N applied during autumn/winter can be summarised as follows:

For the early maturity crop (RB209):

- Supplementary N in October (50 kg/ha) gave a significantly higher proportion of marketable plants than in November,
- An additional 50 kgN/ha in November increased the yield of marketable plants,

- Where 50 kgN/ha was applied in November and January the proportion of marketable plants decreased.

For the mid maturity crop (RB209 +40 kgN/ha):

- Supplementary N in October (50 kgN/ha) led to a higher proportion of marketable plants,
- Late applications (November and January) gave significantly lower proportions of marketable plants than the control and October application,
- There was no significant effect of the rate of supplementary N applied.

For the late maturity crop (RB209+13 kgN/ha):

- This site was largely unresponsive to N fertiliser as the yield difference between the Nil N and control N treated plots was small,
- There was only 4 t/ha growth and 100 kgN/ha uptake by October,
- The control treatment supplied the largest proportion of marketable leeks, adding N in October made no difference but N applied later significantly decreased the proportion of marketable plants.

It must be remembered that these experiments were carried out in a single season, which had an unusually warm winter. There was no frost damage, therefore we saw the full crop potential in terms of improvements in the proportion of marketable plants from application of supplementary N. The conclusions could be quite different in a normal winter, however it is probably the late maturity crops, which are most at risk from frost in the coldest months (late January/February/March/April).

Potential use of nitrification inhibitors

For all crops, Entec (100 kgN/ha) applied at the start of autumn only showed small benefits in terms of marketable yields (summarised in Table 44). The nitrification inhibitor in Entec (DMPP) will in theory keep the N in the soil, and reduce the risk of nitrate leaching, theoretically releasing the N more slowly to the crop over winter. However, the results show that it was the early application of supplementary fertiliser N (i.e. October/November) that was generally best. Therefore there is a danger that Entec would release the N too slowly in the autumn to satisfy crop demand.

Table 44. Effects of Entec treatment (100 kgN/ha applied in October) on marketable yields N in marketable crop and residual SMN (0-90 cm) at harvest, compared to control treatment and individual treatment showing highest marketable yield in each experiment (significance based on LSDs from ANOVA).

Crop maturity	Treatments	Marketable plants FW yield (t/ha)	Marketable crop N offtake (kgN/ha)	Nitrogen in unmarketable crop and residues (kgN/ha)	Residual SMN at final harvest (kgN/ha)†
Early	*Control*	34.8	106	183	34
	Highest¶	45.5	151	217	209
	Entec	32.0	115	206	231
	Significance	ns	ns	ns	
Mid	*Control*	20.6	46	128	7
	Highest	34.6	97	152	18
	Entec	32.8	94	208	86
	Significance	*	*	*P<0.1*	
Late	*Control*	30.4	66	137	103
	Highest	35.4	73	199	97
	Entec	38.8	99	208	278
	Significance	ns	ns	**	

†, No ANOVA carried out for SMN data

¶, Treatments with highest marketable yields in each experiment: Early, 100 kgN/ha Oct/Nov; Mid, 50 kgN/ha Oct/Nov; Late, 100 kgN/ha Oct/Nov.

Patterns of crop growth

A pre-requisite to accurately predicting crop N requirement, is to understand the patterns of growth and when the main phases of N accumulation occur. These experiments were not designed specifically to measure patterns of crop growth in different leek maturity types. However, samplings made on nil N, control and plots prior to application of supplementary N, as well as growth analysis at final harvest, allowed useful comparison of crop growth and uptake over autumn and winter (Figs. 1 to 3).

It appeared that the early maturity crop took up more N early in the season compared to later maturing crops, and clearly needed to have any supplementary N applied by October in order to improve marketable yield. The mid maturity crop was similar in growth pattern to the early crop but had accumulated less N by October. However the late maturity crop was most distinct in that the control treatments (which had received the main grower N applications only) had only accumulated 40 kg/ha more N than the nil N treatments by

October, and had taken up a maximum of ca. 140 kgN/ha. For the mid and early maturity crops, the corresponding figures were 200 and 250 kgN/ha respectively in October 2013. This implies that the late maturing crop has less need for N early in the season, but made up most of its growth at the end of the season. Moreover there would be a danger of applying N too early, as the late maturity crop must normally survive the period of hard winter frosts to carry over marketable crop into April.

Currently, recommendations based on leek maturity type are not taken into account in the Fertiliser Manual, and with the caveat that these results are based on a single site and season (and a warm winter without any appreciable periods of frost), further research would be required to fine tune N recommendations for late leek maturity types. The previous project (FV350) only studied early crops, and there is a need for further data on patterns of growth and N uptake for late (or slower) maturing crops, which may not need N till the following spring. Moreover there may be a greater risk of over-applying N to the late crops early in the season which would then make them susceptible to frost damage in the late winter,

It is not clear why the crops responded best to early autumn applications of N to improve marketable yields, when the main period of uptake of N did not appear to occur until the end of their respective growth periods. It could be that because the leeks roots are in a narrow band between 15 and 45 cm below the soil surface that N applied cannot reach the rooting zone immediately, and needs time to leach through the topsoil and reach the rooting zone. Further work is required to understand where the leek roots are, and what the most efficient way is to deliver fertiliser N to them. Theoretically, one way to improve N use by the leek crop might be to inject N directly into the rooting zone, but this would have to be done without damaging the plants.

Crop nitrogen economy

Total N uptake was significantly increased by supplementary N, and was around 50 kgN/ha greater in the early and late crops, and 75 kgN/ha greater than the control in the mid maturity crop at harvest. The important question however is whether this uptake, is useful to yield or appearance of the crop, or whether it just leads to more N in crop or soil residues which could have deleterious effects for the environment if the following crops do not make use of it.

Supplementary N increased the N removal by the marketable crop in two out of three cases, but also increased the N (kg/ha) in the unmarketable crop fractions and residues. The other way of considering the environmental impacts is to look at the residual SMN left after harvest. Applying 50 kgN/ha as supplementary N left on average 45, 17 and 36 kgN/ha, whereas applying 100 kgN/ha left 210, 67 and 128 kgN/ha (0-90 cm depth) for early, mid and late maturity crops respectively, more than the control in each experiment. This is additional to the N left in crop residues and unmarketable fractions of the crop referred to above. Clearly if this N is not taken into account when making fertiliser recommendations for the following crop, then such winter treatments pose a risk of diffuse pollution in the subsequent season, if not captured by the following crop.

The following crop can benefit directly by requiring less fertiliser N itself because of a higher SNS, or after processing vegetable wastes through an anaerobic digester, with N being returned in digestate. The gap between harvesting the leeks and establishing the future crop will dictate how much N will be of benefit on these light sands.

Assessment of crop N status and soil mineral N to guide fertiliser decisions

Measurements of crop N status (CNS), SPAD and SMN were made just prior to each of the supplementary N applications, to see if they could be used to predict the likely responses to fertiliser N. In these experiments the tests were less conclusive than had been hoped. The results can be summarised as follows:

- CNS and SPAD readings could discriminate between nil N and control treatments in the early and mid maturity crops, but not in the late crop indicating there was no need for additional N,
- CNS and SPAD readings were higher in the early than in the mid maturity crop, supporting the observations of a) of higher total N uptakes in the autumn in the early crop, and b) the greater responsiveness of the mid maturity crop to applied N,
- CNS and SPAD readings were similar for the mid and the late maturity crops, despite the fact that the two crops behaved quite differently; the mid crop being responsive to N, and the late maturity crop being relatively unresponsive to N, until the final month of growth,
- For the crops with an apparent ‘adequate CNS’ (i.e. the early and late crops), the measurements showed a higher CNS in those individual treatments which had previously received 50 or 100 kg/ha supplementary N,
- Measurement of SMN through the winter (i.e. before each 50 kgN/ha addition of supplementary N) also showed that SMN was ca. 10 kgN/ha higher (to 60 cm depth) in the late crop.

Clearly CNS and perhaps SPAD have some potential for assessing crop N requirement, but require further validation across late types. CNS relates actual crop N concentration to expected N concentration based on its total DW. However CNS *per se* cannot predict future N demand, and this is something which probably relates to the rate of development and hence maturity type of the crop. Moreover it is difficult to predict the responses of FW yield and marketability when these appear to be independent of changes in DM yield. There was evidence in these experiments for increases in shaft diameter in response to supplementary N, which implies increases in cell size or number, but it is not clear whether this expansion is physiologically driven and itself drives N uptake, or conversely whether cell expansion is in response to ‘luxury’ N uptake. CNS may be usable to know when not to apply further N, especially when there is risk of frost damage, if say if CNS is > 1.2 (see HDC Factsheet 32/12) further N should not be applied.

Conclusions

- The recommendations provided in the Fertiliser Manual (RB209) are broadly correct for deciding on the main N application to the leek crop,
- Leeks appear to respond to up to 100 kgN/ha of supplementary N in early autumn (October/November), which can be used to increase the proportion of marketable plants and/or marketable yields,
- However there is an indication that late maturing crops may not need this N until later in their growing season, and it may be sensible to delay such applications (and even part of the main dressing) until after the main danger of frost has passed; further work is required to substantiate this, however in this study, late applications of N appeared to reduce the proportion of marketable plants,
- There appears to be little benefit in using an N fertiliser product containing a nitrification inhibitor to provide supplementary N, as it may not release the N quickly enough to benefit the crop in October/November,
- Measurements of crop N status appear to have some potential to identify crops with no further fertiliser N requirement, but more information is needed on CNS of different maturity types in relation to their patterns of growth before they can be used as diagnostic tests to predict the benefits of applying supplementary N,
- Despite the potential benefits, crops over-fertilised with N can become more frost sensitive. The experiments described here were carried out in a very mild winter, with no major periods of frost or snow, but if the winter had been harsh, then marketable yields could well have been lower with supplementary N,

- Growers should take into account the N from crop residues and unmarketable plants and any residual SMN from supplementary N applications when making fertiliser recommendations for the following crop (see HDC Factsheet 09/12).

Further work

Further work is desirable to:

- Understand the patterns of growth and N uptake of late leek maturity types, to confirm whether these should ultimately be reflected in separate recommendations in any future revision of the Fertiliser Manual,
- Understand how the crop's demands for N over time, interacts with its crop N status measured at a point in time in its growth,
- Improve the timing and possibly placement of N to assure its capture and rapid uptake by the leek crop in order to improve efficiency of N use.

Knowledge and Technology Transfer

An article for HDC News 'The right time for a top-up' was published in HDC News 3, November 2014.

A presentation to the Leek Growers at their Agronomy Day in February 2015.

Glossary

ANOVA	Analysis of variance
CNS	Crop nitrogen status
DW	Dry weight
DMPP	Dimethylpyrazole phosphate
FW	Fresh weight
LSD	Least significant different (95% probability)
N	Nitrogen
NVZ	Nitrate vulnerable zone(s)
OM	Organic matter
RB209	Defra Fertiliser manual
SMN	Soil Mineral nitrogen
SNS	Soil nitrogen supply
SPAD	Arbitrary units used to measure chlorophyll concentration index

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Appendices

Table A1. Early maturity leek crop – final SMN to 90 cm depth in 30 cm increments.

Treat code	Desc	SMN 0-30 cm (kgN/ha)	SMN 30-60 cm (kgN/ha)	SMN 60-90 cm (kgN/ha)	SMN 0-90 cm (kgN/ha)
1.	*Control*	10.1	7.8	15.8	33.7
2.	*50 kg late Oct*	39.6	22.7	26.3	88.7
3.	*50 kg late Oct + 50 kg late Nov*	67.2	94.5	47.7	209.4
4.	*50 kg late Nov*	19.4	35.7	13.1	68.2
5.	*50 kg late Nov+ 50 kg early Jan*	196.9	47.6	30.3	274.8
6.	*50 kg early Jan*	121.8	13.0	11.6	146.4
7.	*100 Entec*	161.2	40.7	28.7	230.7
Nil N		4.5	4.2	3.8	12.5

Table A2. Mid maturity leek crop – final SMN to 90 cm depth in 30 cm increments.

		SMN 0-30 cm (kgN/ha)	SMN 30-60 cm (kgN/ha)	SMN 60-90 cm (kgN/ha)	SMN 0-30 cm (kgN/ha)
1	*RB209 control*	3.5	1.6	2.0	7.0
2	*50 kg late Oct*	9.6	3.9	4.1	17.5
3	*50 kg late Oct + 50 kg late Nov*	16.4	17.5	6.9	40.8
4	*50 kg late Nov*	11.6	3.3	2.8	17.7
5	*50 kg late Nov+ 50 kg early Jan*	26.9	6.2	5.0	38.0
6	*50 kg Early Jan*	27.1	5.3	3.8	36.2
7	*50 kg early Jan+ 50 kg late Jan*	196.1	11.9	16.6	224.7
8	50 kg late Jan	5.8	4.6	46.0	56.4
9	*100 Entec*	62.5	13.8	9.7	86.0
Nil N		4.1	2.3	1.6	8.0

Table A3. Late maturity leek crop – final SMN to 90 cm depth in 30 cm increments

Treat code	Desc	SMN 0-30cm (kgN/ha)	SMN 30-60cm (kgN/ha)	SMN 60-90cm (kgN/ha)	Total SMN 0-90cm (kgN/ha)
1	*RB209 control*	74.8	11.2	17.2	103.2
2	*50 kg late Oct*	85.2	19.9	41.2	146.3
3	*50 kg late Oct + 50 kg late Nov*	55.1	17.0	24.4	96.5
4	*50 kg late Oct + 50 kg late Nov+ 50kg late Jan*	131.2	21.5	37.7	190.4
5	*50 kg late Nov*	47.6	10.2	14.2	72.0
6	*50 kg late Nov+ 50 kg late Jan*	69.7	22.6	23.1	115.5
7	*50 kg late Nov+ 50 kg late Jan+ 50 kg late Feb*	321.9	15.3	22.4	359.7
8	*50 kg late Jan*	15.6	26.0	157.9	199.5
9	*50 kg late Jan+ 50 kg late Feb*	132.4	33.5	15.2	181.1
10	*50 kg late Jan+ 50 kg late Feb+ 50 kg March*	198.9	68.0	38.2	305.2
11	50 kg March	17.2	13.6	19.8	50.6
12	*100 Entec*	101.3	152.3	24.9	278.5
Nil N		52.3	11.7	12.0	76.0

Table A4. Total DW yield for early maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		**Total DW (t/ha)**				**Statistical comparisons (LSD)**
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		5.55				
Control		8.40				Control vs individual means in table, ns
Factorial design:	Oct/Nov		7.50	9.75	*8.62*	Timing, ns
	Nov/Jan		10.02	7.96	*8.99*	Rate, ns
	N Rate means		*8.76*	*8.85*		Timing x rate interaction, *** (1.314)

Additional treatments: 100 kgN/ha as Entec = 8.30; Single N application 50 kgN/ha in January = 8.52

Other treatment comparisons *** (1.034)

Table A5. Total DW yield for the mid maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Total DW yield (t/ha)				Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*Timing means*	
Nil-N		6.79				
Control		7.58				Control vs individual means in table, ns
	Oct/Nov		8.46	8.43	*8.46*	Timing, ns
	Nov/Jan		8.26	6.95	*7.61*	Rate, ns
	Early Jan/late Jan		8.46	8.32	*8.39*	
	N Rate means		*8.39*	*7.90*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 9.27; Single N application 50 kgN/ha in late January = 8.45

Other treatment comparisons, ns

Table A6. Total DW yield of the late maturity leek crop with supplementary N applied in autumn/winter period.

Treatments		Total DW (t/ha)					Statistical comparisons (LSD)
	Supplementary N application rates:	*0*	*50*	*100*	*150*	*Timing means*	
Nil-N		8.27					
Control		9.74					Control vs individual means in table, ns
Factorial treatments	Oct/Nov/Jan		10.65	11.56	12.47	*11.56*	Timing, * (0.771)
	Nov/Jan/Feb		10.19	7.71	10.21	*9.37*	Rate, ns
	Jan/Feb/Mar		9.41	10.74	10.45	*10.20*	
	N Rate means		*10.08*	*10.00*	*11.04*		Timing x rate interaction, ns

Additional treatments: 100 kgN/ha as Entec = 12.99; Single N application 50 kgN/ha in March = 10.48

Other treatment comparisons, ns