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Project leader:	Dr Clive Rahn / Mr Rob Lillywhite
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Key staff:	Rob Lillywhite – Project leader 2010/11 Clive Rahn – Project leader 2009/10 James Durnford – Crop recording
Location of project:	Warwick Crop Centre School of Life Sciences, Wellesbourne Campus Wellesbourne Warwickshire CV35 9EF and selected farm sites
Industry Representative:	Gareth Skinner
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Key words:	Leek, over-winter, nitrogen, fertiliser, RB209

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

This project provides more relevant guidelines for fertiliser recommendations in leeks by accurately assessing the N requirements of modern F_1 hybrid leek varieties to achieve their full potential yields.

Background and expected deliverables

During 2007/08, the basis for the nitrogen (N) fertiliser recommendations for field vegetable crops in the Fertiliser Manual RB209 was made more transparent. The recommendations for leeks were revised, however, there was little evidence to support the application of nitrogen during the closed periods in Nitrate Vulnerable Zones. The Leek Growers Association recommended that research was required to support applications of nitrogen for over-wintering crops.

This project aimed to validate the revised fertiliser recommendations for modern F1 Hybrid leeks, contained within the 2010 Fertiliser Manual (Defra 2010). The work also aimed to provide a basis for improved N recommendations for leeks in future revisions of the Defra Fertiliser Manual (Defra 2010).

The work looked to provide justification of the need for supplementary N fertiliser during the (closed) overwinter period where it is necessary to comply with Nitrate Vulnerable Zone regulations. New strategies to synchronise N supply to N demand in order to make more efficient use of N, especially for crops grown on very light soils were looked at. A basis for later improvements to be made to the WELL_N model to provide more accurate fertiliser recommendations was looked at.

Summary of the project and main conclusions

- The results support the revised fertiliser recommendations published in the 2010 edition of the Fertiliser Manual - RB209 (Defra 2010)
- Where leeks are to be harvested in the autumn, the application of additional nitrogen in August and September is justified
- For over-wintered crops, when summer N requirements are met, additional nitrogen may cause reductions in yield due to frost intolerance
- It is important to make allowances for the soil N supply within rooting depth at drilling/planting

In 2009 and 2010, field trials were established to test the response of over-wintered leeks (cultivar Belton) on a sandy loam site at Wellesbourne. Table 1 contains an overview of the main trial details (full details are contained in Appendix 2 of the Science Section). The key findings from both of these experiments are presented in this summary. The full findings are contained in the Science Section in the 2010 and 2011 project reports.

Table 1. Overview of the Wellesbourne field trials.

Start date	Nitrogen treatments	Mineral N at planting (kg/ha) to 90 cm (Index)	Fertiliser recommendation, kg/ha N	Main Harvest date
1 Apr 2009	Response curve to 480 kg/ha additional N at 240 kg/ha summer N level.	54 (0)	200	2 Nov 2009
19 Jul 2010	Response curve to 500 kg/ha additional N at 150 and 200 kg/ha summer N levels.	79 (1)	190	11 Apr 2011

In 2009/10, nitrogen fertiliser, up to a rate of 360 kg/ha N, was applied (as ammonium nitrate) in late May and late June, with additional amounts of 60 kg/ha in August, September, and January, February 2010. One further treatment rate of 480 kg/ha N was used, split between May and August 2009. In 2010/11, the main dressings of nitrogen were applied in August and September, with 25 kg/ha N applied at planting and additional amounts of 50 kg/ha N applied in September, October and January, February 2011.

In the 2009/10 trial, field assessments showed that most of the growth and N uptake occurred between August and November, with little occurring beyond December, and only a small amount in spring 2010. The crop was severely affected by frost in January 2010 and failed to produce any marketable yield at a final harvest in April 2010.

In the 2010/11 trial, most of the growth and N uptake occurred between August and December, despite a later planting date. The crop was severely affected by frost in December, resulting in the loss of dry matter, although the crop had partially recovered by the main harvest in April.

The main aim of the experiments was to test the response of a leek crop to additional amounts of fertiliser in the autumn/spring period. The main questions were:

- In 2009/10, was 180 or 240 kg/ha N the most appropriate amount? (Figures 1 & 2)
- In 2010/11, was 150 or 200 kg/ha the most appropriate amount?
- Were these amounts of fertiliser sufficient to supply the crop N requirement through to the spring without additional applications?
- Where additional fertiliser was required, how much should be applied?

Figure 1 (left): Leek crop in September 2009 where 240 kg/ha N had been applied, split equally between 2-3, 3-4 leaf stages (A nil N plot can be seen to the far right)

Figure 2 (right): Leek crop in September 2009 where 180 kg/ha N had been applied; split equally between 2-3, 3-4 leaf stages.

The results from the trials help to answer these questions (Table 2). In the 2009/10 trial where no nitrogen fertiliser was applied, crop growth was only 40% of that where 240 kg/ha N had been applied, and marketable yield from the unfertilised treatment was severely reduced. Where 180 kg/ha N was applied, crop growth up until November was almost the same as with 240 kg/ha N. Unfortunately, the crop failed to overwinter due to severe weather, so results presented are from the November assessment of marketable yield. Marketable yield was slightly higher where 180 kg/ha N had been applied rather than 240 kg/ha N, but not as high as where 240 kg/ha N had been applied with an additional 60 kg/ha N in both August and September.

The 2010/11 trial also suffered from severe winter weather, but at an earlier stage of growth than in 2009/10, so was able to recover to produce yield of marketable quality in April. There was a clear response up to 200 kg/ha summer applied N. Fresh weight marketable yield declined when higher amounts of N were applied. Where only 150 kg/ha N had been applied in the summer there was benefit in applying an additional 50 kg/ha N. October applied N was marginally more effective than N applied in September or the spring. More than 50 kg/ha additional N was not beneficial. Where 200 kg/ha N had already been applied, there was a depression in yield where further N was applied in the autumn, and no benefit where additional N was applied in the spring. This was associated with the interaction between N in the crop and tolerance to the severe winter conditions.

Table 2. Relative marketable yields in November 2009 and April 2011. Responses to additional N applied at Wellesbourne, where sufficient summer N had been applied. Percentage of yields: relative to 28 t/ha where 240 kg/ha N was applied in 2009, and relative to 22.1 t/ha where 200 kg/ha N was applied in 2011.

Growing season	Main N amount (kg/ha)	% Yield at 200 or 240 kg/ha N	Additional N applied*					
			Aug	**Sep**	**Both**			
2009/10	nil	15						
	180	109	nd	nd	nd			
	240	**100**	116	nd	123			
	360	93						
	480	118						
			Sep	**Oct**	**Both**	**Jan**	**Feb**	**Both**
2010/11	nil	0						
	75	43						
	150	72	84	90	71	84	85	79
	200	**100**	59	74	56	82	81	83
	300	78						
	500	72						

* 60 kg/ha N was applied at each timing in 2009 and 50 kg/ha N in 2010.

nd – not determined

From the measurements of N offtake in the crop, it is possible to estimate fertiliser recovery. Within a month of establishment, recovery was less than 3% of the N applied as fertiliser. Only by September 2009 and October 2010 did recovery reach around 30% of that applied. Any excess fertiliser N would be extremely susceptible to loss whilst the crop and its roots were still poorly developed. However, even by harvest, fertiliser recovery was less than 50%, and was lower in the poorer crop in 2011 (Table 3).

Table 3. Estimated fertiliser recovery in 2009 and 2010 experiments at Wellesbourne.

Date (2009/10 trial)	% Fert. recovery	Date (2010/11 trial)	% Fert. recovery
25 Jun 2009	2		
22 Jul 2009	12		
19 Aug 2009	22	17 Aug 2010	3
22 Sep 2009	34	15 Sep 2010	13
2 Nov 2009	47	18 Oct 2010	26
14 Dec 2009	46	13 Dec 2010	41
2 Feb 2010	46	22 Feb 2011	33
6 Apr 2010	42	14 Apr 2011	37

These results help to explain why earlier experiments (Goodlass et al., 1997) showed yield responses to high levels of fertiliser nitrogen, as it is likely that the fertiliser had been applied too early for efficient utilisation by the shallow rooted leek crop.

It may be that the higher dry weight yield in the 2009/10 trial (10.7 t/ha compared with 5.6 t/ha in 2010/11) explains the difference in response to the additional 100 kg/ha N application between the two growing seasons. Furthermore, the results of the 2009/10 trial suggest that even on fertile sites, well supplied with available N (represented by the high early N plots in the experiment), there might still be a response to additional nitrogen in August and September for an autumn harvested crop. This was not supported by the results in the 2010/11 trial where additional autumn applied N led to reduced yields. However, it must be borne in mind that this crop was planted later, suffered from severe low temperatures, and produced relatively disappointing yields.

The recommendations for leeks in the Fertiliser Manual (Defra 2010) remain valid but need to be tested at a wider range of soil N supply indices. The recovery of N mineralised from soil organic matter in the leek crop was much lower than expected and also requires some further investigation.

The trials at Wellesbourne were supplemented by the monitoring of commercial crops in 2009, 2010 and 2011, at sites representing the main growing areas of leeks in England. The results of this monitoring suggest that the commercial sites were well supplied with nitrogen, with some showing 120% of the critical N level (N status = 1.2) for a given dry matter yield, even at harvest. Figure 3 compares the results at Wellesbourne with the commercial sites in the 2010/11 season. The best yields at Wellesbourne were obtained where the crop had an N status of 0.9 and 200 kg/ha N (W-200) had been applied.

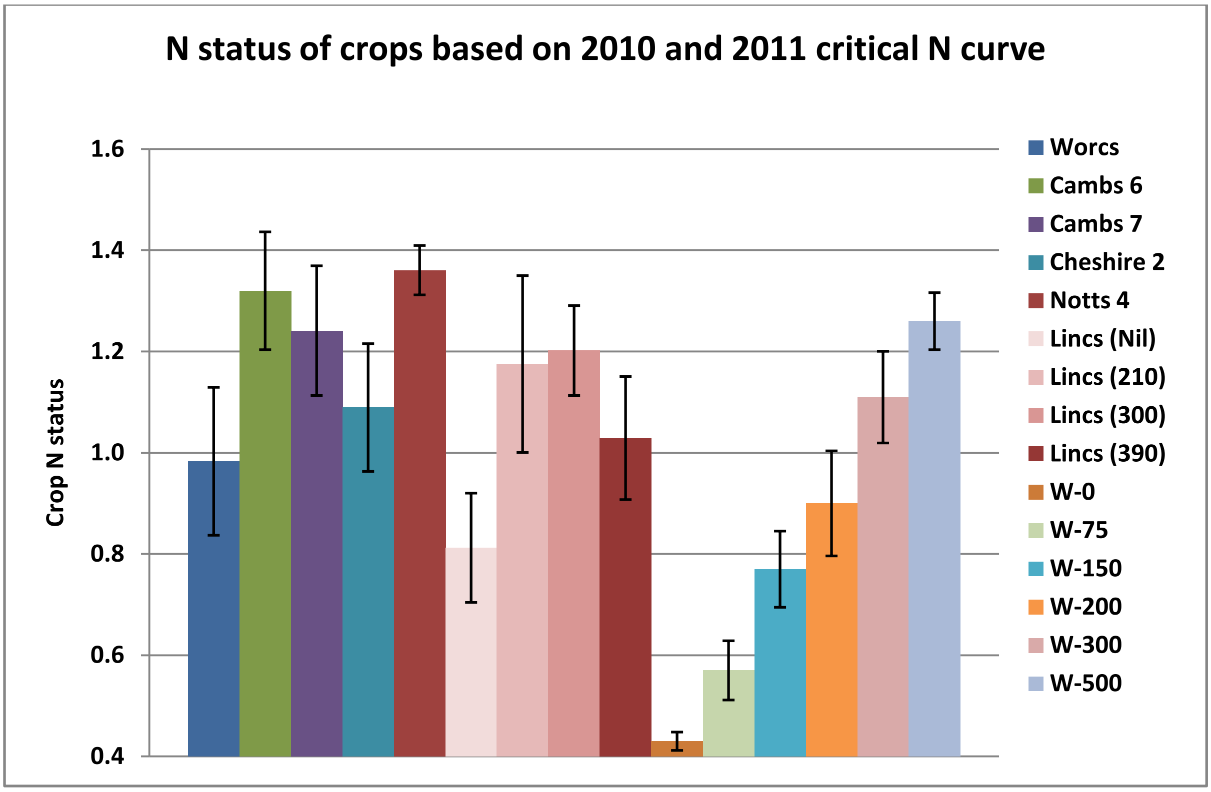


Figure 3. N status of crops in Spring 2011. Data from commercial sites with Wellesbourne (W) for comparison.

At both the commercial sites and at Wellesbourne, attempts were made to use a chlorophyll meter to assess the N status of the crops. Whilst the results indicated some differences between N treatments at a particular site, they provided no guidance on target levels that could be utilised more widely.

However, it may be possible to assess the organic N status and total dry matter yield of the crop, as illustrated above, to manage fertiliser applications. Further work is recommended to test such techniques in commercial situations, and to identify the seasons and crops in which additional N would provide the greatest benefit. This work should also include assessments of the contribution of N from mineralisation, which seems to be much lower than expected.

Financial benefits

Based on a marketable yield of 27.1 t/ha, the price of N at £1/kg N, and trimmed produce in trays ex-packhouse at £850/t, the financial effects of applying an additional 100 kg/ha N to leeks can be large.

For instance, in the 2009/10 season, there was a yield benefit of 20% at the November harvest in response to 100 kg/ha additional N applied in August and September, which resulted in a theoretical financial benefit of £4500/ha. It should be noted that the crop failed to overwinter due to the severe winter, and in April there was no marketable crop to harvest. The benefits from the additional N were only present before the severe weather set in.

However, in the 2010/11 season, there was a yield loss of up to 20% in April where the additional N had been applied in September and October, leading to a financial detriment of up to £4700/ha. In the 2010/11 season, applications of additional N in January and February had little effect on yield where sufficient N had been supplied the previous summer.

Action points for growers

The findings support the following advice:

- It is advantageous to assess soil mineral N ahead of drilling/planting future crops.
- Consider evaluating the N status of representative crops within the holding. If the crop N status is greater than 1.4, it may be that excessive amounts of fertiliser have been applied. Where this occurs, an inventory of the supply of N from soils and fertilisers should be compared with the amount of N contained in the crop.
- Fertiliser nitrogen should be split to match the growth of the crop, as large amounts of fertiliser applied within 2 months of drilling an overwintered crop are likely to be inefficiently used, especially on light soils
- It is more beneficial to apply additional N in the summer than it is to apply large amounts to the seedbed. Note: N applied during the summer will only be available to the crop if there has been rain or irrigation to wash it into the root zone, and that additional applications of N may make the crop more susceptible to frost damage.

SCIENCE SECTION

The FV 350 research project was carried out over a three year period, beginning in 2009 and ending in 2011. Over-wintered leeks were grown in the 2009/10 and 2010/11 growing seasons. The results of the 2009/10 growing season were reported in the 2010 Annual Report. This section reports the results of the 2010/11 growing season and presents conclusions for the whole project.

In the second growing season, the research was split into two parts. The first was a field trial at Wellesbourne, and the second involved the sampling of commercial crops in order to establish the range of yields and nutrient contents achieved in practice at harvest. The overall aim of the 2010/11 trial was to refine the requirements for additional N applied in the autumn or the spring. This was achieved by:

- Determining the pattern of N uptake by the F1 hybrid leek crop, particularly during the overwinter period.
- Determining the patterns of N supply, including that from the mineralisation of soil organic matter.
- Establishing the relationship between growth, marketable yield and N uptake.
- Determining the balance between early and late requirements for N fertiliser.
- Determining the most effective way of matching requirement and supply on a commercial basis.

Introduction

Previous UK experiments to test the response of older OP varieties of leeks to nitrogen (N) have shown that crop yield will increase with N applications, up to an excess of 500 kg/ha N (Goodlass et al., 1997). More recent experiments, on a loamy sand soil, demonstrated a response to 375 kg/ha N (Smith et al., 2000). This is in contrast with leeks grown on the continent where rates of N application are much lower. In these experiments, most of the N was applied within a month of transplanting. It is, therefore, likely that it was not efficiently recovered by the crop.

The decision support system WELL_N does not work well for leeks, predicting a requirement of only 150 kg/ha for the loamy sand site. The new Fertiliser Manual (Defra 2010) recommends 170 kg/ha N, with the option of an additional 100 kg/ha, which would theoretically deliver 89% of the maximum yield on the loamy sand site. However, scientific support for the additional 100 kg/ha N is not available. The proposed maximum application of fertiliser N during the closed period in NVZ areas was only 40 kg/ha N (Defra, 2007). This is in contrast with grower practice where between 80-100 kg/ha N might be required on light Nottinghamshire sands (Personal communication, P Parr, 2007).

During 2007/08, the basis for the N fertiliser recommendations for field vegetable crops in RB209 was made more transparent (Defra, 2010) in order to allow for easier updating as more information became available. The work carried out in this project would support such a revision.

Compared to the 7th edition of RB209, the recommendations for leeks in the new Fertiliser Manual (Defra 2010) provide similar recommendations for low soil nitrogen supply (SNS) soils, but larger recommendations for crops grown on high SNS soils, taking into account the poor rooting of the crop. However, there is no scientific justification for the additional 100 kg/ha across all SNS levels that are included in the recommendation tables. This project aims to investigate the justification for additional N application for the more vigorous F1 hybrid crops which are grown today.

Materials and methods

Wellesbourne field experiment

A field trial of over-winter leeks (variety Belton) was established at Wellesbourne in 2010. The trial comprised 18 treatments to test different rates of spring and overwinter applied nitrogen. Treatment details are shown in Table 4 and Appendix 1 shows the plot plan. Each plot contained 4 row beds of width 1.83 m and length 12 m, and was replicated 3 times in a row and column design. A crop was drilled on 27 April, but was abandoned in early June due to patchy establishment. The trial site was re-cultivated and planted with transplants at a density of 9 plants m^{-2}. The transplants were raised at Wellesbourne, sown on 10 June and transplanted on 19 July at the 2 true leaf stage. Crop husbandry and irrigation were managed according to normal commercial practice and details are shown in Appendix 2.

Nitrogen fertiliser (as ammonium nitrate) was applied at planting, and in August, September, October 2010, and January and February 2011, according to the schedule shown in Table 4. Treatments A to F tested nitrogen response to summer applied N, up to 500 kg/ha N. Treatments G to L and M to R tested the effects of additional N applied in the autumn (September/October) and early spring (January and February) with 150 or 200 summer applied nitrogen respectively.

Table 4. Wellesbourne experiment treatments in 2010/11.

Treatment	Total N applied	Planting 22/07/10	Aug 19/08/10	Sep 17/09/10	Oct 22/10/10	Jan 26/01/11	Feb 24/02/11
Treatments A to F testing response to N rate							
A	0	0	0	0	0	0	0
B	75	25	25	25	0	0	0
C	150	25	62.5	62.5	0	0	0
D	200	25	87.5	87.5	0	0	0
E	300	25	137.5	137.5	0	0	0
F	500	25	237.5	237.5	0	0	0
Treatments G to L testing 150 + 50 or 100 kg/ha additional N							
G	200	25	62.5	62.5	50	0	0
H	200	25	62.5	112.5	0	0	0
I	250	25	62.5	112.5	50	0	0
J	200	25	62.5	62.5	0	0	50
K	200	25	62.5	62.5	0	50	0
L	250	25	62.5	62.5	0	50	50
Treatments M to R testing 200 + 50 or 100 kg/ha additional N							
M	250	25	87.7	87.5	50	0	0
N	250	25	87.5	137.5	0	0	0
O	300	25	87.5	137.5	50	0	0
P	250	25	87.5	87.5	0	0	50
Q	250	25	87.5	87.5	0	50	0
R	300	25	87.5	87.5	0	50	50

Soil mineral N measurements were made on 15 April 2010 at three depths: 0-30, 30-60 and 60-90 cm. Ten cores were taken per block and the samples bulked together for analysis. Further measurements of soil mineral N were made on 13 July, 16 August, 13 September, 20 October and 15 December 2010, and 22 February and 12 April 2011. Plant samples were taken from treatments A to F within 2 days of the soil sampling to determine fresh and dry matter yield and target concentrations of N for different stages of growth. At each sampling date, 1.0 m of double row was taken from the middle row of each plot. Subsamples were taken from this material and dried at 80°C to determine DM% and N content. The final harvest was carried out on 12 April 2011, where marketable yield was assessed. Product was graded according to commercial loose leek specifications (Appendix 6).

Weights of unmarketable plants, marketable product and trimmings were recorded, with sub-samples again dried at 80°C to determine DM% and N content. Root development at harvest was visually assessed.

Chlorophyll content measurements

Measurements of leaf colour were made on 18 October 2010 using a Minolta Chlorophyll Meter (SPAD-502). For each plot, a minimum of 12 readings were taken, each from separate plants. The youngest fully expanded leaf was selected and the reading taken approximately three quarters of the way up from the base, avoiding the mid-rib in all cases.

Sampling of commercial crops

Experimental data from the Wellesbourne trial was used to elucidate the relationship between nitrogen content and total dry matter yield for the leek crop, but only at that site. The wider significance of this relationship can be assessed by comparing it with data from commercial crops. Additionally, data from the commercial sites will illustrate the expected targets for yield and nitrogen offtake required for the production of quality crops of leeks on a wider basis.

For the 2010/11 season, a survey was carried out in the spring to determine targets for dry matter yield and nitrogen content for six commercial crops (Table 5). At the Lincolnshire site, areas within the commercial crop were subjected to four nitrogen fertiliser treatments: 1) normal farm practice, 2) 30% more than normal farm practice, 3) 30% less than normal farm practice and 4) no N fertiliser. Crop samples were collected by Warwick Crop Centre staff from these different treatments just prior to harvest in the spring (see Appendix 3).

Table 5. Commercial sites sampled in 2010/11 season.

Site Name	Soil Type	Previous Crop	Variety	Fertiliser rate (kg/ha)
Worcester	Sandy loam	Barley	na	153
Cambs 6	Black fen over gravel	Sugar Beet	Lexton	207
Cambs 7	Black Fen over gravel	Sugar beet	Lampton	207
Cheshire 2	Silt	na	Galvani	155
Notts 4	Sandy loam	Wheat	Antiope	285
Lincs	Sand	Sugar beet	Belton	0-390

na - information not available.

Data handling and statistics

Curve fitting and determination of critical N curve

For each of the plant sampling dates at Wellesbourne in 2009, 2010 and 2011, nitrogen response curves of the linear exponential form (Goodlass et al., 1997) were fitted to the fresh weight and dry matter yield data in order to determine the optimum organic N concentration for each sampling date.

$$Y = a + br^N + cN$$

Where a, b and c are parameters controlling the shape of the curve, N is the rate of N fertiliser applied and Y the dry matter yield. The value of r was set at 0.99. The optimum N supply was that defined as the minimum amount of fertiliser N providing the maximum dry matter yield.

Dry matter yield and organic N for each of these optimum points was plotted on another graph and a line based on the equation below was fitted to provide a critical N curve. Generally, critical N concentration declined as yields increased in a manner similar to that used by Greenwood (2001). Data was excluded where yields were less than 2 t/ha dry weight (a condition of the Greenwood work).

$$\%N_{Crit} = a(1 + be^{-0.26W})$$

Where a and b are parameters controlling the shape of the curve, and W is the total dry matter yield (t/ha). GENSTAT routines were used to estimate the values of a and b. It was hypothesised that the further a point was away from this critical curve, the more limited growth would be. Further graphs were drawn using Wellesbourne data to compare:

- Actual N% / critical N% (defined as crop N status)
- Dry matter yield achieved /dry matter yield potential

The potential dry matter yield was provided by the yield response curves described above. An N status of 1 indicates that N supply is matched with nitrogen demand, providing the maximum potential for growth. Values greater than 1 indicate an excess of N. Values less than 1, such as those where no fertiliser had been applied, suggest that N was in short supply and that growth was likely to be limited.

These relationships were then used to test the nitrogen status of the crops sampled at the commercial sites in order to provide targets for growth and nitrogen accumulation for the leek crop.

Analysis of Variance

Where appropriate, GENSTAT was used as a tool to calculate the analysis of variance of the data. Errors are shown as standard error of the difference (SED) at the $p = < 0.05$ level, except where indicated.

Weather in the 2010/11 season

Rainfall was exceptionally high in August 2010 but lower than average through the winter and the following spring (March and April 2011 being particularly dry and mild). Temperatures were close to the average except December, which was severely cold with minimum temperatures below -10°C on 7 days between 19 and 27 December (see Appendix 5).

Results 2010/11

Wellesbourne field experiment

Growth

The growth of the crop, as dry matter yield, was monitored on six occasions during the year. The crop was relatively late planted in July, but more than half of the final dry matter was accumulated by December. Dry matter yield declined after the December sampling because of severely low temperatures. However, the crop recovered, with significant growth between February and the final harvest in April (Figure 4 and Table 6).

A strong response to nitrogen fertiliser was expected, since the Fertiliser Manual (Defra 2010) recommended 190 kg/ha N (the SNS Index just prior to planting was nearly two). Growth on unfertilised plots was restricted, with only 36% of the dry matter yield of well fertilised plots achieved by harvest 2011. Plots receiving 150 kg/ha N had 82% of the growth of plots receiving 200 kg/ha N. Plots receiving more than 200 kg/ha N showed similar or lower levels of dry matter growth.

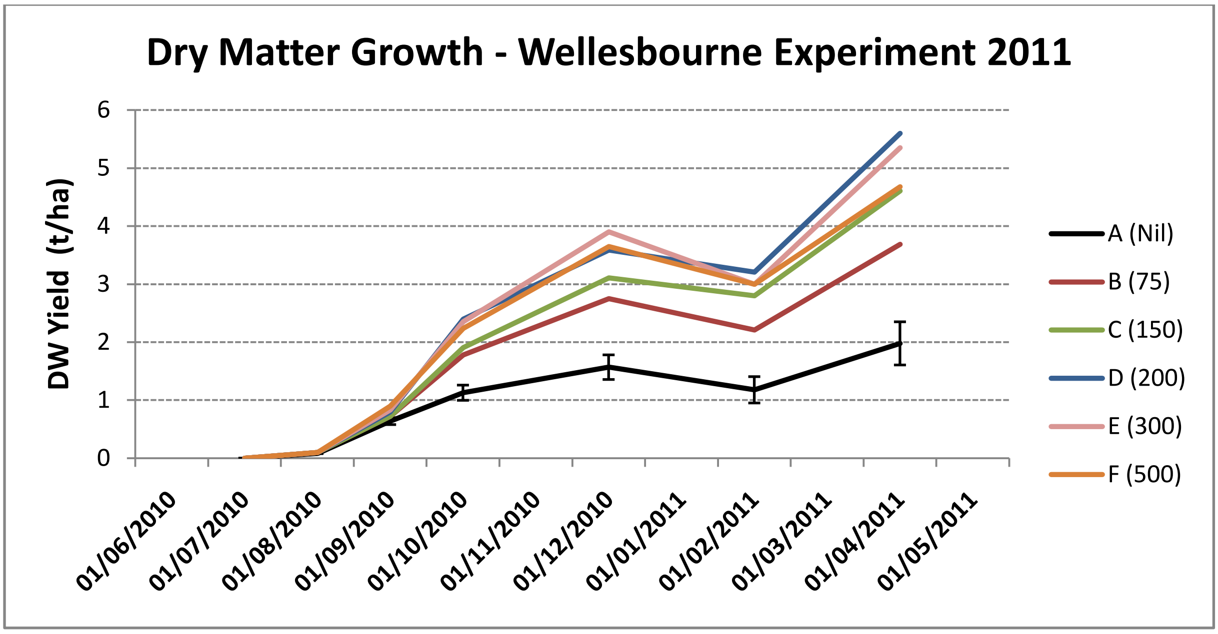


Figure 4. Accumulation of crop dry matter with time. SEDs for all N levels are shown as bars on the unfertilised nil N line.

Table 6. Relative dry matter yield (to 200 kg/ha N) of leeks over time in the 2010/11 Wellesbourne experiment. The figures in parentheses are the actual dry weight yields in t/ha.

Treatment and total N (kg/ha)	17 Aug 2010	15 Sep 2010	18 Oct 2010	13 Dec 2010	21 Feb 2011	12 Apr 2011
A (nil)	83	80	46	44	38	36
B (75)	100*	90	75	78	69	66
C (150)	100*	90	79	86	88	82
D (200)	**100(0.1)***	**100(0.8)**	**100(2.4)**	**100(3.6)**	**100(3.2)**	**100(5.6)**
E (300)	100*	104	96	108	94	96
F (500)	100*	112	92	103	97	84

* 25 kg/ha N was applied at planting and the balance split equally between August and September.

The response to fertiliser nitrogen varied between dates of sampling, with the largest response generally seen later in the growing season. Figures 5 and 6 show the relationships for September 2010 and February 2011, respectively. The response to nitrogen applied in September 2010 was much less than in February 2011. It is interesting to note that there was a response to the maximum amount of N applied (262 kg/ha N) in September 2010. Responses to N remain high until January (see Table 7). This provides some guidance on the concentration of N required within the root zone during the early stages of growth. This may not be important for long season overwintered crops as early differences in growth could be made up for later in the season.

Table 7. Estimated amounts of N for maximum dry matter growth, and organic N content for main sampling dates in 2010 and 2011.

Date	N level for max growth kg/ha	% Organic N at this level of N	Dry matter yield t/ha at this level of N
2010/11			
15 September	>263	3.77	0.9
18 October	357	3.71	2.3
13 December	444	3.65	3.74
22 February	331	3.81	3.11
12 April	269	2.03	5.24
2009/10			
25 June	192	3.21	0.19
19 August	416	2.86	4.21
22 September	217	1.92	6.82
2 November	293	1.99	9.79
14 December	317	2.23	8.89
2 February	339	2.25	10.7

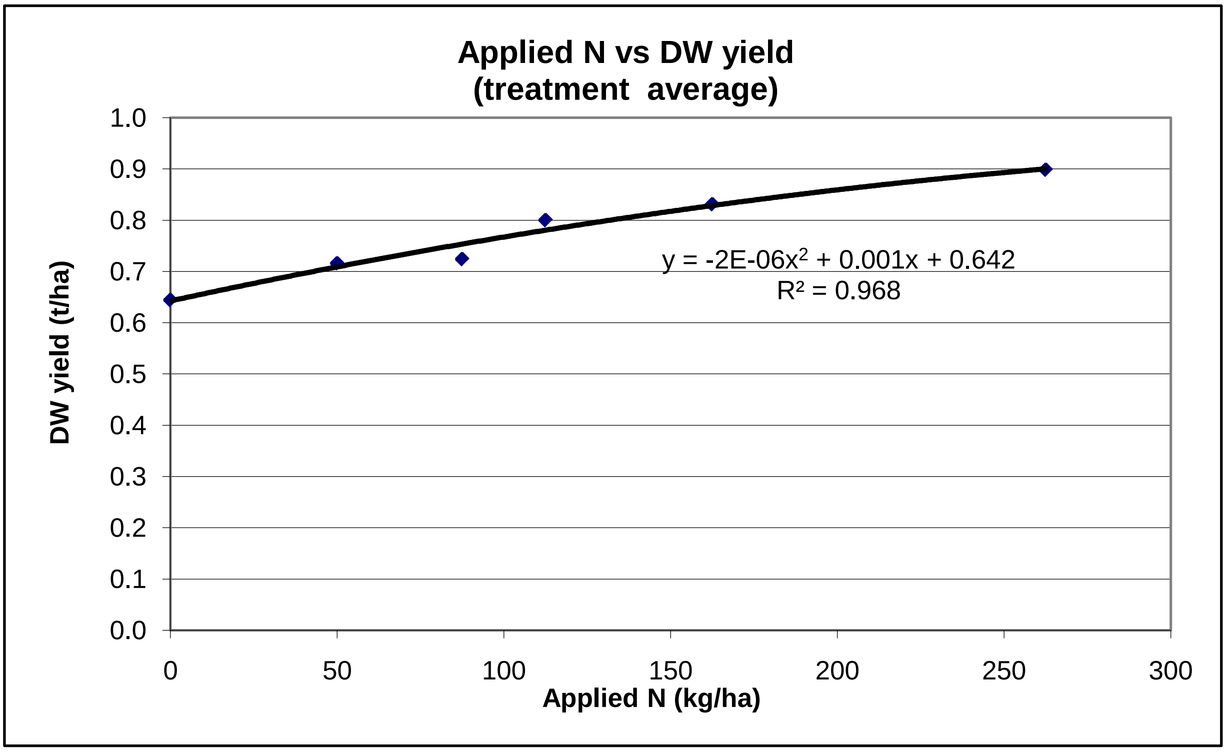


Figure 5. N response curve: dry weight yield 15 September 2010

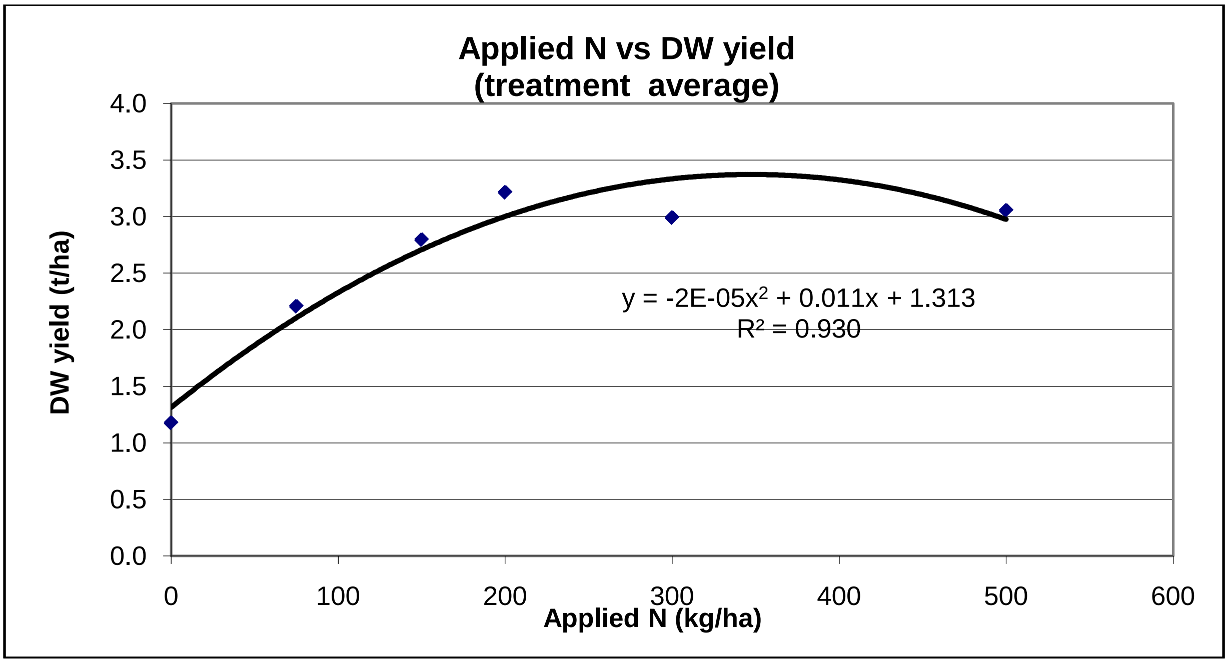


Figure 6. N response curve: dry weight yield 22 February 2011 (with fitted quadratic line shown).

Marketable yield

Table 8 presents the data gathered at the harvest of the second seasons trial in April 2011. All of the data shows a clear response up to 200 kg/ha N. Fresh weight marketable yield declined when higher amounts of N were applied. Where only 150 kg/ha N had been applied in the summer, there was benefit in applying an additional 50 kg/ha N, with October N being marginally more effective than N applied in September or the spring. More than 50 kg/ha additional N was not beneficial. Where 200 kg/ha N had already been applied, there was a depression in yield where additional N was applied in the autumn or the spring. This was associated with the interaction between N in the crop and tolerance to the severe winter conditions. Figure 7 shows the fitted response of fresh weight marketable yield. Maximum yield was obtained with 264 kg/ha N. If the Fertiliser Manual (Defra 2010) recommended rate of 190 kg/ha N had been applied, 97% of the yield would have been achieved. It could be argued on the basis of this fitted line that additional N may provide additional yield, but in practice this was not the case as additional N applied in the autumn had a large adverse effect on yield. Additional N applied in the spring provided no benefits compared with 200 kg/ha N applied in the summer.

The figures for the percentage number of plants planted achieving marketable yield varied in a similar manner to fresh weight marketable yield. In the unfertilised treatments, the main reasons for non-marketability were small size, whereas internal browning and rotting were the main reasons in those plots receiving more than 200 kg/ha N.

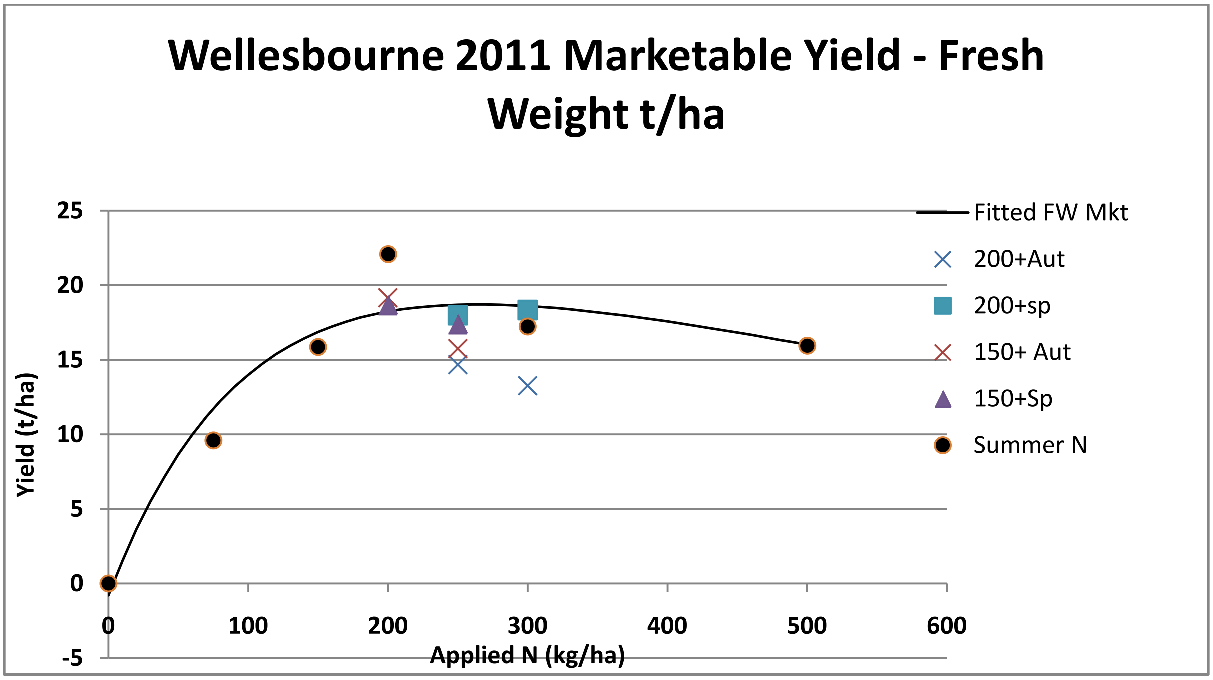


Figure 7. Marketable yield and the effect of additional N applied in autumn and spring on yield. Line fitted from data (circles) using the linear exponential model, (R^2 = 0.8), where a maximum fitted yield of 18.7 t/ha was achieved with 264 kg/ha N. The yield estimated at 200 kg/ha summer N was 18.2 t/ha.

Table 8a. Wellesbourne, 2010/11 trial. Marketable yield (t/ha) at final harvest. Marketable yields graded according to Simms and Wood.

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	0	-	-	-	-	-	-
75	9.6	-	-	-	-	-	-
150	15.9	18.5	19.8	15.8	18.5	18.8	17.4
200	22.1	13.0	16.4	13.3	18.1	17.9	18.3
300	17.2	-	-	-	-	-	-
500	15.9	-	-	-	-	-	-

SED = 2.891, p = 0.045

Table 8b. Wellesbourne, 2010/11 trial. Percentage of total crop that was marketable.

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	0	-	-	-	-	-	-
75	44	-	-	-	-	-	-
150	63	68	57	62	65	68	68
200	71	46	63	55	66	62	63
300	59	-	-	-	-	-	-
500	57	-	-	-	-	-	-

SED = 9.9, p = 0.39

Table 8c. Wellesbourne, 2010/11 trial. Total fresh weight yield (t/ha).

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	15.3	-	-	-	-	-	-
75	29.1	-	-	-	-	-	-
150	38.1	45.2	44.5	41.0	44.2	41.2	40.1
200	48.6	39.0	38.8	36.0	40.7	46.9	42.4
300	45.8	-	-	-	-	-	-
500	41.5	-	-	-	-	-	-

SED = 3.82, p = <0.001

Table 8d. Wellesbourne, 2010/11 trial. Total dry weight yield (t/ha).

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	2.0	-	-	-	-	-	-
75	3.7	-	-	-	-	-	-
150	4.6	5.3	5.2	4.7	5.2	4.8	4.5
200	5.6	4.4	4.3	4.0	4.5	5.5	5.0
300	5.4	-	-	-	-	-	-
500	4.7	-	-	-	-	-	-

SED = 0.49, p = <0.001

Table 8e. Wellesbourne, 2010/11 trial. Residue fresh weight yield (t/ha).

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	15.3	-	-	-	-	-	-
75	19.6	-	-	-	-	-	-
150	22.2	26.7	24.6	25.3	25.7	22.4	22.7
200	26.5	26.0	22.4	22.7	22.6	29.0	24.0
300	28.6	-	-	-	-	-	-
500	25.6	-	-	-	-	-	-

SED = 2.14, p = <0.001

Patterns of total fresh weight yields and total dry weight yield follow those of marketable yield, with the optimal quantity of nitrogen being around 200 kg/ha. The amounts of fresh residues left at harvest were largest where 300 kg/ha N had been applied in the summer.

Nitrogen offtake

Figure 8 summarises above ground crop nitrogen offtake. Offtake was relatively small until September 2010, with the main period of uptake being from August until December 2010. N offtake peaked in December 2010 before falling after the sharp December frosts. However, offtake measured in February 2011 was only slightly lower than that measured in December 2010. In spite of additional growth in treatments A to F between December 2010 and harvest in April 2011, there was little additional uptake of N.

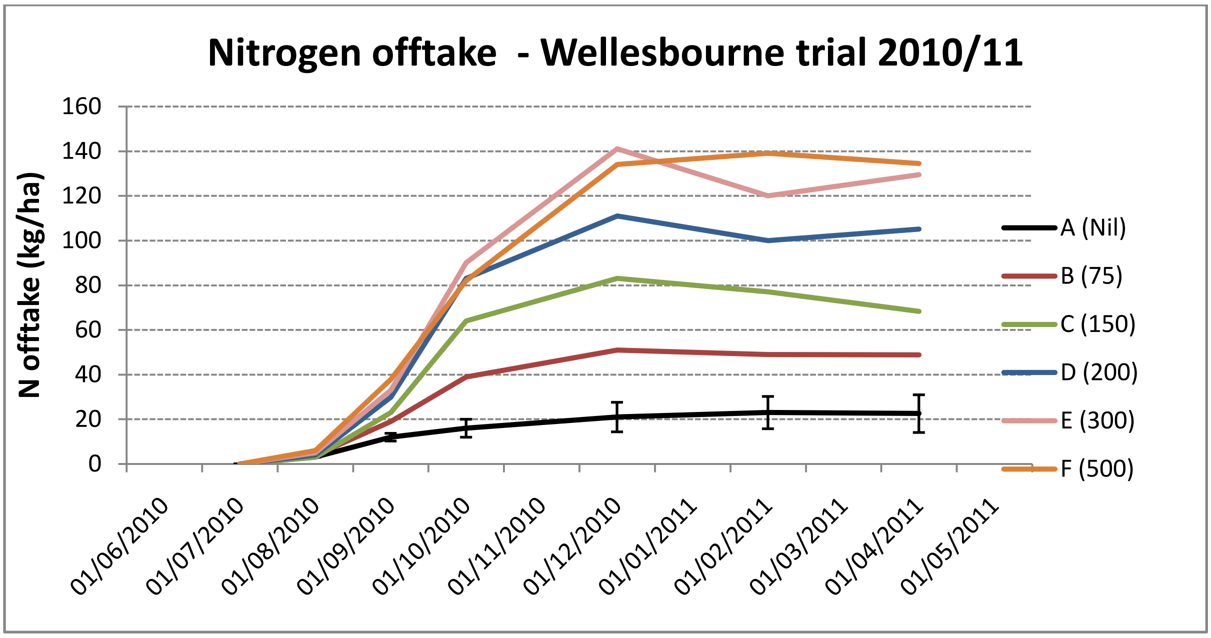


Figure 8. The pattern of nitrogen offtake over the growing season. SEDs for all N levels are shown as bars on the unfertilised, nil N line

Total N offtake at harvest is tabulated in Tables 9 a,b and c. N offtake increases with increasing N applied in the summer, the differences being smaller at the higher N rates. Where only 150 kg/ha N had been applied, there was benefit in applying additional N in the autumn or the spring, with 50 kg/ha additional N being as effective as an additional 100 kg/ha supplied in the summer. Where 200 kg/ha summer N had been applied, autumn or spring N increased N offtake, with 50 kg/ha applied in the spring increasing N offtake by a similar amount to 300 kg/ha additional N applied in the summer.

The colour of the crop was strongly influenced by the concentration of N it contained, which rose sharply with the amount of summer N supplied. Where 150 kg/ha summer N had been applied, increasing amounts of autumn and spring fertiliser N increased N concentration. Where 200 kg/ha summer N had been applied, additional N in the autumn or spring also increased the crop N concentration. It should be noted that increases in crop N concentration had limited effects on marketability, as size rather than poor colour was responsible for the unfertilised crop failing to reach marketable quality.

Where adequate amounts of fertiliser nitrogen had been applied to achieve marketable yield, residues of nitrogen in the crop at harvest were above the 75 kg/ha threshold, bringing the crop into the low end of the moderate category as described in the new Defra Fertiliser Manual. Additional amounts of N in the summer, autumn or spring led to increased amounts of crop residue N. Tables 9 a, b and c contain details of whole crop nitrogen offtake, nitrogen content and quantity of nitrogen left behind in crop residues.

Table 9a. Wellesbourne, 2010/11 trial. Total nitrogen offtake (kg/ha).

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	23	-	-	-	-	-	-
75	49	-	-	-	-	-	-
150	69	102	107	116	108	97	106
200	105	114	101	113	106	129	128
300	129	-	-	-	-	-	-
500	134	-	-	-	-	-	-

SED = 11.4, p = <0.001

Table 9b. Wellesbourne, 2010/11 trial. Whole crop plant % nitrogen (%).

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	1.1	-	-	-	-	-	-
75	1.3	-	-	-	-	-	-
150	1.5	1.9	2.0	2.5	2.1	2.0	2.4
200	1.9	2.6	2.4	2.8	2.4	2.4	2.6
300	2.4	-	-	-	-	-	-
500	2.9	-	-	-	-	-	-

SED = 0.13, p = <0.001

Table 9c. Wellesbourne, 2010/11 trial. Crop residue nitrogen content (kg/ha).

Summer N (kg/ha)	Extra N (kg/ha)	Sep 50	Oct 50	Autumn 100	Jan 50	Feb 50	Spring 100
0	23	-	-	-	-	-	-
75	38	-	-	-	-	-	-
150	49	73	76	85	78	65	74
200	74	89	73	83	72	93	88
300	97	-	-	-	-	-	-
500	96	-	-	-	-	-	-

SED = 8.3, p = 0.004

Recovery of N fertiliser was estimated using graphs of N offtake versus N fertiliser applied at each sampling date. It was estimated that by 17 August 2010, only 2.7% of the N applied had been taken up by the crop. This was confirmed by visual inspection which showed that the crop was extremely small at this time, with few roots at depth or across the row. Later in the season, as the crop grew, fertiliser recovery increased so that by 13 December 2010, 41% of the fertiliser N had been recovered. Applications of 500 kg/ha N were in excess of crop requirements, reducing fertiliser recovery by 10% compared with the optimal treatments. Fertiliser recovery was affected by the sharp frosts, reducing to 33% in February 2011 and 37% at harvest in April 2011 (see Table 10).

Soil N supply just prior to planting was assessed as 79 kg/ha to 90 cm, the top end of SNS Index 1. Nitrogen recovered by the crop at harvest was equivalent to less than a third of the N in the soil at planting.

Table 10. Fertiliser recovery and Soil N uptake

Date	% Fert. recovery	Soil N uptake (kg/ha)
17 Aug 2010	2.7	3.1
15 Sep 2010	13	12
18 Oct 2010	26	20
13 Dec 2010	41	22
22 Feb 2011	33	26
14 April 2011	37	22

Critical nitrogen levels

The critical N curve was estimated from a plot of the organic N content and above ground dry matter for each of the sampling dates listed in Table 7. They were combined with data gathered previously in 2010. The data were complementary, with low yields in 2011 and higher yields in the 2010 season. Figure 9 shows the fitted critical N curve for 2010 and 2011 to be higher than the curve currently in the WELL_N Model.

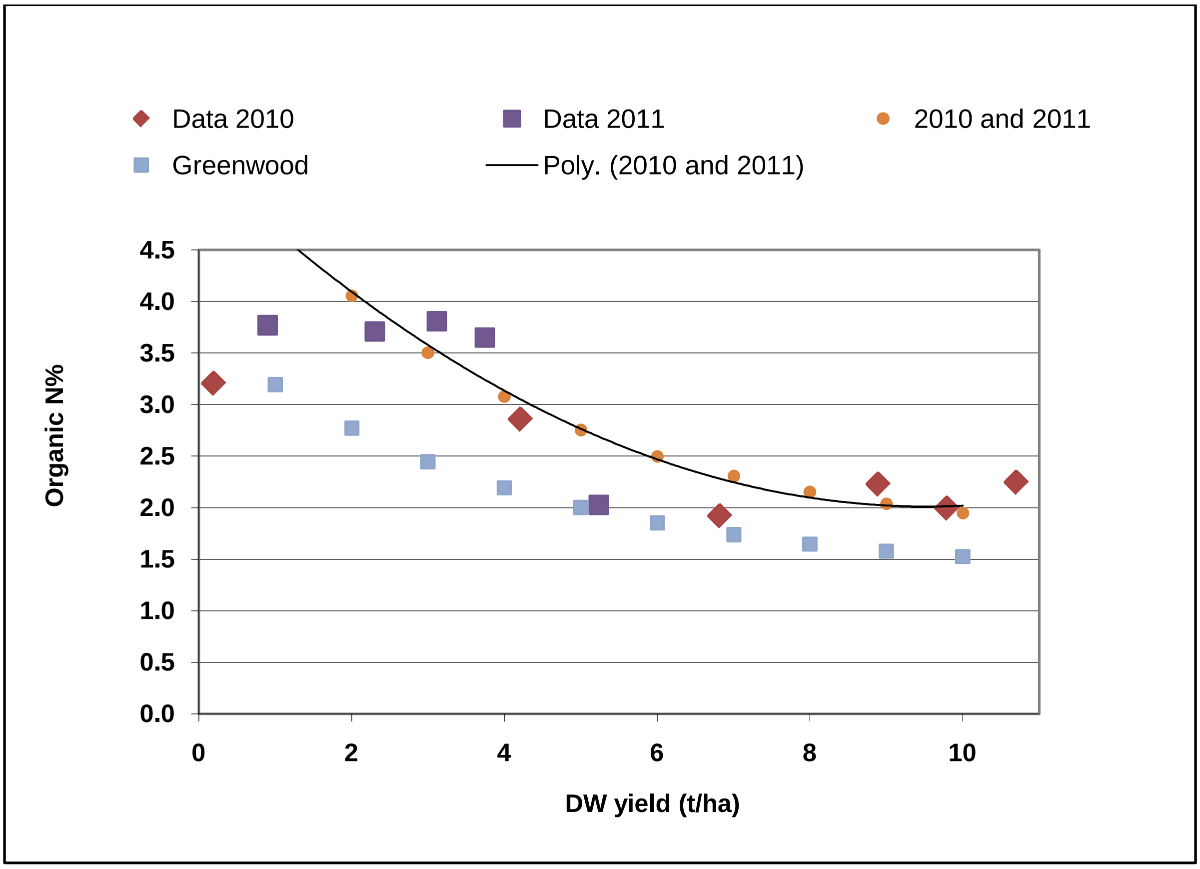


Figure 9. Critical N curve from data presented in Table 5 (solid line), and curve from WELL_N model (Greenwood) (excluding points less than 2 t/ha).

In WELL_N, it is assumed that daily growth is restricted more severely as organic N content declines below this critical level for a given dry matter yield.

- N status (ratio N) = % organic N crop / critical organic N %
- Growth status (ratio dry matter) = actual yield / potential yield (with optimum N)

This assumption was tested for the experimental data collected at Wellesbourne for each sampling date (Appendix 4). Figure 10 includes data from the response experiment on the commercial farm in Lincolnshire. Compared with an optimally fertilised crop, yield reduction increased as N status fell further below 1. Where N status was at or above the critical level, further applications of N did not significantly increase yield.

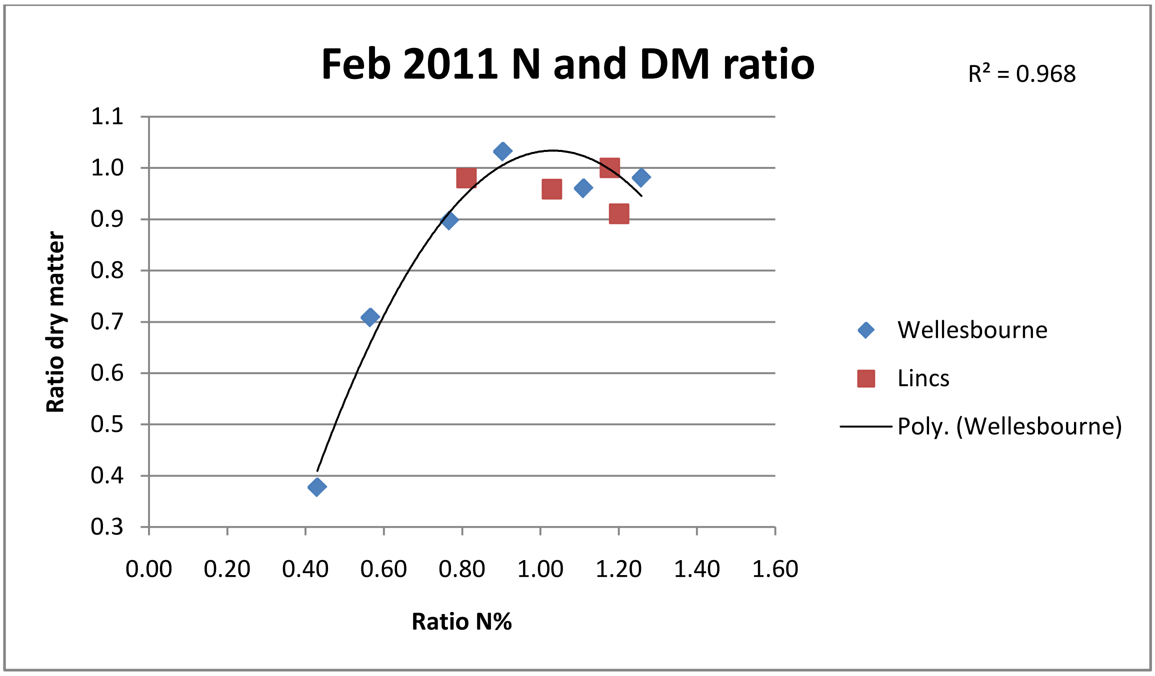


Figure 10. The relationship between the N and growth status for crops in February 2011. Poly. (Wellesbourne) was fitted using a quadratic curve. Commercial data from the Lincolnshire site.

Soil mineral N status at Wellesbourne

Soil mineral N levels (0-90 cm) are shown in Figure 11. The mineral N level just before planting was 79 kg/ha (top end SNS index 1), with more than half of the mineral N in the top 30 cm. Where no fertiliser had been applied, mineral N levels reached a peak in August 2010 but fell to less than 30 kg/ha in spring. Where 150 or 200 kg/ha N fertiliser had been applied, mineral N levels were higher, particularly in October 2010 (Table 11) but still much lower than the applied level of fertiliser N. Mineral N levels were stimulated where 500 kg/ha N fertiliser had been applied, posing a leaching risk. In spite of four rainfall events of over 12 mm each in August 2010 following the fertiliser application, the amount of N in the crop and soil in October 2010 was closely related to both the soil mineral N at planting and to the amount of applied fertiliser (Figure 12). Where fertiliser had been applied, much of the mineral N was in the top 30 cm of the soil, and therefore still available for uptake. Mineral N levels declined by December 2010 and dropped sharply by February 2011.

Where up to 200 kg/ha N had been applied, mineral N levels at harvest were less than 40 kg/ha to 90 cm depth. Additional N in the summer or autumn increased the mineral N level to around 60 kg/ha. Where 100 kg/ha additional N had been applied in the spring, the mineral N level was just over 100 kg/ha (Table 12), which, in combination with the crop residues, would need to be taken into account when assessing soil nitrogen supply to subsequent crops.

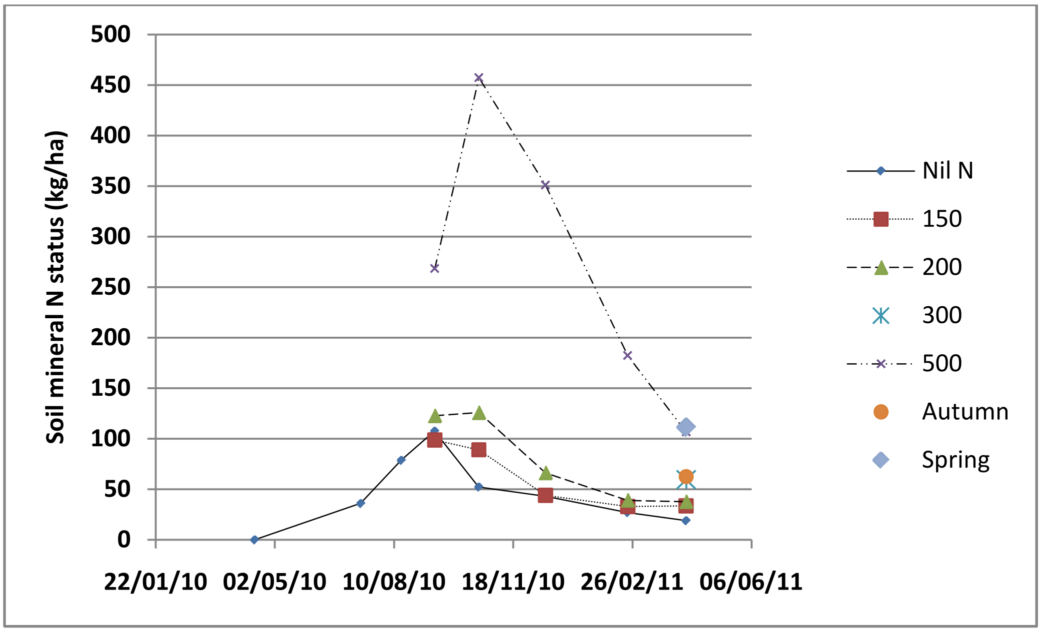


Figure 11. Wellesbourne soil mineral N status 0–90 cm. Points labelled autumn and spring received 200 kg/ha N in the summer, with an additional 100 kg/ha N applied in the autumn or spring.

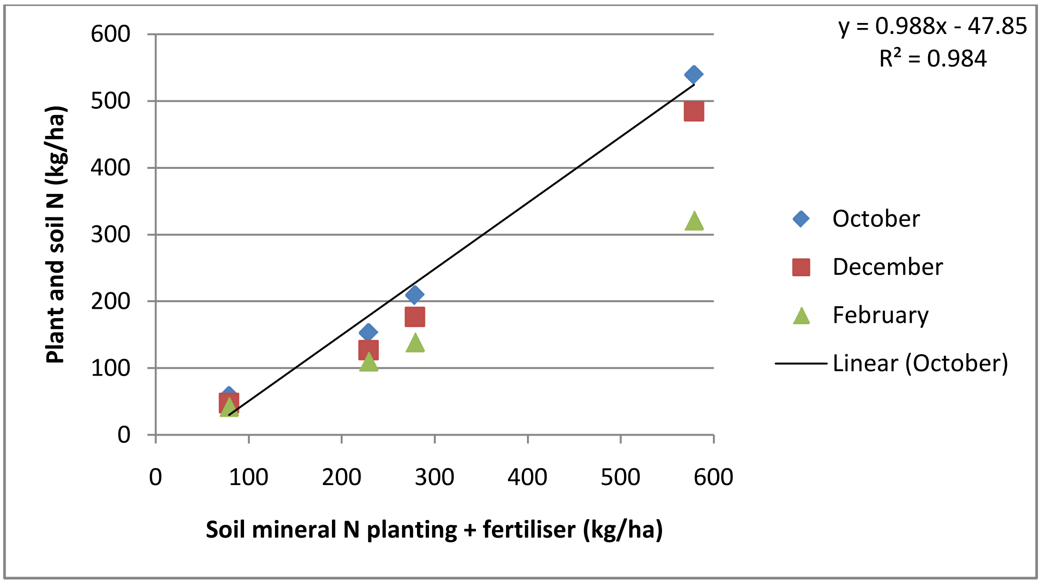


Figure 12. The relationship between the N status of the crop and soil in October and December 2010 and February 2011, compared with the amount of applied fertiliser

Table 11. Soil mineral nitrogen to 90 cm and crop N content at Wellesbourne, 20 October 2010.

Treatment N rate (kg/ha)	Soil mineral N, kg/ha 0-30 cm	30-60 cm	60-90 cm	0-90 cm	Plant N (kg/ha)	Soil and crop N
Nil	7	16	21	43	16	59
150	26	29	34	89	64	153
200	49	42	35	126	83	209
500	284	110	64	457	82	539

Table 12. Soil mineral nitrogen to 90 cm and crop N content at Wellesbourne, 12 April 2011.

Treatment N rate (kg/ha)	Soil mineral N, kg/ha 0-30 cm	30-60 cm	60-90 cm	0-90 cm	Plant N (kg/ha)	Soil and crop N (kg/ha)
Nil	10	9	11	29	23	52
150	9	9	16	34	68	102
200	11	11	16	38	105	143
300	24	16	20	60	129	189
500	37	29	41	107	134	241
200+ Aut*	24	15	24	63	116	178
200+Spr*	71	15	25	111	106	217

200+Aut – an additional 50 kg/ha N was applied in both September and October
200+Spr - an additional 50 kg/ha N was applied in both January and February

There was no indication from this season that there were excessive residues of readily available nitrogen at harvest, even at the highest N application rate. The reason for the sharp decline in mineral N in September is only partially explained by plant uptake of N. The N level contained in the plant and soil at harvest (51.7 kg/ha) was lower than the mineral N at planting (79 kg/ha), suggesting a net immobilisation of 27 kg/ha N. This differs widely from the contribution of N from mineralisation of 132 kg/ha N suggested in the fertiliser manual. Computer modelling techniques would need to be utilised to explain the likely cause of this discrepancy.

<u>Rooting Depth</u>

The distribution of roots with depth was determined on fertilised and unfertilised treatments at harvest. Most roots were in the top 30 cm.

<u>Chlorophyll Measurements</u>

Relative chlorophyll measurements based on leaf colour were made in October 2010 at the Wellesbourne site using a Minolta SPAD-502 meter. Measurements increased as applied N increased, see Figure 13. The highest measurements broadly corresponded with the highest DM yields. The readings for the Lincolnshire site in January are also shown. The range of SPAD readings again differed to those made at Wellesbourne.

This suggests that a full response curve on each field would be necessary to decide whether additional fertiliser is required. Without such a response curve, interpretation of the SPAD readings would be difficult, as the target reading varies with time of year, and probably also with variety and site. Therefore, isolated use of such techniques would not be particularly helpful in deciding whether and how much supplementary N is required.

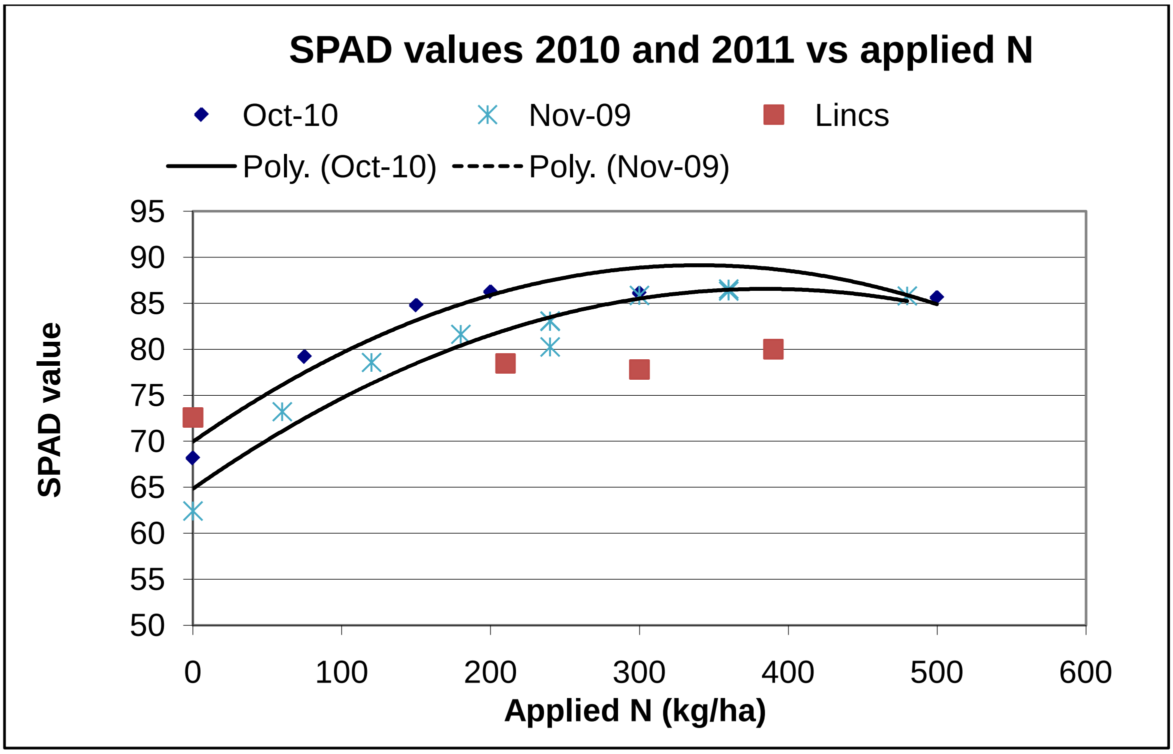


Figure 13. SPAD chlorophyll readings from 2010 and 2011 Wellesbourne experiments (readings taken in October 2010 and early November 2009, respectively). Data also shown from measurements made at the Lincolnshire site in 2011. Fitted lines shown for each sampling date.

Sampling of commercial crops

Six sites were available for sampling. At the Lincolnshire site, four areas of N supply were available. Sampling was carried out in February/March of 2011. The results are summarised in Table 13, where average values are shown (excluding unfertilised crops in Lincolnshire). Table 14 presents the results for each site.

Table 13. Results from crop sampling campaigns on assessments of crop growth and nitrogen offtake

	Commercial Feb/Mar 2011	Wellesbourne Feb 2011 (200 N)	Wellesbourne Apr 2011 (200 N)
Total dry weight yield (t/ha)	6.4	3.2	5.6
Marketable fresh weight yield, (t/ha)	21.6	nd	22.1
Marketable % dry matter	10.4	Nd	11.5
Field harvest index	0.35	nd	0.45
Total % N	3.0	3.1	1.9
N offtake (kg/ha)	183	100	105

nd – not determined

Whilst the marketable yields at the commercial sites were similar to Wellesbourne, the dry matter yields were higher at the commercial sites, reflecting the earlier establishment. The crop at Wellesbourne produced 10% more marketable yield for each tonne of fresh crop grown in the field. The %DM of the marketable material was similar. N offtake was lower, as was the %N, for the 200 kg/ha N treatment.

Figure 12 compares the N status of the commercial crops with the critical N curve derived from the Wellesbourne experiment described above. A value of 1 indicates that N supply was matched with nitrogen demand, providing the maximum potential for growth. Values greater than 1 indicate an excessive supply of N. Values less than 1, such as those where no fertiliser had been applied, suggest that N was in short supply and that growth was likely to have been limited. A value of 1.2 indicates an excess of 20%, whilst a value of 0.8 indicates a 20% shortage compared to the N content expected from the critical N curve. The application rate of 200 kg/ha N produced the highest marketable yields, and had an N status of 0.9. Lower nitrogen application rates resulted in lower N status and reduced yield.

For the commercial sites, the N status ranged from 0.81 to 1.4. The Worcester and Cheshire sites showed the closest match between N supply and crop N demand as judged by their N status. At the Lincolnshire site, the yield in the unfertilised area was little different to the areas receiving fertiliser. The N status varied from 0.81 without fertiliser to 1.22 where 300 kg/ha N fertiliser had been applied; with little difference in total dry weight or fresh marketable yield (Table 14). The site with the most positive N status was in Nottinghamshire, which had a large amount of fertiliser applied but was associated with a lower yield at the time of sampling.

Table 14. Data collected at the commercial sites in spring 2011.

Site	Soil	Variety	Drilling Date	Sampling Date	Marketable Fresh wt t/ha	% DM Marketable	Total dry wt Yield t/ha	N Offtake Kg/ha
Worcester	Sandy Loam	na	5-8/3/10	17/02/11	17.3	10.3	7.5	162.1
Cambs 6	Black Fen	Lexton	30/04/10	08/03/11	34.7	9.9	7.9	225.2
Cambs 7	Black Fen	Lampton	01/05/10	08/03/11	19.7	10.3	4.6	163.7
Cheshire 2	Silt	Galvani	29/04/10	15/03/11	27.7	10.4	7.6	185.9
Notts 4	Sandy loam	Antilope	19/05/10	09/03/11	10.9	10.4	4.7	181.1
Lincs								
0	Sand	Belton	04/05/10	25/01/11	20.2	12.6	5.9	121.4
210 kg/ha					19.3	11.2	6.1	178.1
300 kg/ha					18.1	10.5	5.5	172.9
390 kg/ha					20.4	10.7	5.8	152.0

na – information not available

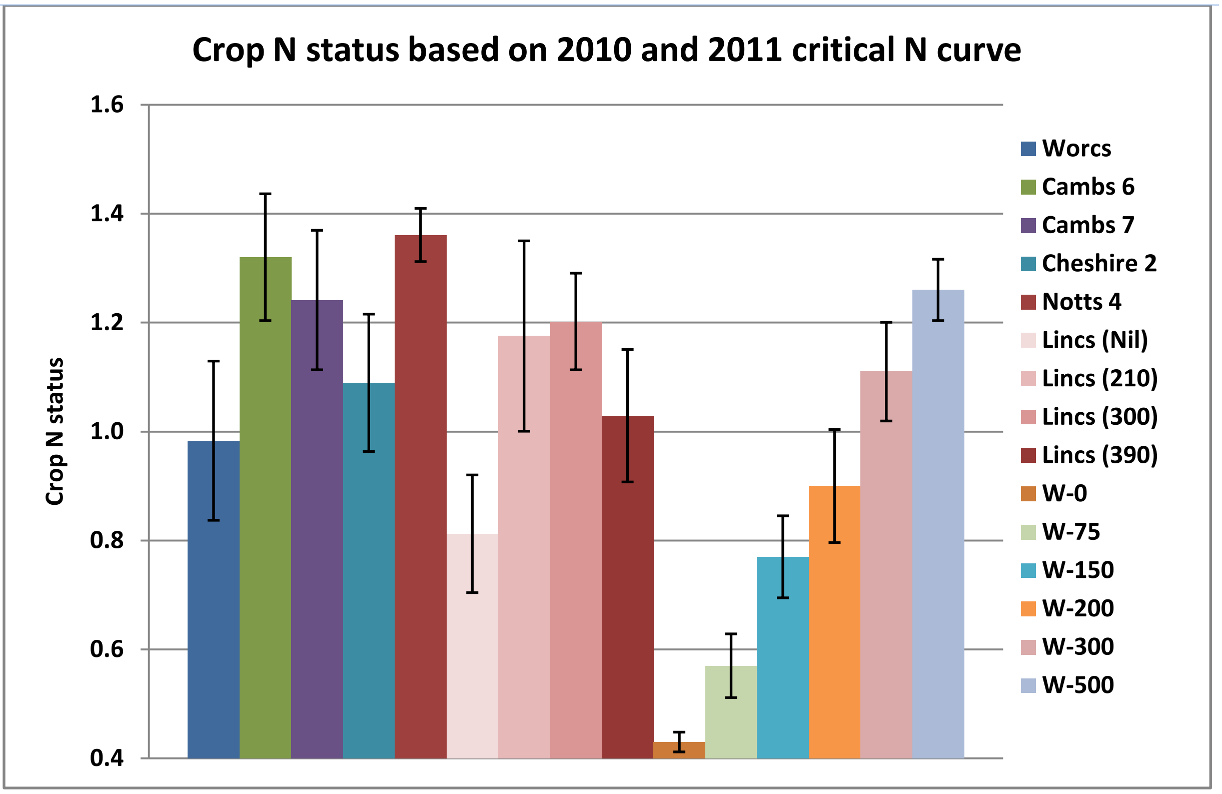


Figure 14. N status of crops in Spring 2011. Data from commercial sites with Wellesbourne (W) for comparison.

Discussion

The most important result is that the data from the experiments at Wellesbourne support the fertiliser recommendations in the Fertiliser Manual (Defra 2010). That is, for a low SNS soil, 200 kg/ha N is required, followed by an additional dressing of up to 100 kg/ha N in some situations, such as in 2009/10 growing season. The benefits from additional N were not without risk. In the 2010/11 season, where additional N was applied in the autumn, the crop suffered due to frost and subsequent rotting. The crop grew substantially between February and harvest in 2011. In spite of the increased uptake of N, where sufficient N had been applied the previous summer, there was no yield response to January and February N applications by harvest time in April.

The results suggest that the large yield responses to 500 kg/ha N found by Goodlass (1997) were due to the inefficient utilisation of N. In order to maintain a balance between N supply and demand, the N status of a crop could be monitored. This would be done by sampling crops to determine their organic %N and dry matter yields. Comparing these values with the critical N curve derived from the Wellesbourne trials would identify any imbalance in supply and demand for N. A perfect balance would be seen when the value is 1, but this provides no insurance for times when N uptake may be limited.

Ideally, the aim would be to keep N status at least at the critical N level for all stages of growth, with a small positive margin to allow for luxury consumption during the main growing period in the summer, providing reserves to allow further growth during the winter/early spring period.

If N concentration is between 1 and 1.20 times the critical N level for a given level of total dry matter yield, it would appear that the fertilisation strategy is in step with crop N requirement. Any sites showing figures of more than 1.2 times or less than 0.8 times the critical N level should be inspected. For instance, excessive concentrations may occur when yields are limited by other factors such as drought or disease. At the other extreme, if N concentrations are excessively low, this may be associated with genuine N deficiency, but could also be a result of very rapid growth and high yields.

Should yield levels and N concentration levels relative to critical N value for that crop be 0.8 or less, and there are no obvious disease, pest or rooting problems with the crop, then supplementary fertiliser nitrogen is likely to be required.

The challenge is to decide how much supplementary nitrogen to apply. This will depend on the yield increase expected from the additional fertiliser, current crop N content, expected crop N content, and the possible supply of nitrogen from the soil. Such calculations could be guided by using computer decision support systems.

- At Wellesbourne the amount of growth reduction from an optimally nitrogen fertilised crop was in proportion to the ratio of the measured organic N content relative to the critical organic N content.

- The N status of commercial sites, as judged by the critical N curve, showed that most sites were between 100 and 120%, and some were above 140%, indicating a measure of over fertilisation.

The likely N demand will depend on overall yield which varied between seasons. **Table 15** tabulates the yields and their components across three seasons of commercial crops and two seasons of trials and includes the data in Appendix 9 of the Fertiliser Manual (Defra 2010).

Marketable yields were generally disappointing in 2011 compared to 2009 and 2010, reflecting the severity of the growing conditions. The dry matter content of marketable yields were similar between seasons. Overall growth of the crops as represented by total dry matter yield was also disappointing in 2011, especially at Wellesbourne. The proportion of the crop grown that was harvested, as represented by the field harvest index, was lowest on the commercial sites in 2011. Crop nitrogen offtake was lowest in the 2011 season.

Table 15. Comparison of yield and N offtake of leeks from this project and The Fertiliser Manual (Defra 2010, Appendix 9).

	Commercial			Wellesbourne			
	2009	**2010**	**2011**	**2010 Opt N**	**2011 (200)**	**Average**	**Fertiliser Manual**
Marketable fresh weight yield (t/ha)	36.6	28.4	22.1	na	22.1	27.1	47.0
Marketable % dry matter	10.6	11.0	10.4	na	11.5	10.8	14.2
Field harvest index	0.48	0.43	0.35	na	0.45	0.43	0.57
Total dry weight yield (t/ha)	8.04	7.16	6.39	10.7	5.6	7.58	11.8
% N	2.9	2.9	3.0	2.3	1.9	2.6	2.4
N offtake (kg/ha)	227	205	183	241	105	192	279

The results are compared with those in The Fertiliser Manual (Defra 2010) and indicate:

- Generally lower levels of marketable yield
- Higher DM% and lower field harvest index
- Lower critical N values than used currently
- A smaller contribution of N from mineralisation

The average marketable yields were less than those used in the Fertiliser Manual (Defra 2010), which were taken from van Geel et al. (2006) or in the KNS recommendations (Carmen et al., 2007). The result of the lower marketable yield, dry matter % of marketable product, and lower harvest index, was that the nitrogen requirement of approximately 192 kg/ha was lower than the current figure of 279 kg/ha in the Fertiliser Manual (Defra 2010) revision framework. However, whilst the N required by the crop was lower, the contribution of N supplied by mineralisation from soil organic matter was also much lower than the 132 kg/ha N allowed for in the Fertiliser Manual (Defra 2010). The estimates of mineralised N captured by the unfertilised leek crop at the Wellesbourne site were much lower than that. It may be that not all of the mineralised N is available for crop uptake because the leek crop is too small or inactive at the time of mineralisation. Some N may have been lost by leaching or re-immobilised into soil organic matter. The turnover processes in soil are complex and the simple approach in the Fertiliser Manual (Defra 2010) for such shallow rooted crops is not ideal.

The adjustment for the smaller contribution from N mineralisation from soil organic matter, and its subsequent use by the leek crop, is the most challenging value in the framework. Computer modelling of the turnover of N in soils may be the only way of making proper estimates of net mineralisation.

Whilst the results from the trials and commercial sites suggest that modifications are required to the framework which supports the Fertiliser Manual (Defra 2010), the published recommendations appear generally sound. This is the most important conclusion of this research.

To support agronomic practice and future revisions to Fertiliser Manual (Defra 2010), it would be useful to test the strategies of additional fertiliser N on a wider range of experimental sites and in less extreme seasons on more frost tolerant cultivars of leeks.

Conclusions

- The most important result is that the data from the trials at Wellesbourne supports the fertiliser recommendations in the new Fertiliser Manual (Defra 2010) and, specifically, for a low SNS soil, 200 kg/ha N is required, with benefits from the application of additional N in some seasons.

- At Wellesbourne, the amount of growth reduction from an optimally nitrogen fertilised crop was in proportion to the ratio of the measured organic N content relative to the critical organic N content.

- The N status of commercial sites, as judged by the critical N curve, showed that most sites were between 100 and 120%, and some were above 140%, indicating a measure of over fertilisation.

- The actual contribution of N supply from mineralisation of soil organic matter was much lower than assumed in the current fertiliser recommendation framework.

Technology Transfer

The results from the 2010 trial were presented to the Leek Growers Association in May 2011.

References

CARMEN, F., FINK, M., MAYNC, A., LABER, M., PASCHOLD, P.J., SCHARPF, H.-C., SCHLAGHECKEN, J., STROHMEYER, K., WEIER, U. & ZIEGLER, J. (2007). *Düngung im Freilandgemüsebau - Datenbasis für eine erfolgreiche Düngung im Freilandgemüsebau* . Published - Institut für Gemüse- und Zierpflanzenbau Großbeeren/Erfurt e.V. (IGZ), Theodor-Echtermeyer-Weg 1, 14979 Großbeeren Germany.

DEFRA (2007). NVZ Consultation Document. Annex A – Mandatory reference figures for use in calculations.

DEFRA (2010). Fertiliser Manual (RB209) 8th Edition June 2010

GOODLASS, G., RAHN, C. R., SHEPHERD, M. A., CHALMERS, A. G. & SEENEY, F. M. (1997). The nitrogen requirements of vegetables: comparisons of yield response models and recommendation systems. *Journal of Horticultural Science*, 72, 239-254.

GREENWOOD, D.J. (2001). Modelling N-response of Field Vegetable Crops grown under Diverse Conditions with N_ABLE: A review*. J. Plant Nutr*. 24, 1799-1815

SMITH, J.U. (2001). Decision Support System to Design Whole Farm Rotations that Optimise the use of Available Nitrogen in Mixed Arable and Horticultural Systems: On-Farm Testing. (Report of Defra Link Project 164).

VAN GEEL, W.C.A., RADERSMA, S., MEURS, E.J.J. & GRASHOFF, C. (2006). Comparison of Split Nitrogen Application Strategies in Leek (*Allium porrum*) to Reduce N Fertilization on Sandy Soils in the Netherlands IN Proc. IS Towards Ecologically Sound Fertilisation 241 Strategies for Field Vegetable Production Eds. F. Tei, P. Benincasa and M. Guiducci . *Acta Hort.* 700, ISHS 2006

Appendix 1 – Experimental plan

H E A D L A N D

Guard plants | 12m | 38m

Rep 1

	G	M	J	O	K	L	A	I	R	N	H	C	Q	P	D	F	B	E
	P18	P17	P16	P15	P14	P13	P12	P11	P10	P9	P8	P7	P6	P5	P4	P3	P2	P1
July	25	25	25	25	25	25	0	25	25	25	25	25	25	25	25	25	25	25
Aug	62.5	87.5	62.5	87.5	62.5	62.5	0	62.5	87.5	87.5	62.5	62.5	87.5	87.5	87.5	237.5	25	137.5
Sep	62.5	87.5	62.5	137.5	62.5	62.5	0	112.5	87.5	137.5	112.5	62.5	87.5	87.5	87.5	237.5	25	137.5
Oct	50	50	0	50	0	0	0	50	0	0	0	0	0	0	0	0	0	0
Jan	0	0	0	0	50	50	0	0	50	0	0	0	50	0	0	0	0	0
Feb	0	0	50	0	0	50	0	0	50	0	0	0	0	50	0	0	0	0
	200	250	200	300	200	250	0	250	300	250	200	150	250	250	200	500	75	300

Rep 2

	H	N	K	P	L	M	B	J	A	O	I	D	R	Q	E	G	C	F
	P36	P35	P34	P33	P32	P31	P30	P29	P28	P27	P26	P25	P24	P23	P22	P21	P20	P19
July	25	25	25	25	25	25	25	25	0	25	25	25	25	25	25	25	25	25
Aug	62.5	87.5	62.5	87.5	62.5	87.5	25	62.5	0	87.5	62.5	87.5	87.5	87.5	137.5	62.5	62.5	237.5
Sep	112.5	137.5	62.5	87.5	62.5	87.5	25	62.5	0	137.5	112.5	87.5	87.5	87.5	137.5	62.5	62.5	237.5
Oct	0	0	0	0	0	50	0	0	0	50	50	0	0	0	0	50	0	0
Jan	0	0	50	0	50	0	0	0	0	0	0	0	50	50	0	0	0	0
Feb	0	0	0	50	50	0	0	50	0	0	0	0	50	0	0	0	0	0
	200	250	200	250	250	250	75	200	0	300	250	200	300	250	300	200	150	500

Rep 3

	I	O	L	Q	M	N	C	K	B	P	J	E	A	R	F	H	D	G
	P54	P53	P52	P51	P50	P49	P48	P47	P46	P45	P44	P43	P42	P41	P40	P39	P38	P37
July	25	25	25	25	25	25	25	25	25	25	25	25	0	25	25	25	25	25
Aug	62.5	87.5	62.5	87.5	87.5	87.5	62.5	62.5	25	87.5	62.5	137.5	0	87.5	237.5	62.5	87.5	62.5
Sep	112.5	137.5	62.5	87.5	87.5	137.5	62.5	62.5	25	87.5	62.5	137.5	0	87.5	237.5	112.5	87.5	62.5
Oct	50	50	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0	50
Jan	0	0	50	50	0	0	0	50	0	0	0	0	0	50	0	0	0	0
Feb	0	0	50	0	0	0	0	0	0	50	50	0	0	50	0	0	0	0
	250	300	250	250	250	250	150	200	75	250	200	300	0	300	500	200	200	200

Guard plants

20 beds
36.6m

Appendix 2 – Field experiment diary

Wellesbourne leek trial 2010/11: Diary summary	
15/04/10	Mineral N 0-90cm = 35.9 kg/ha (Index 0)
26/04/10	Ground preparation
27/04/10	Drilled at 13 seeds per metre (≈284,000 seeds/ha). Variety: Belton
01/05/10	Residual herbicide: Dacthal @ 6 kg/ha, Stomp @ 1 l/ha, Pyramin @ 0.5 kg/ha
01/05/10	28mm rain
18/05/10	Cotyledons emerging
01/06/10	Emergence looking patchy
04/06/10	Herbicide: Stomp @ 0.5 l/ha, Pyramin @ 0.5 kg/ha, Totril @ 0.35 l/ha
08/06/10	Decision taken to start trial again using transplants
10/06/10	Hort Services sowed 100 trays of 'Belton' (30,800 seeds)
18/06/10	Cotyledons of transplants showing
30/06/10	Field trial sprayed off with glyphosate
12/07/10	Field trial sprayed with Dursban @ 1.2 kg/ha in 620 L/ha for cutworms
13/07/10	Soil sampled each replicate: Mineral N to 90 cm was 78.7 kg/ha
15/07/10	Transplants at 2 true leaves
19/07/10	Re-cultivated existing beds
19-20/07/10	Planted transplants at 9 plants per metre. Irrigated in.
22/07/10	Residual herbicide: Stomp @ 1.5 l/ha, Pyramin @ 0.4 kg/ha. 1st top dressing. Irrigated.
28/07/10	Sprayed for thrips: Dursban @ 1 kg/ha, Celect @ 2.5 l/ha.
02/08/10	Irrigated using T-Tape
10/08/10	Sprayed for thrips: Tracer @ 0.2 l/ha, Celect @ 2.5 l/ha.
16/08/10	Soil sampled treatment A
19/08/10	Sprayed for thrips and broad-leaved weeds: Tracer @ 0.2 l/ha, Totril @ 0.35 l/ha
19/08/10	Second N top dressing applied, 14 mm rain
22/08/10	19mm rain
23/08/10	13mm rain
25/08/10	33mm rain
13/09/10	Soil sampled treatments A,C,D,F.
15/09/10	First plant sampling
17/09/10	Third N top dressing
05/10/10	Sprayed for rust (precautionary measure): Amistar @ 1 l/ha, Folicur @ 1 l/ha.
18/10/10	SPAD measurements. Second plant sampling
20/10/10	Soil sampled treatments A,C,D,F.
22/10/10	Fourth N top dressing (selected plots). 7 mm rain
13/12/10	Third plant sampling
15/12/10	Soil sampled treatments A,C,D,F.
26/01/11	Fifth N top dressing
21/02/11	Fourth plant sampling
22/02/11	Soil sampled treatments A,C,D,F.
24/02/11	Sixth N top dressing
11-12/04/11	Final plant sampling. Soil sampled treatments A, C, D, E, F, O, R

Appendix 3 – Protocol for on farm samples

FV 350 – Nitrogen Requirements of Leeks - Winter Sampling 2008

Method

At least 6 random spots should be selected in each field. Count the number of plants in a 1 metre length of row in each of these areas. Pull complete plants including any attached roots from at least 50cm single row length within this area. Loose soil should be removed if possible. Leeks from each spot should go into separate labelled (field name and spot number) sealed plastic bags.

Record

Row width cm, No of rows within beds, distance between bed centres. Number of plants in each 1 m length of row. Length of row sampled.

Send samples as soon as possible with completed form to James Durnford co Central Stores, Warwick HRI, University of Warwick, Wellesbourne, Warwick CV35 9EF. *Please let James know when you have sent any samples and he will look for them.* Tel. 024 7657 4985; e-mail james.durnford@warwick.ac.uk

Sampler –

Name:		**Tel:**	
Address:		**Fax:**	
		Email:	

Cropping Details –

Field Name

Soil texture (e.g – sandy, sandy loam, silt loam etc)

Cultivar

Planting Date

Intended commercial Harvest Date

Intended Plant Population (plant/ha or plants/acre)

Actual Plant population (at time of sampling)

Row Width (cm)

Rows per bed

Bed Width (m)

Distance between bed centres (m)

Plants per 1m length of Row (count in 6 representative areas in field)

1)
2)
3)
4)
5)
6)

Lay a tape measure along a row and count the number of plants within a metre length of a single row.

Previous Crop

Crop

Date incorporated

Soil mineral N (If measured)

Date

0-30 cm

30-60 cm 60-90 cm **State Total (Nitrate and Ammonium N) and include units kg/ha or mg/kg**

Fertiliser Applied (Amount of N fertiliser most important)

Date	Product	Rate kg/ha

Plant Sampling Date

Sample Taken (Very important to record this)

At least 6 **random spots** should be selected in each field. Count the number of plants in a 1 metre length of row in each of these areas. Pull **complete** plants including any attached roots **from at least 50cm single row length** within this area. Loose soil should be removed if possible. Leeks from each spot should go into separate labelled (field name and spot number) sealed plastic bags. Send to Wellesbourne for analysis. **Record sample length taken (50 cm of row minimum)** **Number of random spots sampled in field**

Comments about crop

Make comments about the look of the crop i.e. evenness colour, frost damage etc.

Appendix 4 – Wellesbourne experiment - Growth and N offtake

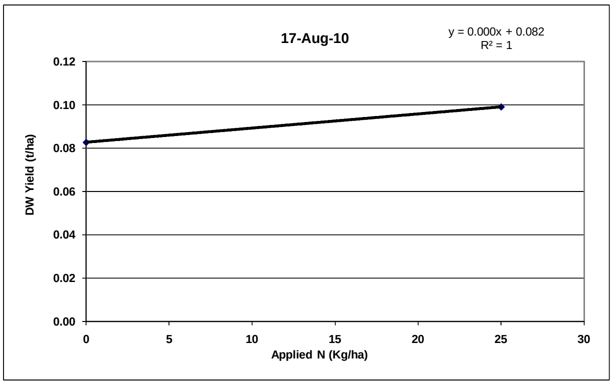
Table 16. Total dry weight yield (t/ha)

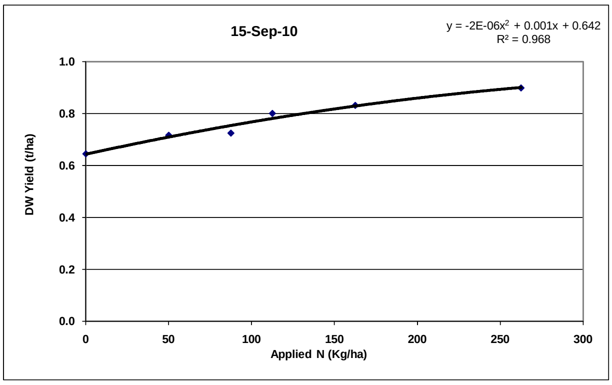
N (kg/ha)	0	75	150	200	300	500
17 Aug 2010	0.09	0.09	0.06	0.10	0.11	0.09
15 Sep 2010	0.64	0.72	0.72	0.80	0.83	0.90
18 Oct 2010	1.13	1.78	1.91	2.40	2.35	2.23
17 Dec 2010	1.57	2.75	3.11	3.59	3.90	3.65
21 Feb 2011	1.18	2.21	2.79	3.21	2.99	3.05
12 Apr 2011	1.98	3.69	4.61	5.59	5.35	4.68

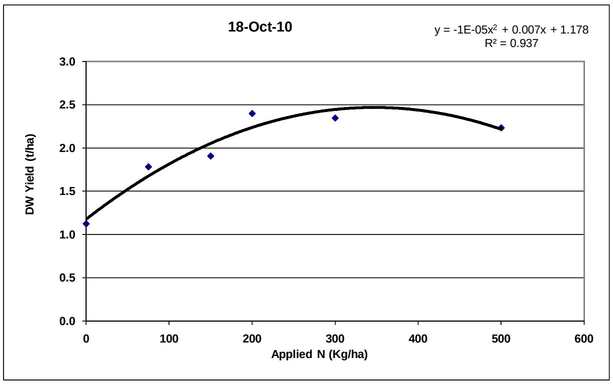
Table 17. Total N offtake (kg/ha)

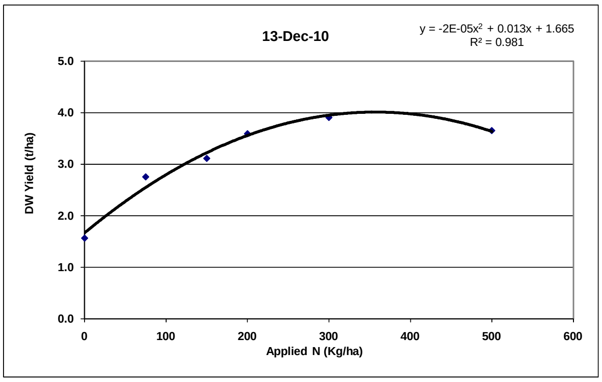
N (kg/ha)	0	75	150	200	300	500
17 Aug 2010	3.6	3.6	2.4	3.5	4.3	3.3
15 Sep 2010	11.9	19.4	23.4	30.0	32.6	38.0
18 Oct 2010	15.5	39.2	63.7	83.3	90.2	81.8
17 Dec 2010	21.0	51.0	83.1	110.6	140.6	133.7
21 Feb 2011	23.4	49.4	77.4	99.8	120.1	139.1
12 Apr 2011	22.6	48.8	68.2	105.1	129.4	134.4

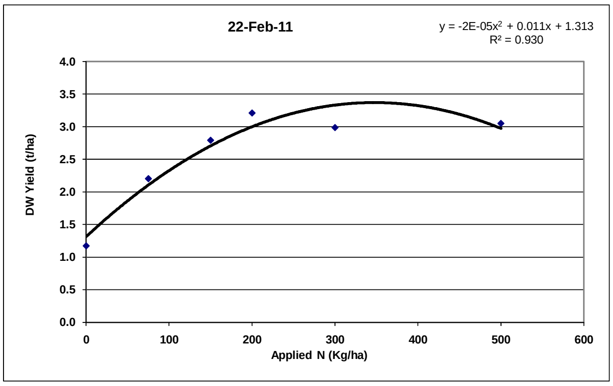
Nitrogen Response Curves – Above ground Dry weight Yield t/ha for each sampling date. Fitted Quadratic Lines.

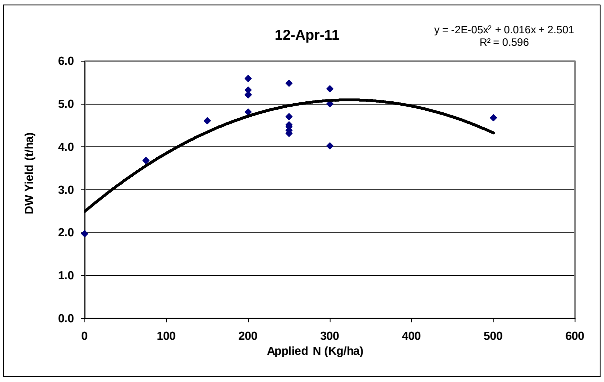












Appendix 5 – Wellesbourne meteorological data

	1980-2009 Mean		2010		2011	
	Air temp (°C)	Rainfall (mm)	Air temp (°C)	Rainfall (mm)	Air temp (°C)	Rainfall (mm)
Jan	4.2	50.6			3.8	30.5
Feb	4.2	37.4			6.6	49.7
Mar	6.8	43.5			7.0	5.1
Apr	9.4	46.6	9.4	30.6	12.0	2.4
May	12.9	52.6	11.6	46.1		
Jun	15.8	52.6	15.6	32.1		
Jul	18.0	56.7	17.9	20.4		
Aug	17.7	52.7	15.9	128.3		
Sep	14.9	55.7	14.4	34.9		
Oct	10.9	60.8	10.6	58.9		
Nov	6.9	55.6	5.6	34.2		
Dec	4.5	53.2	-0.9	20.7		

1980 - 2009 Data based on mean of instantaneous readings recorded each day at 9.00 GMT.

2010 and 2011 Data based on mean of maximum and minimum daily air temperatures

Rainfall values refer to mean monthly rainfall.

Appendix 6 – Marketing criteria used in the experiments.
Taken from Simms and Woods - Raw Material Specification

Country Of Origin:	UK	
General Description	Leeks must be sound, fresh, and clean. Leeks should be evenly straight and even in diameter along the whole length. Leaves should be neatly trimmed and roots cut cleanly to the basal plate.	
Defects - Minor:	**Tolerance - 10% by count of leek** Excessive flag (>40% total length after final trim) Torn / split / crushed flag leaf Dehydration Thrip damage Yellowing of flag Rust >8 pustules Telescoping Bolting >75% up the shank length Pink stripe / shadows Bulbing >30% difference between bulb and shank Insufficient white Over trimming / removal of basal plate Under or over size diameter (see size spec) Under or over length (see length spec)	
Defects - Major:	**Tolerance – 2% by count of pack** Excessive flag yellowing Rots, Moulds & Breakdown Pest Damage Pest infestation Brown stripe / shadows Surface splits on shank Soil deposits in solid part of shank	
Nil Tolerance:	Exceedance of MRL for an approved chemical or presence of unapproved chemical Foreign bodies Uncharacteristic taints and odours	
Total Defects:	10% Total Defect Tolerance	
Target Weight	15kg / crate	
Packaging	Simms & Woods Field Crates Only	
Min / Max Length (mm)	30cm minimum	40cm maximum
Min / Max diameter (mm)	25-40mm 30-45mm	**Clearly marked on pallet which diameter range, ranges not to be mixed on pallet**
Temp on arrival	1^0C minimum	7^0C maximum