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| Project Leader | Dr C Paterson<br>Horticulture Research International (HRI)<br>Willington Road<br>Kirton<br>Boston,<br>Lincs PE20 1NN |
| Project Consultant | Dr C Rahn |
| Project Co-ordinator | Mr P Effingham |
| Location | Lincolnshire, Kent and Cornwall |

**PROJECT LEADER**

Dr C D Paterson BSc

**AUTHORS**

R L Wood BSc

Dr C Rahn BSc MISoilSc

**AUTHENTICATION**

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

________________________________________

(Signature)

R L Wood, Site Manager

Horticulture Research International Willington Road, Kirton, Boston, Lincs, PE201NN

Date: _____________

Report authorised by:

________________________________________

(signature)

Dr I G Burns, Head of Horticultural Services

HRI, Wellesbourne Warwick, CV35 9EF

Date: _____________

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**GROWER SUMMARY**

The results of this project have been summarised in factsheet number 22/02, which is available from HDC. This was done in place of a full report grower summary.

## SCIENCE SECTION

## INTRODUCTION AND BACKGROUND

### Commercial Objectives

There are a number of overwinter heading varieties of cauliflower grown in a range of climatic conditions from Cornwall to Yorkshire, with 80% being grown in areas designated as Nitrate Vulnerable Zones in Thanet. Crops grown have a range of maturity dates from February to June each having different requirements for nitrogen; too much nitrogen could contribute to crops being less hardy and too little may reduce frame size and the potential for production of curds. The overall nitrogen requirement is likely to be up to 275 kg/ha, but current MAFF recommendations provide little information on when this should be applied. WEll-N (the HRI N advisory model) provides more specific recommendations but needs some improvement to cover the range of maturity dates in commercial practice. Project FV179 was set up to investigate this topic.

### Background

Trials in 1996/97 showed that the crops in Kent and Lincolnshire showed very similar growth patterns and could be treated together, whereas the crop in Cornwall behaved differently even where the same varieties were grown. In Eastern England the target growth pattern would be to produce at least 2-tlha dry matter by late autumn of a high dry matter content, followed by some slow growth overwinter to reach 3.5 t/ha by early spring. The main growth then occurs with plants reaching 8-12 t/ha dry matter at harvest in a relatively short period.

The N requirements of the crops could be met by taking account of the soil mineral nitrogen levels, and maturity period. In order to satisfy N requirements to support this growth at low mineral N sites a small base dressing of nitrogen would be required followed by a larger spring top dressing to support rapid growth in the spring.

The 1996/7 trial to establish appropriate base dressing rates only showed a response to 50kg/ha N on an N index 1 site. The top dressing trial on a higher SMN site following a dry winter showed no response to top dressing above 100 kg/ha N. In setting up these trials attention was paid to soil mineral N levels and fertilizer base rates were selected to take account of these. In lincolnshire base rates of 0, 25, or 50 kg/ha were selected and 0 and 40 kg/ha in Kent, both sites were index 1.

However the levels of base and top dressing tested in 96/97 were not wide enough to show optimum amounts of fertilizer dressings required. Indications from the two years of trials suggest that with 100-150 kg/ha N as mineral N at planting, a base dressing of between 50 and 100 kg/ha may be required.

Observations of the trials suggests that low base dressings of nitrogen can be used, as little as 25 kg/ha for late maturing crops, and that perhaps around 175 kg/ha may suffice for total topdressing applications. Early maturing crops may need higher base rates in order to assist establishment and to encourage root growth so that mineralised nitrogen can be intercepted.

The objective of this work was to test the requirement for base and top dressings of nitrogen in overwinter cauliflower crops in Kent and Lincolnshire.

**Experimental Work**

Two detailed experiments were carried out, one in Kent and one in Lincolnshire. Results were subject to statistical analysis using analysis of variance.

**Treatments**

**1) Lincolnshire site**

The trial site, at Wigtoft, was kindly provided by Marshall Brothers of Butterwick, and was selected as a low nitrogen site. Soil sampling indicated soil mineral nitrogen levels at planting of 47 kg/ha (0-30 cm) 92 kg/ha (30- 60cm) and 73 kg/ha (60-90cm), a total of 213 kg/ha. The previous crop was brassicas.

Transplants of the varieties Maverick and Ace High were grown to standard commercial practice, and planted on the 19 August. All crop production practices were as standard, including phosphate and potash applications.

Nitrogen treatments (as Nitram, 34.4%N) were weighed out and applied by hand on the 20th August as base dressings, and on the 19 February and 22 March as top dressings, with 50% being applied at each date. The following rates of fertiliser were applied:

| Base dressing rate kg/ha N | Top dressing rate kg/ha N |
|---|---|
| 0 (control) | 0 (Control) |
| 0 | 160 |
| 0 | 240 |
| 40 | 160 |
| 40 | 240 |
| 80 | 160 |
| 80 | 240 |

Harvesting begun on the 30 April and finished on the 21 May.

**2) Kent site.**

Mr Robert Montgomery of Monkton Road Farm kindly provided the trial site. Soil sampling at planting indicated soil mineral nitrogen levels of 52 kg/ha (0- 30 cm), 43 kg/ha (30-60cm) and 48 kg/ha (60-90cm), a total of 143 kg/ha. The site followed potatoes.

Plants of the varieties Maverick and Late Enterprise were planted by machine on the 13 August. Base dressings were applied pre-planting, and topdressings were split between the 25 February and the 24 of March, 50% being applied on each date.

| Base dressing rate kg/ha N | Top dressing rate kg/ha N |
|---|---|
| 0 (control) | 0 (Control) |
| 40 | 160 |
| 40 | 240 |
| 80 | 160 |
| 80 | 240 |
| 120 | 160 |
| 120 | 240 |

Harvesting was carried out between the 21 of April and the 28 of May.

**Experimental design and recording**

At harvest, each plot was inspected three times a week, and recorded according to EC standards (MAFF 1981). Any head reaching marketable size (over 110mm) and condition was recorded according to class (one, two, or unmarketable), size (4 = 110-130mm, 5 = 130-150mm, 6 = 150-170mm, or 7 = over 170mm) and depth of curd (shallow, medium, deep). For any unmarketable heads, the reason for downgrading was noted. Heads not reaching marketable size were recorded as small. Frost killed or missing plants were noted.

**Soil and plant sampling**

Soil samples for mineral nitrogen (NH4-N and NO3-N) were taken from the whole site, pre top dressing and at harvest for selected treatments. Pre- planting and post-planting Mineral N was tested by laboratory analysis at HRI Wellesbourne.

Plant fresh weights (5 plants per plot) were recorded prior to top dressing, and at harvest.

On site testing of soil mineral N at planting was carried out using water extraction and a Merck nitrate test strip. Otherwise standard laboratory methods were used.

 

## RESULTS

### Lincolnshire

**Table 1** Number of marketable, class 1, size grade 5 curds, and missing plants as % of number planted for Maverick and Ace High in Lincolnshire as Angle Transformation (Back transformation in brackets)

| Variety | Fertiliser treatment kg/ha N (base, top) | % Marketable | % Class 1 | % Size 5 | % Missing |
|---|---|---|---|---|---|
| **Maverick** | 0,0 (control) | 30.8 (26.2) | 22.0 (14.0) | 6.1 (1.1) | 38.3 (38.4) |
| | 0,160 | 32.4 (28.7) | 20.3 (12.0) | 7.4 (1.7) | 32.6 (29.0) |
| | 0,240 | 29.3 (23.9) | 22.8 (15.0) | 9.3 (2.6) | 23.3 (15.6) |
| | 40,160 | 39.2 (39.9) | 30.4 (25.6) | 18.5 (10.1) | 22.1 (14.1) |
| | 40,240 | 40.7 (42.5) | 29.5 (24.2) | 20.0 (11.7) | 20.8 (12.6) |
| | 80,160 | 41.3 (43.6) | 28.0 (22.0) | 15.8 (7.4) | 31.7 (27.6) |
| | 80,240 | 42.3 (45.3) | 29.5 (24.2) | 19.4 (11.0) | 28.6 (22.9) |
| **Ace High** | 0,0 (control) | 26.3 (19.6) | 20.3 (12.0) | 8.4 (2.1) | 27.0 (20.6) |
| | 0,160 | 35.7 (34.0) | 32.9 (29.5) | 13.7 (5.6) | 24.1 (16.7) |
| | 0,240 | 37.6 (37.2) | 32.7 (29.2) | 15.7 (7.3) | 24.3 (16.9) |
| | 40,160 | 38.2 (38.2) | 31.8 (27.8) | 18.9 (10.5) | 22.0 (14.0) |
| | 40,240 | 37.7 (37.4) | 32.8 (29.3) | 17.6 (9.1) | 27.5 (21.3) |
| | 80,160 | 37.3 (36.7) | 31.5 (27.3) | 10.5 (3.3) | 30.9 (26.4) |
| | 80,240 | 49.9 (58.5) | 45.8 (51.4) | 18.5 (10.1) | 19.0 (10.6) |
| SED | 26df | 8.82 | 9.83 | 6.22 | 6.53 |

The marketable yield (Class 1 and 2) of Maverick; was little affected by applied fertiliser nitrogen, though 40,160 or 40,240 provide the best yields. However there were significant advantages in at least 40-kg/ha base and 160 or 240 in spring for larger proportions of Class1 and larger size 5 curds. Providing too much N in the autumn, gave no advantage, and may have lead to reduced yields of class 1 curds.

The response to nitrogen fertilizer for Ace High~ was similar to that of Maverick with the main differences being observed in the number of class 1 and size 5 curds. For this later maturing variety, there was less benefit from applying 40 kg/ha N as a base dressing, provided 240 kg was applied as topdressing. There was little or no benefit in applying 80 kg/ha N in the base; the high yield with 80,240 may be artefact of fewer missing plants rather than any response to fertiliser.

Larger numbers of missing plants were as a result of a combination of factors; I poor establishment and bird damage, but did not appear to be related to any of the fertiliser treatments applied.

Data not presented, indicated that the length of cut tended to be shorter for higher fertiliser applications, which also were quicker to 50% maturity.

Table 2 shows levels of soil mineral nitrogen (kg/ha) at selected dates and at depths 0-30 cm, 30-60 cm, 60-90 cm and 0-90 cm. The first two samples were taken before any topdressing were made, The levels of mineral N in December are very large and were increased by the application of N to the seedbed. The movement of nitrogen through the soil profile can be seen, with the highest base application having high levels in the middle horizon in December. By the middle of January all three treatments had similar but much reduced levels of nitrogen in the top 60cm. The difference in mineral N between December and February was not explained by nitrogen uptake in the crop, Table 4 so the difference is likely to be due to nitrogen losses by leaching.

This pattern of mineral N with depth remains the same at harvest, higher topdressing rates have higher amounts of nitrogen in the 60-90cm horizon compared with other treatments. The control plots have lower mineral nitrogen in all horizons at harvest. Mineral N levels are lower for the later harvested Ace High variety, there is relatively little difference in nitrogen levels from all treatments bar the 80 base 160 topdress application, which has relatively high amounts in the 0-30 cm and the 60-90cm.

 

**Table 2** Soil Mineral nitrogen levels at various sample dates, at depths 0- 30,30-60 and 60-90cm

| Variety | Sample date | Fertiliser kg/ha N Base dressing | Fertiliser kg/ha N Top dressing | Kg/ha N 0-30cm | Kg/ha N 30-60cm | Kg/ha N 60-90cm | Kg/ha N 0-90cm |
|---|---|---|---|---|---|---|---|
| **Maverick** | 7/12/98 | 0 | 160 | 42.3 | 99.4 | 104.6 | 246.4 |
| | 7/12/98 | 40 | 160 | 53.4 | 104.6 | 98.7 | 256.7 |
| | 7/12/98 | 80 | 160 | 67.9 | 209.2 | 137.1 | 414.2 |
| | 16/2/99 | 0 | 160 | 32.4 | 41.7 | 69.7 | 143.8 |
| | 16/2/99 | 40 | 160 | 16.5 | 22.3 | 91.2 | 130.0 |
| | 16/2/99 | 80 | 160 | 15.6 | 30.7 | 136.1 | 182.4 |
| | 14/5/99 | 0 | 160 | 40.4 | 18.9 | 67.2 | 126.6 |
| | 14/5/99 | 40 | 160 | 54.9 | 30.8 | 57.6 | 143.3 |
| | 14/5/99 | 80 | 160 | 36.2 | 37.4 | 81.8 | 155.4 |
| | 14/5/99 | 0 | 0 (Control) | 13.6 | 8.3 | 56.0 | 77.5 |
| **Ace high** | 21/5/99 | 0 | 160 | 16.0 | 6.1 | 52.1 | 74.2 |
| | 21/5/99 | 40 | 160 | 9.2 | 8.9 | 62.7 | 80.9 |
| | 21/5/99 | 80 | 160 | 36.2 | 17.2 | 80.5 | 133.9 |
| | 21/5/99 | 0 | 0 (Control) | 16.4 | 7.6 | 34.6 | 58.6 |

NB, top dressings applied on the 19 February and 22 March

Crop dry weights and nitrogen uptake are presented in tables 3 and 4. Figures indicate little evidence of any response to the applications of fertiliser. There is little growth or nitrogen uptake between December and February. The decline in mineral N between December and February is not explained by plant uptake. At harvest dry weights were highest for Maverick and Ace High with high applications of fertiliser. However, the dry weights did plateau for a group of treatments, and it is suggested that the high rates of fertiliser may be superfluous.

**Table 3** Crop dry matter weights (t/ha), at various sampling dates

| Variety | Fertiliser kg/ha N | | Mean Dry Matter (t/ha) | | |
|---|---|---|---|---|---|
| | **Base Dressing** | **Top Dressing** | **17/12/98** | **25/2/99** | **50% harvest** |
| **Maverick** | 0 | 0 (Control) | 0.8 | 0.8 | 5.5 |
| | 0 | 160 | 1.0 | 0.9 | 4.7 |
| | 0 | 240 | 0.7 | 0.6 | 6.2 |
| | 40 | 160 | 0.9 | 1.1 | 7.0 |
| | 40 | 240 | 1.2 | 1.1 | 5.8 |
| | 80 | 160 | 0.5 | 1.0 | 6.8 |
| | 80 | 240 | 0.9 | 1.1 | 7.0 |
| **Ace High** | 0 | 0 (Control) | 0.8 | 0.8 | 8.5 |
| | 0 | 160 | 0.5 | 0.6 | 7.8 |
| | 0 | 240 | 0.7 | 1.1 | 8.2 |
| | 40 | 160 | 0.9 | 1.1 | 8.3 |
| | 40 | 240 | 0.9 | 0.8 | 8.2 |
| | 80 | 160 | 0.6 | 0.9 | 9.3 |
| | 80 | 240 | 1.1 | 1.4 | 10.4 |

**Table 4** N uptake (kg/ha) for Maverick and Ace High in Lincolnshire

| Variety | Treatment | | Sample Date | |
|---|---|---|---|---|
| | **Base Dressing** | **Top Dressing** | **07/12/98** | **16/2/99** |
| **Maverick** | 0 (Control) | 0 | 20.8 | 24.8 |
| | 0 | 160 | 24.0 | 28.3 |
| | 0 | 240 | 15.4 | 18.5 |
| | 40 | 160 | 18.2 | 35.3 |
| | 40 | 240 | 17.0 | 32.1 |
| | 80 | 160 | 13.8 | 30.3 |
| | 80 | 240 | 22.3 | 33.1 |
| **Ace High** | 0 (Control) | 0 | 21.14 | 24.8 |
| | 0 | 160 | 9.1 | 18.8 |
| | 0 | 240 | 18.6 | 40.5 |
| | 40 | 160 | 21.6 | 34.5 |
| | 40 | 240 | 21.6 | 23.8 |
| | 80 | 160 | 15.1 | 30.1 |
| | 80 | 240 | 20.6 | 44.1 |

**Kent**

**Table 5** Number of marketable, class 1, size 5 curds, and missing plants as % number planted of Maverick and Late Enterprise, as Angle transformation. (Back transformation in brackets)

| Variety | Fertiliser kg/ha N (base, top) | % Marketable | % Class 1 | % Size 5 | % Missing |
|---|---|---|---|---|---|
| **Maverick** | 0,0 (control) | 55.8 (68.4) | 31.9 (27.9) | 17.5 (9.0) | 21.1 (12.9) |
| | 40,160 | 46.4 (52.4) | 31.5 (27.3) | 25.2 (18.1) | 28.3 (22.5) |
| | 40,240 | 54.8 (66.8) | 36.7 (35.7) | 26.9 (20.5) | 19.2 (10.8) |
| | 80,160 | 46.9 (53.3) | 30.2 (25.3) | 25.3 (18.3) | 31.0 (26.6) |
| | 80,240 | 53.2 (64.1) | 32.6 (29.0) | 31.6 (27.4) | 19.8 (11.5) |
| | 120,160 | 43.6 (47.6) | 27.7 (21.6) | 20.4 (12.5) | 31.6 (27.5) |
| | 120,240 | 52.0 (62.1) | 31.6 (27.5) | 25.2 (18.1) | 19.9 (11.6) |
| **Late Enterprise** | 0,0 (control) | 37.4 (36.9) | 16.7 (8.3) | 11.4 (3.9) | 34.2 (31.6) |
| | 40,160 | 50.9 (60.2) | 29.0 (23.5) | 18.2 (9.7) | 31.1 (26.7) |
| | 40,240 | 52.3 (62.6) | 21.9 (13.9) | 18.8 (10.3) | 20.3 (12.0) |
| | 80,160 | 43.6 (47.6) | 23.4 (15.8) | 18.8 (10.4) | 32.1 (28.3) |
| | 80,240 | 54.4 (66.1) | 22.1 (14.1) | 13.7 (5.6) | 10.6 (3.4) |
| | 120,160 | 43.6 (47.6) | 26.2 (19.5) | 13.5 (5.4) | 32.7 (29.1) |
| | 120,240 | 50.4 (59.4) | 23.0 (15.3) | 19.7 (11.3) | 19.1 (10.7) |
| SED | (26 df) | 6.45 | 5.30 | 4.33 | 4.91 |

Table 5 shows the marketable yields of crops harvested in Kent. In Maverick; there was very little response to nitrogen in terms of marketable yield. However, if the production of large curds was demanded, then higher applications of fertiliser were required, although it was unclear whether that should be from autumn or spring application. There was no benefit in applying more than 40,240 kg/ha N, and a suggestion that high base applications, 120 kg/ha, lowered yields.

With late enterprise: there was a larger response to nitrogen, with definite increase in marketable yield from application of fertiliser. However, there was no benefit in applying more than 40,160; where high yields of class 1 and size 5 curds were obtained.

Again there was a high number of missing plants in this trial, as a result of either poor establishment or bird damage. The number of missing plants were not affected by base dressing treatment. The lowest numbers of missing plants were associated with the highest 240-kg/ha N spring fertiliser application but this did not improve the numbers of marketable curds, see earlier.

Data not presented indicated that higher fertiliser applications reduced the length of cut for Late Enterprise, but there was little difference in the effect of treatment on length of cut for Maverick, and the number of days to 50% cut for both varieties.

 

**Table 6** Soil mineral nitrogen (kg/ha) from the Kent trial site

| Variety | Sample date | Fertiliser kg/ha n Base dressing | Top dressing | Kg/ha N 0-30cm | Kg/ha N 30-60cm | Kg/ha N 60-90cm | Kg/ha N 0-90cm |
|---|---|---|---|---|---|---|---|
| **Maverick** | 17/12/98 | 0 | 0 (control) | 27.4 | 28.6 | 60.4 | 116.4 |
| | 17/12/98 | 40 | 160 | 32.8 | 27.2 | 55.1 | 115.1 |
| | 17/12/98 | 80 | 160 | 39.4 | 23.0 | 69.2 | 131.6 |
| | 17/12/98 | 120 | 160 | 35.4 | 57.0 | 83.2 | 175.6 |
| | 25/2/99 | 0 | 0 (control) | 0.0 | 0.0 | 0.0 | 0.0 |
| | 25/2/99 | 40 | 160 | 4.7 | 0.0 | 4.0 | 8.7 |
| | 25/2/99 | 80 | 160 | 13.3 | 5.3 | 0.0 | 18.6 |
| | 25/2/99 | 120 | 160 | 12.0 | 12.0 | 29.2 | 53.2 |
| | 27/4/99 | 0 | 0 (control) | 6.1 | 6.8 | 0.0 | 12.9 |
| | 27/4/99 | 40 | 160 | 34.6 | 8.0 | 0.0 | 42.6 |
| | 27/4/99 | 80 | 160 | 31.4 | 0.0 | 6.0 | 37.4 |
| | 27/4/99 | 120 | 160 | 22.5 | 5.3 | 23.7 | 51.5 |
| **Late enterprise** | 17/5/99 | 0 | 0 (control) | 12.8 | 2.0 | 5.8 | 20.6 |
| | 17/5/99 | 40 | 160 | 52.4 | 9.9 | 23.8 | 86.1 |
| | 17/5/99 | 80 | 160 | 7.5 | 27.4 | 4.0 | 38.9 |
| | 17/5/99 | 120 | 160 | 12.5 | 3.2 | 4.6 | 20.3 |

NB Top dressings were made on the 25 February and 24 March

Soil mineral N levels were relatively low in the autumn and were lifted by the application of fertiliser N to the seedbed. However, most of the 120 kg/ha was seen in the 30-60 or 60-90 cm layers out of root range of young plants. By February mineral N levels had declined markedly. Levels of soil min eral N even with base dressings of nitrogen were very low, less than 60 kg/ha N. Levels of soil mineral N remained less than 60 kg/ha at harvest.

Crop dry wt and nitrogen offtake are shown in tables 7 and 8. In the Autumn crop dry wt was around 1 t/ha with no effect of base fertiliser. At this stage only 40 kg/ha N had already by taken up by the crop – easily satisfied by amounts of soil mineral N. By February crop growth had increased to around 3t/ha (3 times that at Wigtoft). However there was still no response to any of the base dressing treatments. Nitrogen offtake had increased to over 100 kg/ha. The increase in nitrogen offtake was exactly balanced by decrease in mineral N.

**Table 7** Dry matter production (t/ha) for Maverick and Late Enterprise in Kent

| Variety | Fertiliser kg/ha n | | Mean Dry Matter (t/ha) | | |
|---|---|---|---|---|---|
| | Base dressing | Top dressing | 17/12/98 | 25/2/99 | 50% harvest |
| **Maverick** | 0 | 0 (control) | 1.0 | 3.7 | 7.5 |
| | 40 | 160 | 1.1 | 3.9 | 7.0 |
| | 40 | 240 | - | - | 7.1 |
| | 80 | 160 | 0.9 | 3.7 | 7.2 |
| | 80 | 240 | - | - | 7.3 |
| | 120 | 160 | 1.1 | 3.5 | 6.8 |
| | 120 | 240 | - | - | 6.7 |
| **Late enterprise** | 0 | 0 (control) | 0.9 | 3.1 | 11.2 |
| | 40 | 160 | 0.9 | 2.5 | 7.6 |
| | 40 | 240 | - | - | 7.6 |
| | 80 | 160 | 0.9 | 2.9 | 7.0 |
| | 80 | 240 | - | - | 6.1 |
| | 120 | 160 | 0.9 | 3.0 | 6.9 |
| | 120 | 240 | - | - | 7.1 |

**Table 8** N Uptake (kg/ha) for Maverick and Late Enterprise in Kent

| Variety | Fertiliser kg/ha n | | Sample Dates | | |
|---|---|---|---|---|---|
| | Base dressing | Top dressing | 17/12/98 | 25/2/99 | 50% harvest |
| **Maverick** | 0 | 0 (control) | 36.0 | 105.5 | 226 |
| | 40 | 160 | 37.0 | 121.6 | - |
| | 80 | 160 | 30.1 | 116.9 | 268 |
| | 120 | 160 | 40.2 | 109.4 | 247 |
| **Late enterprise** | 0 | 0 (control) | 33.5 | 103.2 | - |
| | 40 | 160 | 34.1 | 109.1 | - |
| | 80 | 160 | 34.2 | 95.7 | - |
| | 120 | 160 | 36.3 | 104.4 | - |

NB top dressings made on the 35 February and the 24 March

**Discussion**

Due to the large number of missing plants in these trials the, provision of clear guidelines is not easy. However, valuable information has been produced which can be reviewed with the previous work in this project.

Many factors have to be taken into account when making recommendation for over-winter cauliflower crops. For example the amounts of overwinter growth expected, and the amount of available nitrogen to support that growth.

In Lincolnshire, where high reserves of N tend to be found, there was a small response to base fertiliser; in spite of the large reserves of N. The reserves from previous crops were inefficiently used and were leached below rooting depth of young plants. This also explained the need for relatively high amounts of spring fertiliser. This also explained the need for relatively high amounts of spring fertiliser. This is a good example where residues from previous crops were not particularly well used. Cool weather conditions and slow plant growth between October and February meant that soil reserves lost.

In contrast, at the Kent site, there was little benefit from any fertiliser except for the late harvested variety. Crops grew well in the autumn, producing three times the dry matter of the Lincolnshire crop by February. Whilst the levels of soil mineral N were more modest in Kent they were more available to the young crop. Decreases in soil mineral N level between December and February were needed to support growth to harvest.

Further work must now be carried out to put these conclusions into a working version of the WELL_N model which will allow more efficient matching of N supply to crop demand, taking into account the different climatic conditions under which the crops are grown. The use of WELL_N can also help avoid situation where large residues are left by previous crops that could be used more efficiently.