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PROJECT REPORT No. 174

EXPLOITATION OF VARIETIES FOR UK CEREAL PRODUCTION (VOLUME III)

VARIETAL RESPONSES TO SOIL AND FERTILIZER N AVAILABILITY

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VARIETAL RESPONSES TO SOIL FERTILIZER N AVAILABILITY

by

E M WHITE[1], F E A WILSON[2], P S KETTLEWELL[3], R SYLVESTER-BRADLEY[4], M J FOULKES[5] & R K SCOTT[5]

[1] Department of Agriculture for Northern Ireland, Applied Plant Science Division, Plant Testing Station, 50 Houston Road, Crossnacreevy, Belfast BT6 9SH
[2] The Queen's University of Belfast, Department of Applied Plant Science, Plant Testing Station, 50 Houston Road, Crossnacreevy, Belfast BT6 9SH
[3] Crop and Environment Research Centre, Harper Adams Agricultural College, Newport, Shropshire, TF10 8NB
[4] ADAS Boxworth, Boxworth, Cambridgeshire CB3 8NN
[5] Division of Agriculture and Horticulture, School of Biological Sciences, University of Nottingham, Sutton Bonington Campus, Loughborough LE12 5RD

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Summary

The main objective was to examine whether there are varietal differences in crop N uptake and efficiency of utilization conferring differential relative performance of winter wheat varieties under low and high soil N conditions. Approximately 60% of UK wheat crops are grown where the soil provides less than one-third of the optimum supply and 10% where the soil provides more than two-thirds of the optimum supply. Experiments were conducted at each of three sites (i) Boxworth, Cambridgeshire, (ii) Crossnacreevy, Belfast and (iii) Harper Adams, Shropshire in three seasons (1993-4, 1994-5, 1995-6). In each experiment, three soil N amounts were established in the set-up season (R0 - low, R1 - intermediate, and R2 - high) and three or two amounts of fertilizer N (F0 - nil N, F1 - 40 kg/ha N, and F2 - optimum fertilizer N) were superimposed on soil N treatments. Within each soil N x fertilzer N treatment combination, ten varieties (Apollo, Avalon, Cadenza, Haven, Hereward, Hunter, Longbow, Mercia, Riband and Rialto) were randomised on sub-plots. The varieties selected included bread and feed types and covered a range in ability to acquire soil N, based on results from an analysis of a Variety x Fertilizer N trial series 1982-92 provided by Levington Agriculture. Results from this analysis indicated that, at nil fertilizer N, more modern varieties (of those introduced during the period 1969-88) had poorer N offtake (0.7 kg/ha worse per year), indicative of poorer ability to acquire soil N. Also more modern varieties required more fertilizer N, were better at recovering it (0.9 % better recovery per year), and had higher N optima (2.8 kg/ha N higher per year). In current experiments, for six of the nine site-seasons (those at Boxworth and Harper Adams) large differences in soil N residue treatments were established in the late autumn of the experimental year, typically > 200 kg N/ha at R2 compared to only about 50 kg N/ha at R0. Smaller differences were established at the Crossnacreevey site. In the presence of adequate application of fertilizer N in the spring (i.e. at F2), the overall effect of soil N residue treatment on yield performance was minimal, with means of 8.49 (R0), 8.33 (R1) and 8.48 (R2) t/ha. In the absence of fertilizer N (i.e. at F0), there were larger effects, with overall values of 4.76 (R0), 5.61 (R1) and 6.79 (R2) t/ha. For grain yield the soil N/variety interaction was non-significant in seven out of the nine site-seasons, varieties generally ranking similarly with differing residual soil N amounts. Overall the lack of consistent differences among varieties in their response to soil N suggested soil N residue status does not greatly affect relative varietal rankings for yield. There were few interactions between soil N residue levels and variety for characteristics potentially affecting crop N uptake and utilization : e.g. crop N offtake, green area index, canopy N requirement (g/m^2) : (calculated by dividing the N in the canopy by its green area index), above-ground harvest biomass and nitrogen harvest index. Although a few varieties stood out in having unusual expressions of traits (e.g. Rialto had high N uptake and high biomass at all growth stages and Longbow generally low N uptake and low biomass), the lack of consistent differences amongst varieties for traits was consistent with the general lack of an observed soil N/variety interaction for grain yield. Varieties did, however, show differences in response to availability of soil N by showing differences in their recovery of fertilizer N applied in early spring. Therefore, Sub-Project findings showed that savings in fertilizer N costs may be achieved where soil mineral N levels are high. Despite the absence of evidence to corroborate the original hypothesis that varieties respond differently to soil N for grain yield, significant findings were produced from current work through the analysis of the Levington Agriculture fertilizer N/variety trial series. The trend for greater N fertilizer requirement for more modern varieties in the Levington results was confirmed in the present experiments. Survey evidence indicates that since 1985 national fertilizer N usage on winter wheat has remained broadly stable at c. 185 kg/ha N per annum. The inference from the Levington analysis is that current usage may be underestimating the requirement for N now, or alternatively the requirement for N may have been overestimated in previous years. It seems breeders may have been selecting for varieties during the last 15 or so years better adapted to exploiting large amounts of fertilizer N. The corollary is that they may have inadvertently selected for modern varieties poorly adapted at acquiring soil N.. Therefore, given the possibility that with no change in national N usage in future years the chances of underfertilizing some varieties may increase, there could be scope for the testing agencies to keep a watch for varieties with significantly higher fertilizer N requirements compared to the norm.

VARIETAL RESPONSES TO SOIL AND FERTILIZER N AVAILABILITY

1. INTRODUCTION

Nitrogen is one of the major limiting inputs and determinants of yield and quality in winter wheat. The amount of nitrogen taken by the crop and the timing of its capture will affect the capacity of the crop to obtain other resources and to utilise both these resources and the nitrogen to produce grain. The condition of the crop when it captures the nitrogen will affect its utilisation of this nitrogen.

1.1. Environment and wheat performance

1.1.1. Extremes in soil nitrogen

All crops have access to nitrogen (N) available in the soil other than that being provided by applications of fertilizer. This soil nitrogen will vary in availability depending on the soil type, field history and, during the crop's life, soil conditions and crop growth.

1.1.1.1. High soil nitrogen levels

High levels of available soil nitrogen are common:

- in organic soils (*e.g.* peats, fenland, 'meadow land') with associated problems of lodging, manganese deficiency, and take-all.
- in moisture retentive soils e.g. clays and silts.
- after grass and arable crops that produce high residual N levels *e.g.* oil seed rape, peas, beans, potatoes and some vegetables.
- after set aside.
- after an over-fertilized cereal crop.
- after low rainfall over winter, especially if the autumn and winter months were also warm and dry.

1.1.1.2. Low soil nitrogen levels

Low levels of available soil nitrogen often occur:

- in easily leached soils *e.g.* sandy or shallow soils.
- in soils with a high C:N ratio *e.g.* some peats, or after a low N input/ high N output grass crop (*e.g.* grass for silage that has not been highly fertilised).
- after crops that leave little residual nitrogen *e.g.* cereals, sugar beet, linseed, and sunflowers.
- after high rainfall over winter (this may be complicated by cold autumns and winters delaying mineralisation of crop residues until spring, particularly in northerly situations such as Northern Ireland and Scotland).

1.1.1.3. Distribution of high and low N soils in the UK

Organic matter was greater than 5%, and therefore capable of releasing substantial N in 17% of the 400+ fields in arable rotations included in the Representative Soil Sampling Scheme Survey of England and Wales in 1983-85. In this survey, in 1990-92, the proportion of wheat grown in ley-cum-arable rotations, in which the soil N levels would be expected to be moderate or large, was about 19%. Autumn dressings of organic manures were applied to 11 to 12% of winter wheat fields in England and Wales sampled in the Survey of Fertiliser Practice during 1988-92 (Burhill & Fairgrieve, 1993). These fields are likely to have high soil N availability. In addition soils under other crops which wheat may follow, such as maincrop potatoes, oilseed rape and sugar beet, and to which organic manures were applied, may also have high soil N availabilities because of the residues from such dressings. However more than 50% of the winter wheat area in England and Wales, according to MAFF Winter Wheat Disease Survey data 1987-91, was sown after another cereal, sugar beet or linseed where the soil N availability would be expected to be low (Polley & Slough, 1992).

Based on this evidence, Scott *et al.* (1994) suggested that about 10% of winter wheat is grown in conditions where the soil can provide more than two-thirds of the available nitrogen needed to support optimal growth, about 30% is grown where the soil can provide between one and two thirds of this supply and the remaining 60% is grown where the soil provides less than one third of the optimum supply.

1.1.2. The relationship between variation in soil nitrogen and the performance of winter wheat

Nitrogen affects all the crop processes that contribute to growth and yield, namely:

(a) the capacity of the plants to recover nitrogen from the soil,
(b) the utilisation of the nitrogen for the formation and maintenance of the photosynthetic canopy, primarily through production of tillers, and hence biomass,
(c) the efficiency of retranslocation of this nitrogen for grain filling and protein deposition in the grain, and
(d) the success of harvest.

The crop's requirement for and response to nitrogen at any point in its life cycle will depend on its stage of development, its potential for growth as determined by previous growth and the extent to which current environmental conditions favour growth. The effect of soil N on crop processes is likely to be more significant prior to application of fertilizer nitrogen in the spring, albeit during a period (i.e. the winter months) when conditions do not favour growth and the crop is young.

As opposed to variation in sowing date, drought and take-all infection, farmers have the ability to compensate for variation in soil fertility, through the application of fertilizer. Hence the analysis of crop performance in relation to variation in soil fertility should take account of this complication.

If an unfertilized crop of winter wheat is considered; growth (but not development) is markedly stimulated by high soil nitrogen availability over the whole range found in arable fields (50 - 300 kg/ha). Tillering, green area index (GAI), total dry weight and grain yield are all much increased with a high soil nitrogen supply compared to a low one (when no fertilizer is applied). For example, with low soil nitrogen, the yield of an unfertilized crop might be 2 - 3 t/ha, whereas with high soil nitrogen the yield could be as much as 10 - 11 t/ha, and no response to fertilizer (if applied) would be seen. Ideally, with high soil nitrogen, less fertilizer nitrogen should be used and the effects of high soil N are likely to be small and subtle; the value of the soil N will be in terms of saved costs of fertilizer N.

However, where soil N residues are large, farmers often apply too much fertilizer N, either because they are unaware of the amount of soil N available, or because they lack confidence that this N will be effective. The national average nitrogen fertilizer rate has leveled out at about 180 kg/ha since 1984, mainly applied in the spring (Sylvester-

Bradley, 1993). Only 18 % of winter wheat fields in England and Wales receive less than 150 kg/ha (British Survey of Fertilizer Practice for 1993). It is therefore likely that most high N residue fields are substantially over-fertilised. The effects of high soil N combined with high fertilizer N levels may include:

- increased frost susceptibility.
- weak stems, giving a greater risk of lodging.
- greater weed competition, *e.g.* blackgrass and cleavers (Bloom, 1987).
- higher levels of disease *e.g. Septoria*, mildew and rust.
- higher stem and ear numbers.
- large canopy size.
- high straw yield.

1.2. Candidate indicative physiological traits

It is possible that there are varietal (genotypic) differences in the ability of the crop to recover and utilize nitrogen. Differences in fertilizer requirements between bread and feed varieties are recognized but apart from this, varieties all have similar amounts of fertilizer applied. Since varieties do not give the same yield, there may be differences between them in their optimum nitrogen levels, i.e. the nitrogen level at which the yield response reaches a plateau, and/or in their N uptake and/or in their utilization of nitrogen. Such differences, if they are consistent, will be important generally because they will indicate that fertilizer management ought to be tailored to varietal types irrespective of whether varietal types ought to be tailored to growing conditions. But, in addition, varietal differences may also indicate suitability of some types to certain environmental conditions more than others.

During the winter, differences in availability of soil N may have a large effect on the amount of growth which takes place. Low soil N is disadvantageous to growth and traits which enable crops to minimize these drawbacks are desirable. Such traits are also likely to enable crops to take advantage of high soil N availability but may generate problems through their enhancement of growth. Conversely, other traits may minimize these indirect disadvantages of high soil N availability.

Where soil nitrogen availability is low, varieties efficient at recovering nitrogen from the soil and able to produce an adequate green canopy area early in the season, before the application of fertilizer nitrogen, would be beneficial for crop production. In high soil nitrogen environments, however, these attributes could possibly lead to production of an excessively lush canopy early in the season and so increase the chances of problems with disease and lodging. In such situations varieties which produce smaller canopies and good resistances to disease and lodging would be better suited.

From the discussion above, the following traits can be identified as potentially playing a role in conferring suitability to different soil mineral nitrogen environments:

- **Crop nitrogen offtake**: total crop nitrogen offtake without fertilizer is equivalent to the nitrogen recovered from the soil by the crop and relates closely to over-winter assessments of soil mineral nitrogen (Vaidyanathan *et al.*, 1987).
- **Recovery of fertilizer nitrogen**: this is calculated by dividing the change in total crop nitrogen by the difference in applied nitrogen that gave rise to it. Recovery of

fertilizer nitrogen varies with site and weather conditions, but the average recovery is about 65% (Bloom *et al.*, 1988).

- **Green area index** (GAI): this increases and then decreases as the growing season progresses. Maximum GAI is greater and senescence is delayed as more nitrogen is applied. Genotypic differences in canopy size were reported by Austin *et al.* (1980). The semi-dwarf varieties, Hobbit and Mardler, introduced in the 1970s had leaf area indices on 22-23 May of 6.3 and 7.6 respectively, compared with 8.2 for the older non-semi-dwarf Maris Huntsman.
- **Canopy nitrogen requirement** (CNR) (g/m^2): this is calculated by dividing the nitrogen in the canopy by its GAI. It is expected to be relatively constant throughout the canopy's life (Sylvester-Bradley *et al.*, 1990).
- **Shoot number** (per m^2): this increases and then decreases to a plateau at about anthesis. Maximum shoot number is greater and the proportion surviving to produce ears is higher as more nitrogen is applied.
- **Biomass** (t/ha): this increases throughout most of the growing season, i.e. when green area is present. It increases as more nitrogen is applied.
- **Nitrogen Harvest index** (NHI): this tends to be fairly constant, with a small decrease from about 0.80 to 0.75 as more nitrogen is applied (Sylvester-Bradley, 1993).
- **Grain N%**: this increases slightly at nitrogen levels greater than optimum N. Grain N% is a consequence of yield and nitrogen uptake and, therefore is affected by the factors that affect these. Most of the nitrogen in the grain is provided by retranslocation from the canopy of nitrogen taken up before anthesis.
- **Harvest index** (HI): this tends to be fairly constant, with a small decrease as more nitrogen is applied.
- **Resistance to lodging**.

1.3. Empirical evidence for varietal types

1.3.1. Variety x fertilizer N experiments

Differences between varieties in their response to fertilizer N have been found in some experimental programmes (Holbrook *et al.*, 1983). However, Johnston (1984), evaluating experimental programmes on spring barley by a number of organisations, reported that ADAS advice stated that there was no evidence that one variety consistently differs from another in response to fertilizer N. Since variation in soil N availability affects crop growth during an earlier phase of development than fertilizer N, it is still possible that differences between varieties in response to soil N may be found.

1.3.2. Levington Agriculture experimental programme 1982-92

As discussed in the HGCA Annual Interim Project Report 1994, a desk study based on the Levington Agriculture data set (from data gathered over a decade, from the period in which varieties in these experiments were first introduced) suggested certain findings (Foulkes *et al.*, 1998). Effects due to introduction of variety from 1980 to 1989 were :

(a) Grain yields increased by 0.96 t/ha (i.e. about 0.1 t/ha/yr, which is consistent with the trend in yields from the MAFF census and from ADAS farms during the same period; Sylvester-Bradley & Scott, 1990).

(b) Grain nitrogen concentration (at 2.26%) did not change, so

(c) Nitrogen in the grain increased by 21 kg/ha,

(d) Nitrogen recovered from the soil decreased by 7.7 kg/ha, so

(e) Nitrogen required from fertilizer increased by 29 kg/ha.

(f) Recovery of fertilizer nitrogen increased from 44 to 53 %, so

(g) Nitrogen supplied as fertilizer increased by 28 kg/ha.

The Levington Agriculture data set suggests that when no fertilizer nitrogen is applied there is a trend for more modern varieties to have lower nitrogen offtakes than older varieties. This would indicate less ability to acquire soil nitrogen. The data set also suggests that modern varieties require more fertilizer nitrogen, are better at acquiring it, and have higher nitrogen optima than older varieties.

1.3.3. Breeding progress

Innovations in plant breeding, during the last decade or so, may have contributed to the increase in crop nitrogen offtakes and nitrogen optima observed for some of the more modern varieties. The introduction of *Rht* genes, responsible for a semi-dwarf phenotype, has led to higher harvest indices. The second major innovation was the introduction of the 1B/1R translocated rye genes (mostly to feed wheats). These are associated with increased leaf "greenness" and greater persistence of green canopy, leading to increased grain filling and higher specific weights.

1.4. Aims

The aims of the Soil Nitrogen Availability Sub-Project were to:

(a) Attempt to verify the trends, apparent in the Levington Agriculture data set, amongst (mainly current) commercial varieties,

(b) Investigate whether there are varietal differences in crop uptake and utilization of nitrogen under conditions of contrasting soil nitrogen availability, and

(c) Identify associated varietal traits that would provide early indication of differences in commercial performance.

1.5. Experimental programme

On the basis of results from the Levington programme and the Length of Growing Season Sub-Project (Cockle Park 1992-3 growth analysis data, see Vol. IV), a range of varieties introduced over a fourteen year period and with differing N offtakes and CNR's were included in the experimental programme.

2. MATERIALS AND METHODS

2.1. Experimental design and treatments

Experimental trials were conducted for three seasons at three sites, Boxworth (BW), Crossnacreevy (CC) and Harper Adams (HA). The three experimental seasons (1993-4, 1994-5, 1995-6) each followed on from a pre-treatment season designed to establish three residual soil nitrogen (soil N) levels (R0, R1, R2) at each site. In order to accomplish this, three different levels of nitrogen (N) fertilizer were applied to a pre-treatment crop, as several split applications, over the growing season. The three fertilizer levels were:

R0: 0 kgN/ha.
R1: 200 kgN/ha.
R2: 800 kgN/ha.

At each site the pre-treatment crops produced on the residual nitrogen plots were either harvested or burnt off (with glyphosate) in the autumn. The biomass was then removed from R0 plots while the crops on the R1 and R2 plots were ploughed into the soil to provide a residual soil nitrogen supply for the following season's winter wheat crop. At Boxworth the pre-treatment crop was oil-seed rape; after harvest of the seeds, the stems of the crop were ploughed into the plots (on the R1 and R2 plots). At Harper Adams the pre-treatment crop was grass which was cut several times during the growing season and left to wilt on the R1 and R2 plots, and removed from the R0 plots. In the autumn the plots were burnt off (with glyphosate), the biomass on the R1 and R2 plots was ploughed in and that on the R0 plots was removed. The pre-treatment crop at Crossnacreevy was also grass, but at this site in 1992-3 and 1993-4 the grass was not cut until the autumn, when it was burnt off (with glyphosate) and chopped and ploughed in (on the R1 and R2 plots). In an attempt to increase the differences between the residual soil N levels, the pre-treatment protocol at Crossnacreevy in 1994-5 was changed to that used at Harper Adams.

In the autumn of each experimental season ten varieties of winter wheat were sown at each site in the residual nitrogen plots. The varieties and the reasons for their selection are outlined below. Throughout the growing season, at Boxworth and Crossnacreevy, three levels of fertilizer nitrogen (fertilizer N) (F0, F1, F2) were applied to different plots of each of the residual nitrogen treatments (R0, R1 and R2). At Harper Adams the size of the trial was restricted by lack of field space and, therefore, only two levels of fertilizer nitrogen were applied (F0, F2). For the plots receiving high levels of N fertilizer (F2) the application was split into an early dressing of 40 kg N/ha (the same amount as the F1 plots received at Boxworth and Crossnacreevy) and a later, larger application. The fertilizer treatments are outlined below:

F0: nil fertilizer N.
F1: 40 kg N/ha (not undertaken at Harper Adams).
F2: sufficient fertilizer N applied to make the total N available in spring, calculated from the soil plus fertilizer (including the 40 kg N/ha, F1, early application) = 300 kg N/ha. The N available from the soil was based on an early spring soil analysis.

Varieties
The varieties selected for the Sub-Project included bread and feed types and covered a range in nitrogen uptake (based on the Levington data set) and canopy nitrogen requirement (CNR) (based on the Length of Growing Season Sub-Project at Cockle Park, 1992-3). The varieties used were:

(a) Apollo. (Breeder: Breun, Germany. Parentage: Maris Beacon x Kronjuwel)
Apollo was first entered in national list (NL) trials in 1985. It first appeared on the NIAB recommended cereals list for England and Wales (RL) in 1988 and was described as a high-yielding (for 1988), soft endosperm, feed wheat with good standing power. It is early maturing and has good resistance to yellow rust and above average resistance to *Septoria* diseases. Apollo contains 1B/1R genes and the *Rht1* gene. The variety had a high grain N offtake with nil fertilizer N in the Levington Agriculture trials (1982-92).

(b) Avalon. (Breeder: PBI Cambridge. Parentage: Maris Ploughman x Bilbo)
Avalon was first entered in NL trials in 1977 and appeared on the RL in 1979. It was described as a very high yielding (for 1979), early maturing, hard endosperm variety with moderately high bread-making quality and good standing power. It is susceptible to yellow rust, *Fusarium* ear blight and *Septoria* diseases. Avalon has the *Rht2* gene but no 1B/1R genes. The variety had a low grain N offtake with nil fertilizer N in the Levington Agriculture trials (1982-92) and a low CNR, measured in the Length of Growing Season Sub-Project at Cockle Park in 1992-3 (see Vol. IV).

(c) Cadenza. (Breeder: Cambridge Plant Breeders. Parentage: Axona x Tonic)
Cadenza was entered in NL trials in 1990 and appeared on the RL in 1994. It is a hard endosperm variety suitable for some bread-making processes, and has reasonable standing power. The variety contains no *Rht* or 1B1R genes. It has a very low vernalization requirement and has performed particularly well from late autumn sowing, but its yield is approximately 5% lower than the highest yielding feed varieties (from October sowings).

(d) Haven. (Breeder: PBI Cambridge. Parentage: (Hedgehog x Norman) x Moulin)
Haven was entered in NL trials in 1987 and appeared on the RL in 1989. It is a hard endosperm feed variety with good standing power. The variety is susceptible to yellow and brown rust, and liable to ear sprouting during wet harvests. Haven contains 1B/1R genes and the *Rht2* gene. It had a low grain N offtake with nil fertilizer N in the Levington Agriculture trials (1982-92).

(e) Hereward. (Breeder: PBI Cambridge. Parentage: Norman 'sib' x Disponent)
Hereward was entered in NL trials in 1988 and appeared on the RL in 1991. It is a hard endosperm variety widely used for bread-making, yielding approximately 10% below the highest yielding feed varieties. The variety has good standing power and resistance to brown rust. It contains 1B/1R genes and the *Rht2* gene. Hereward had a low grain N offtake with nil fertilizer N in the Levington Agriculture trials (1982-92).

(f) Hunter. (Breeder: PBI Cambridge. Parentage: Apostle x Haven)
Hunter was entered in NL trials in 1990 and appeared on the RL in 1993. It is a high yielding, soft endosperm, feed variety with a good spectrum of disease resistance and good standing power. The variety contains 1B1R genes and the *Rht2* gene. Hunter

exhibited a low CNR, when measured at Cockle Park (1993), and is apparently capable of performing well in reduced input situations.

(g) Longbow. (Breeder: PBI Cambridge. Parentage: TJB268/175 x Hobbit)
Longbow was entered in NL trials in 1979 and appeared on the RL in 1983. It is a soft endosperm variety with biscuit-making potential and had the highest treated yield potential of any variety on the 1985 recommended list. It appears to respond well to early drilling, but is susceptible to yellow rust and *Septoria*, and has only moderate standing power. The variety contains the *Rht2* gene but no 1B1R genes. Longbow had a high grain N offtake with nil fertilizer N in the Levington Agriculture trials (1982-92).

(h) Mercia. (Breeder: PBI Cambridge. Parentage: (Talent x Virtue) x Flanders)
Mercia was entered in NL trials in 1983 and appeared on the RL in 1986. It is a non semi-dwarf, hard endosperm variety acceptable for all bread-making processes and yielded approximately 13% below the highest yielding feed varieties in 1994-5. It is susceptible to brown rust and has moderate standing power. The variety contains no 1B/1R or *Rht* genes. Mercia had a high grain N offtake with nil fertilizer N in the Levington Agriculture trials (1982-92) and is a standard variety used across Sub-Projects.

(i) Rialto. (Breeder: PBI Cambridge. Parentage: Haven 's' x Fresco 's')
Rialto was entered in NL trials in 1991 and appeared on the RL in 1995; it is the newest variety used in this Sub-Project. It is a hard endosperm variety with a high yield potential and is suitable for some bread-making processes. It has moderate standing power and contains 1B/1R genes and the *Rht2* gene. Rialto apparently requires careful management to obtain full yield and quality potential; thus providing an opportunity to examine the effects of high yield potential and high grain N% on performance with differing soil nitrogen levels.

(j) Riband. (Breeder: PBI Cambridge. Parentage: Norman x (Maris Huntsman x TW161)
Riband was entered in NL trials in 1985 and appeared on the RL in 1988. It is a soft endosperm feed variety (also used for biscuit making and distilling) with high treated yields. It has very good standing power, but is susceptible to yellow and brown rusts and *Septoria tritici*. The variety contains the *Rht2* gene but no 1B/1R genes. Riband is a standard variety used across Sub-Projects.
The two additional varieties sown at Crossnacreevy for the 1994-5 and 1995-6 harvests were:

(k) Maris Huntsman. (Breeder: PBI Cambridge. Parentage: [(CI 12633 x Cappelle Desprez) x Hybrid 46] x Professeur Marchal)
Maris Huntsman was entered in NL trials in 1969 and appeared on the RL in 1972. It is a high-yielding (for 1980) feed wheat with good resistance to *Septoria nodorum*, but is susceptible to brown rust. Maris Huntsman is a non-dwarf wheat, producing a large canopy and does not have any 1B/1R genes. It was the oldest variety used in the Levington Agriculture trials (1982-92). Maris Huntsman was included in the experiment because of its age and lush vegetative growth habit.

l) Soissons. (Breeder: Desprez, France. Parentage: Jena x HN 35.)

Soissons was accepted on to the EU Common Catalogue in *c.* 1990 and appeared on the RL in 1994-5. It is an early maturing, hard endosperm wheat suitable for some bread-making processes. It has good standing power and contains no 1B/1R genes, but does contain the *Rht1* gene. The variety should not be sown before October because of its rapid development. Soissons was included in the experiment because of its extreme earliness.

This combination of treatments gave a total of nine soil N x fertilizer N treatments at Boxworh and Crossnacreevy and six at Harper Adams. Each treatment combination was replicated in a second block, giving a total of 180 plots at Boxworth and Crossnacreevy, and 120 at Harper Adams. At Crossnacreevy in the 1994-5 and 1995-6 seasons, the plots were narrower (1.53 m compared with 2 m in 1993-4) which allowed room for two extra varieties - Maris Huntsman and Soissons (see above) - to be sown, giving a total of 216 plots.

Table 2.1. Summary of experimental design

Centre	Blocks	Residual N levels	Fertilizer N levels	Variety number	Plot number	Plot area (m^2)
Boxworth	2	3	3	10	180	36.00
Crossnacreevy	2	3	3	10/12*	180/216*	36.00/27.54*
Harper Adams	2	3	2	10	120	28.00

**First value for 1993-4 season, second value for 1994-5/1995-6.*

2.2. General management

2.2.1. General agronomy and husbandry of trials.

All the trials were cultivated and managed in accordance with current standard good husbandry practices for winter wheat at each site. Lime, potassium (K) and phosphate (P) fertilizer and growth regulator were applied as required for good growth of the crop, with sufficient P and K provided for the highest yields that could be expected. Crop protection regimes were consistent with other, parallel, HGCA projects; *i.e.* the crops were managed to limit weeds, pests and diseases to very low levels. Details of sowing and harvest dates, and nitrogen fertilizer application can be found in the Appendix table 2.

2.2.2. Seed rates and sowing date.

The seed rate for each variety was calculated with reference to 1,000 grain weight to achieve a target spring plant population of 275 plants per m^2. All seed was treated with a fungicide seed dressing (Panoctine at 2 ml/kg). Sowing dates varied between the 29 September at Boxworth in 1994-5, and the 22 October at Crossnacreevy in 1993 (see Materials and Methods Appendix). In the 1995-6 season an effort was made to sow earlier (if ground conditions permitted) in order to give the seedling crop an opportunity to capture some of the soil mineral N available in the autumn, in case some of it would be lost through leaching later in the autumn.

2.3. Plant measurements.

The following measurements were carried out on the trials:

2.3.1. Crop establishment.

The number of plants established in the autumn/winter of the growing season was assessed by placing a 1.0 or 0.5 m cane between 2 rows and counting the number of plants in each row to either side of the cane. This was repeated three times per plot, sampling at random within the whole plot. Results were then converted to plants per m^2. This was carried out at Boxworth for the 1993-4 season, Crossnacreevy for 1993-4 and 1994-5 and at Harper Adams for 1993-4 and 1995-6. Results can be found in Appendix table 3.

2.3.2. Radiation interception.

At Crossnacreevy, in the 1993-4 and 1994-5 seasons, % ground cover was visually assessed in the variety sub-plots on several occasions prior to canopy closure. Ground cover was also scored once at Boxworth in 1993-4. Results can be found in Results Appendix tables 4.1. and 4.2.

2.3.3. Stage of plant development.

At each time of plant sampling for growth analysis, the growth stage of the plants was noted. As well as this, some dates were determined in the field (by casual observation of sub-plots) for growth stages such as:

(i) GS 31: first node detectable.
(ii) GS 39: flag leaf fully emerged (*i.e.* when half of all shoots have flag leaves fully emerged).
(iii) GS 55: half of ears emerged (*i.e.* when half of all ears have fully emerged).
(iv) GS 61: the beginning of anthesis (*i.e.* when half of all ears have some anthers showing).
(v) The end of green area (*i.e.* when there is no green area left).

2.3.4. Crop height.

Crop height was measured once a season, after ear emergence, from the ground to the top of the ear on plants (three per variety sub-plot) randomly selected through the canopy. This was carried out at Boxworth in 1993-4, and at Crossnacreevy in all three seasons. Results are tabulated in the Appendix tables 5.1.and 5.2.

2.3.5. Lodging and leaning assessment.

Lodging was scored from first occurrence until harvest at a minimum interval of 2 weeks, using the following scoring system.

Index 1: % crop upright (crop at an angle up to 5° from the vertical).
Index 2: % crop leaning (crop leaning between 5° and 45° from the vertical).
Index 3: % crop lodged (crop lodged between 45° and 90° from the vertical - this degree of angle being evident at the base of the stem).
Index 4: % crop flat (severe lodging).
Index 5: % area brackled (buckling of straw above ground level: >1/4 or more up its length)

Results can be found in the Appendix table 6.1.

2.3.6. Plant growth analysis.

Plants were sampled for growth analysis at four points through the season:

(i) Growth Analysis 1: towards the end of February / at the beginning of March, before any fertilizer had been applied to the plots.
(ii) Growth Analysis 2: at GS 31 (usually April).
(iii) Growth Analysis 3: at GS 61, the beginning of anthesis (usually early June).
(iv) Growth Analysis 4: at harvest, a few days before the expected date of combining.

At Boxworth in the 1993-4 and 1994-5 seasons the first growth analysis was not carried out. Due to the constraints of personnel and time available, not all treatments could be sampled at each growth analysis. Normally only F0 plots were sampled in early spring and at GS 31. At GS 65, both F0 and F2 plots were sampled in all years at Crossnacreevy, and in 1995-6 at Boxworth. In 1994-5 and 1995-6, all plots were sampled before harvest at all sites (Growth Analysis 4). Further details of plot selection for sampling are outlined at the bottom of the relevant results tables. The area of crop sampled varied slightly between sites and growth analyses, but usually was between 0.5 and 0.75 m^2. Full details of the methods of plant sampling and growth analysis techniques can be found in the general Materials and Methods section to the report (Vol. I, Part 1, Section 6). The plant characteristics normally measured at each growth analysis are outlined below.

(i) Growth analyses 1 and 2.
Growth stage; fertile shoot number (per m^2); total dry weight (t/ha); dry weight of green lamina (g/m^2); dry weight of green stem and sheath (g/m^2); dry weight of dead lamina (g/m^2); green lamina area index; green stem and sheath index; %N in shoots; total N uptake (kg N/ha); canopy nitrogen requirement (CNR) (g N per m^2 of canopy).

(ii) Growth analysis 3.
Growth stage; fertile shoot number (per m^2); total dry weight (t/ha); dry weight of green lamina (g/m^2); dry weight of green stem and sheath (g/m^2); dry weight of emerged green ears (g/m^2); dry weight of unemerged green ears (g/m^2); dry weight of non-green ears (emerged + unemerged) (g/m^2); dry weight of dead lamina (g/m^2); green lamina area index; green stem and sheath index; emerged green ear index; %N in shoots and ears; N uptake of shoots and ears (kg N/ha); CNR (gN/m^2).

(iii) Growth analysis 4.
Total crop above-ground biomass (t/ha); ear number per m^2; grain number per m^2; grain number per ear; thousand grain weight (g at 100% dry matter); chaff dry weight (t/ha at 100% dry matter); straw dry weight (t/ha at 100% dry matter); biomass harvest index (HI); N% in grain; N% in straw plus chaff; total N uptake (kg N/ha at 100% dry matter); nitrogen harvest index (NHI).

2.3.7. Grain yield.

When the crop was combined grain yield (t/ha at 85% dry matter) was recorded for each variety sub-plot, and grain N offtake (kg/ha at 100% dry matter) calculated. If grain nitrogen concentration had not been determined from samples from the pre-harvest growth analysis, it was measured from samples taken from the combine harvest. The same was true of thousand grain weight calculations.

2.4. Environmental measurements

2.4.1. Meteorological measurements

Daily records of temperature, rainfall and total incident radiation were taken at the three experimental sites. The records are summarized in Appendix tables 1.1 - 1.4.

2.4.2. Soil mineral nitrogen (SMN) analysis

Soil mineral nitrogen levels were measured on (usually) five or six occasions at each site during each season. Samples were normally taken at emergence (November/December), prior to F1 application (mid-February/early March), prior to F2 application (early April), anthesis (mid/late June), and after harvest. For some site-season combinations further samples were taken, and at Boxworth in 1995-6 one measurement in May replaced those from April and June.

Samples were taken from three soil horizons: 0-30, 30-60 and 60-90 cm depth. At Boxworth and Harper Adams sampling was done with a manual auger and two cores for each soil depth were taken from each of three variety sub-plots in each main plot (R*F*). The three variety sub-plots used were Haven, Longbow and Riband. The cores for each depth were then bulked across variety sub-plot. This was done to reduce the amount of samples to be sent for SMN analysis. At Crossnacreevy a mechanical auger was used. In each main plot the same varieties were sampled as at the other two sites, but the samples were kept separate (three cores taken and bulked, for each soil horizon, per variety sub-plot at each sampling date).

The soil samples from Crossnacreevy were analysed in a Department of Agriculture for Northern Ireland (DANI) laboratory. The samples from Boxworth and Harper Adams were analysed in the ADAS laboratory in Wolverhampton. A sub-sample of 100 g soil was taken for DM determination. The soil samples were extracted as 100 g of moist soil in 200 ml of 2M KCl on the day of collection, shaken for 1 hr and filtered. The extracts were refrigerated prior to flow injection analysis (Tecator) for NH_4N, NO_2N and NO_3N detection. For soil from each site bulk density was determined at each of 0-30, 30-60 and 60-90 cm depths.

2.5. Data handling and statistical analysis

Statistical analysis of data from all three sites was carried out at Crossnacreevy. Most analyses involved the 'Genstat' analysis of variance progam (using a mainframe computer). The 'Microsoft Excel 5' spreadsheet package for pc.s was used for regression analyses and graph drawing.

3. RESULTS

Where a parameter has been measured in more than one fertilizer treatment, e.g. at all sites at harvest and at Crossnacreevy at GS 65, the tabled values for varieties and residual soil N treatments are not meaned over fertilizer treatment (i.e. the means at F0 are presented in the first table and the means at F2 in the second table), and the probabilities and estimated standard errors included refer to fertilizer N x variety (or soil N) interaction. For comparative purposes, where means for individual site-seasons have been calculated at the bottom of tables, these do not take into account values for Maris Huntsman and Soissons at Crossnacreevy in 1994-5 and 1995-6.

3.1. Soil Mineral Nitrogen.

The three sites chosen for the Soil N Availability Sub-Project were quite different in climate and soil environment, as outlined in Appendix tables 1.1 - 1.4. Due to these differences the fate of soil nitrogen at the three sites would also be expected to be different. It is thought that the climatic conditions at Boxworth would encourage some mineralization, but that little leaching would occur because of the heavy clay soil type. The light soil at Harper Adams, on the other hand, would permit more leaching of any mineralized nitrogen. Leaching would also be expected in the wetter soil conditions at Crossnacreevy, but how much mineralization would occur at this site is difficult to predict, given the high organic matter and cool conditions.

At Boxworth (Fig. 3.1.1) the pattern of soil mineral nitrogen (SMN) availability was very similar for all three seasons. In the autumn preceding each growing season the pre-treatment of 800 kgN/ha (R2) produced a much greater residual soil nitrogen level than both the R1 and R0 treatments, ranging from approximately 260 kg N/ha in December 1993, to just over 500 kg N/ha in November 1995. Throughout each season the R1 and R0 plots provided similar amounts of SMN as each other. In each season the gap between the R2 and the other treatments decreased over the winter until by late spring / early summer there was no significant difference between the residual nitrogen available from each (although in 1995-6 there was still noticeably more SMN in the R2 plots at the end of the season than in the others).

At Crossnacreevy (Fig. 3.1.2.), at the beginning of the 1993-4 season, there was more SMN in the R2 plots than in the other treatments, but levels were much lower than at Boxworth or Harper Adams, with a maximum value of 103 kg N/ha in October 1993. From January 1994 onwards the residual soil mineral nitrogen levels at Crossnacreevy were very similar for all treatments and lower than at the other two sites (under 40 kg N/ha for all treatments). In 1994-5 SMN levels at Crossnacreevy were again very low and very similar for all three residual N levels throughout the season. The maximum value measured was 54 kg N/ha for R2 plots in November 1994.

The reasons for the poor establishment of differences between treatments at Crossnacreevy, for the first two experimental years, are not entirely clear. It may be that the nitrogen in the ploughed-in grass was rapidly mineralized, and subsequently denitrified, in the early autumn (before soil samples were taken). More nitrogen could have been lost through denitrification and leaching over the winter months, which were wet in both years (see Results Appendix table 1.1).

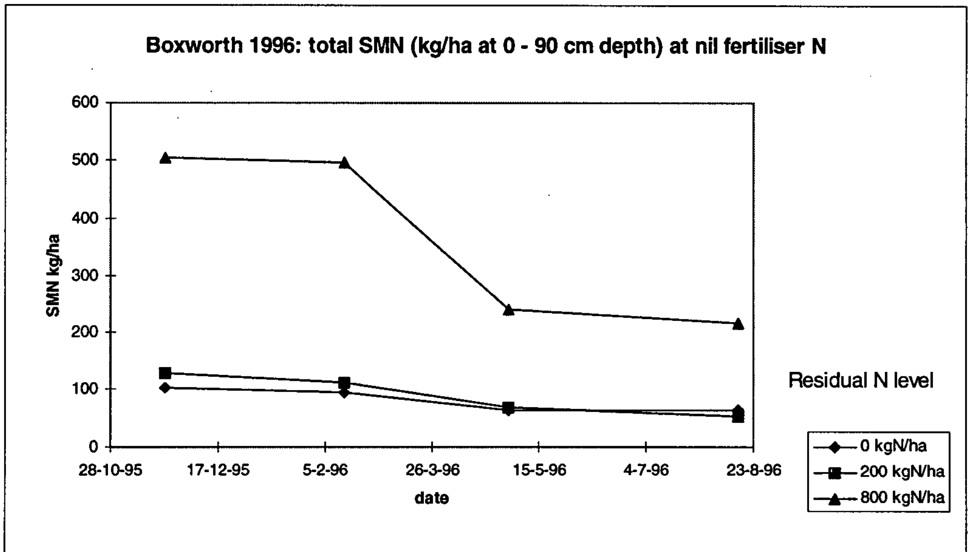
An alternative explanation is that the soil nitrogen in the R2 treatment was immobilized because of a high carbon:nitrogen ratio of the grass pre-treatment at

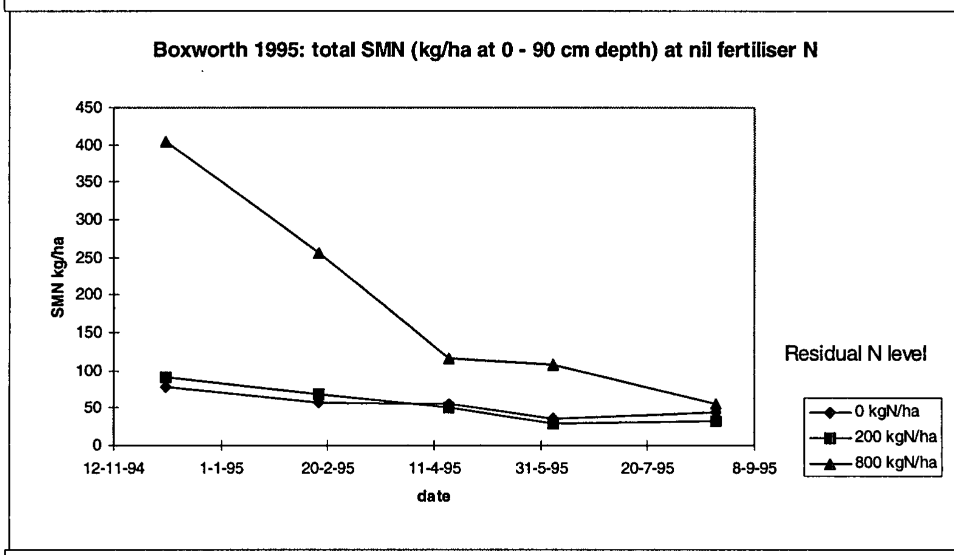
Crossnacreevy. The C:N ratio would be expected to be higher there than at the other two sites: grass would fix a larger amount of carbon than the oil seed rape grown at Boxworth. At Harper Adams the grass was mown and wilted throughout the season, rather than cut only once (and chopped) before ploughing in at the end of the season, as it was at Crossnacreevy. Hence, at Crossnacreevy soil micro-organisms may have "locked up" the nitrogen in the R2 residues while consuming the large amounts of carbon suddenly available and proliferating. This nitrogen would then only slowly become available as the C:N ratio decreased.

In order to try and increase the difference between the residual nitrogen treatments at Crossnacreevy, the grass pre-treatment plots for the 1995-6 experimental season were managed in line with the protocol observed at Harper Adams. Grass was mown and left to wilt on the plots several times during the late spring and summer. In late summer the plots were 'burnt off' with glyphosate and ploughed in.

When SMN levels were determined in August and September 1995 a large difference was seen between the amounts of available soil N in the R2 plots and the two other treatments, with SMN reaching a maximum value of 267 kg N/ha in September 1995. The difference between the treatments was statistically significant until November 1995 and still noticeable in April 1996. The altered pre-treatment of the grass plots may, therefore, have produced larger differences in the residual, available N levels; perhaps because of a decrease in the C:N ratio compared to previous years. On the other hand, such differences may have existed in previous years but were not identified because measurement started later in the season; by which time the differences could have had disappeared because of denitrification in the early autumn.

At Harper Adams, during the autumn and winter of 1993, differences between residual soil nitrogen levels were well defined (Figure 3.1.3.) and the amounts of SMN available increased between the October and December measurements. This may have been due to further microbial breakdown of the ploughed in grass, and subsequent nitrogen mineralization, occurring in late autumn in the comparatively warm, light soil at that site. Variation between treatments had, however, virtually disappeared by April. This suggests that mineral soil nitrogen was leached from the light soil in late winter, perhaps in December which was quite a wet month for this site (see Appendix table 1.1 - 1.4.). In the autumn and winter of 1994 there again were higher SMN levels in the R2 plots than in the R1 and R0 plots (which had similar levels). This difference disappeared by early spring, probably once more due to over-winter leaching losses, and soil N availability in the three treatments was similar, and low, for the rest of the season. In the 1995-6 season, variation in SMN levels between the treatments was again obvious until the soil sampling carried out in April 1996, with a maximum value of 189 kg N/ha for R2 in October 1995. This was lower than the 1994 October value (230 kg N/ha for R2), but similar to the 1993 figure.





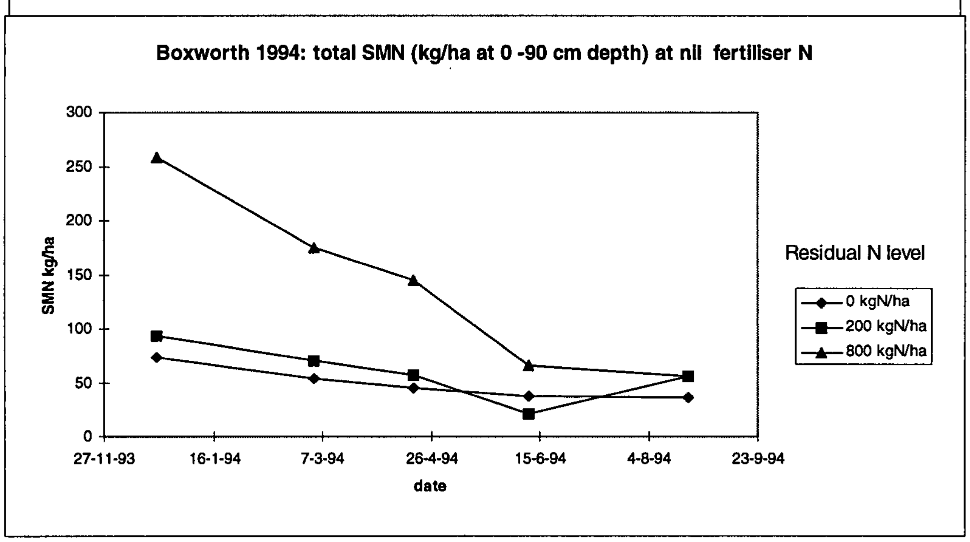
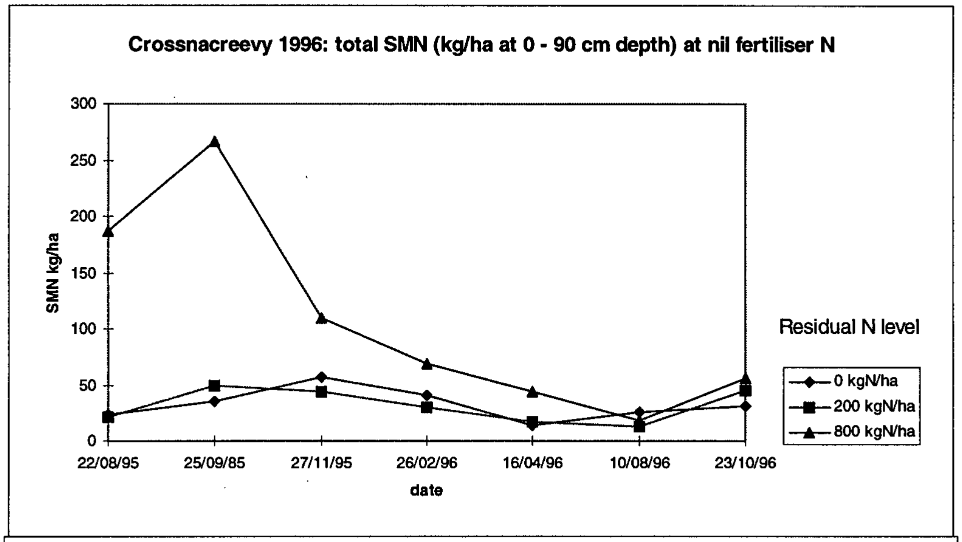
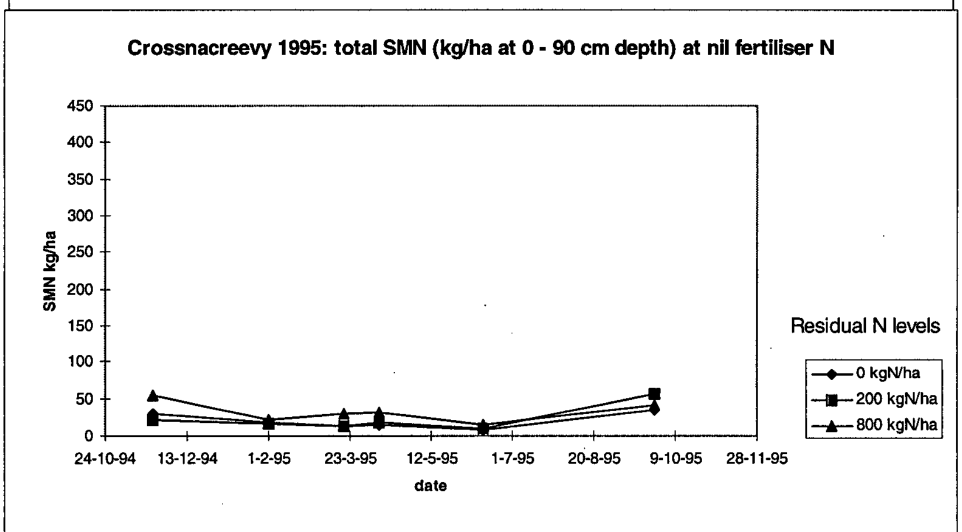


Fig. 3.1.1 Soil mineral N at ADAS Boxworth at R0 (0 kg/ha N), R1 (200 kg/ha N) and R2 (800 kg/ha N) at nil fertilizer N.





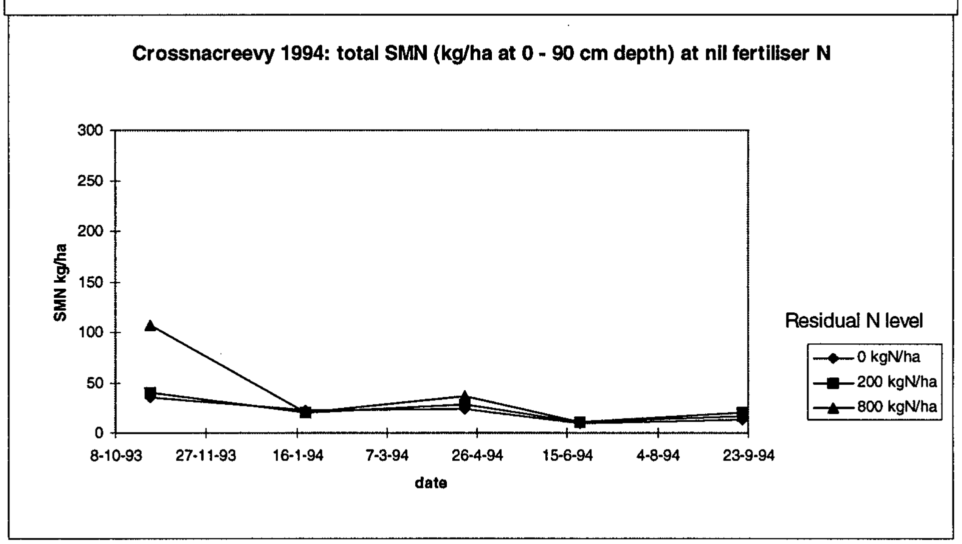


Fig. 3.1.2. Soil mineral N at Crossnacreevey at R0 (0 kg/ha N), R1 (200 kg/ha N) and R2 (800 kg/ha N) at nil fertilizer N.

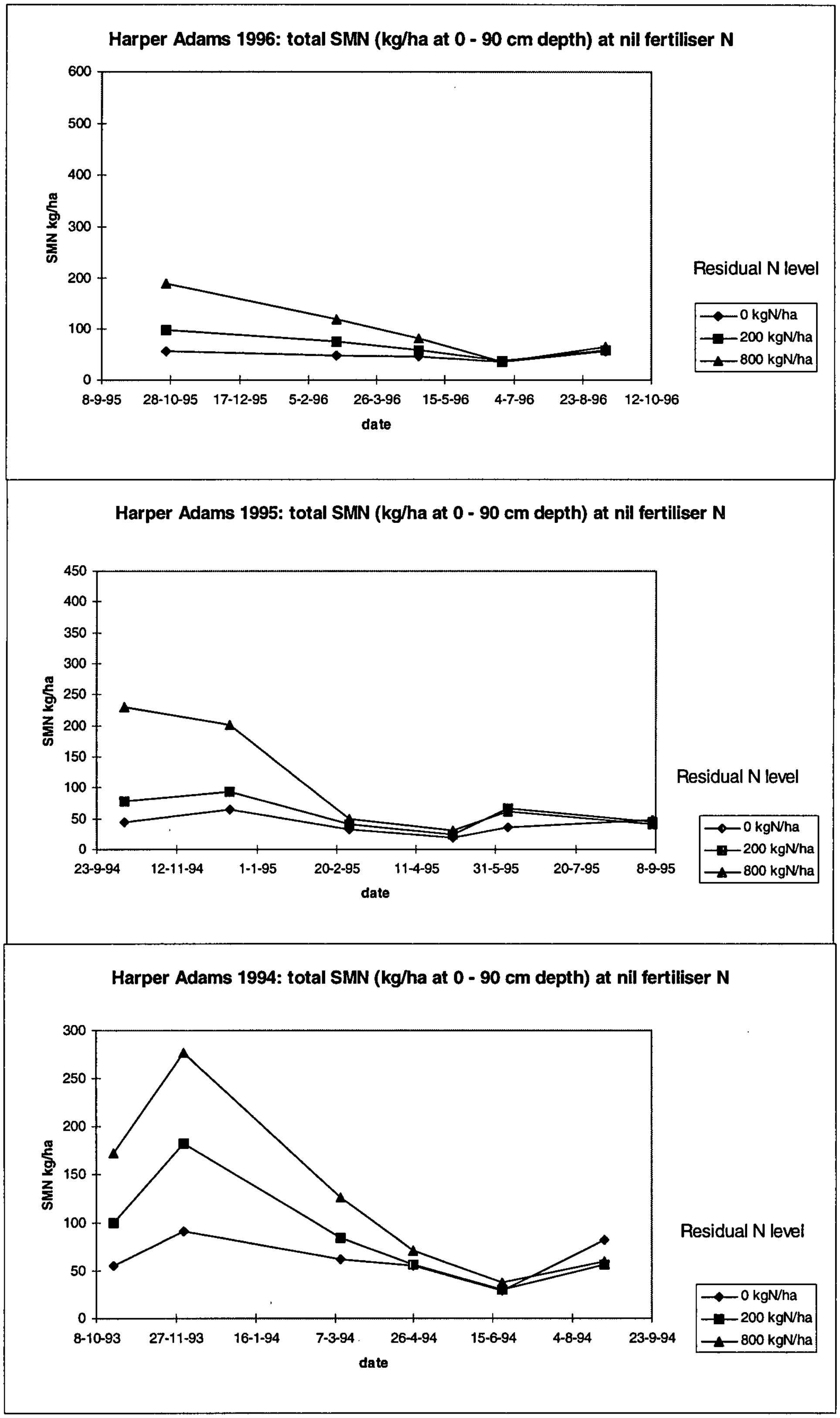


Fig. 3.1.3. Soil mineral N at Harper Adams at R0 (0 kg/ha N), R1 (200 kg/ha N) and R2 (800 kg/ha N) at nil fertilizer N.

3.2. Yield.

Table 3.1.a Combine grain yield at F0 (t/ha at 85% dry matter).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**[a]	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**[b]	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	6.50	5.61	7.91	3.77	4.40	5.03	3.59	6.09	6.37	5.47
Avalon	6.53	5.54	8.28	3.44	3.64	5.39	3.23	6.04	6.31	5.38
Cadenza	7.09	5.74	7.36	3.52	4.35	5.55	3.52	6.00	6.58	5.52
Haven	6.22	6.04	9.06	3.94	4.27	6.04	4.20	7.20	7.40	6.04
Hereward	6.78	5.57	8.22	3.65	4.10	5.80	3.84	5.96	6.24	5.57
Hunter	6.82	6.02	8.59	3.72	4.33	5.61	3.63	7.33	6.45	5.83
Longbow	6.59	5.90	8.68	3.09	4.01	6.44	3.37	6.02	6.64	5.64
Mercia	6.71	5.93	8.13	3.92	4.52	6.02	3.73	6.45	6.47	5.76
Rialto	7.00	6.08	8.70	3.92	4.58	6.38	4.00	7.54	7.04	6.12
Riband	6.69	6.22	8.74	3.79	4.55	6.02	3.83	7.25	6.70	5.99
M.Huntsman	-	-	-	-	4.17	5.76	-	-	-	4.97
Soissons	-	-	-	-	3.74	4.97	-	-	-	4.36
significance	*0.500*	*0.311*	*0.129*	*<.001*	*0.001*	*<.001*	*0.565*	*0.648*	*0.269*	
e.s.e.	*0.225*	*0.109*	*0.137*	*0.218*	*0.188*	*0.153*	*0.165*	*0.208*	*0.312*	
R0	5.20	4.58	7.34	2.57	3.74	4.59	2.94	6.11	5.76	
R1	5.95	5.37	8.46	3.74	4.27	5.23	3.94	6.92	6.59	
R2	8.93	7.65	9.30	4.72	4.65	7.42	4.20	6.74	7.51	
significance	*<.001*	*<.001*	*<.001*	*0.148*	*0.597*	*<.001*	*0.211*	*0.138*	*0.116*	
e.s.e.	*0.193*	*0.167*	*0.115*	*0.376*	*0.472*	*0.123*	*0.322*	*0.165*	*0.376*	
c.v.	7.0	4.0	3.8	8.9	7.2	4.6	9.1	7.3	10.9	
mean	6.69	5.86	8.37	3.68	4.27	5.83	3.69	6.59	6.62	

[a]At Boxworth in 1995-6 there was a soil N x variety interaction (*P*<.001), but no fertilizer N x soil N x variety interaction. The yield (meaned over fertilizer treatments) of some varieties, *e.g.* Avalon, Longbow and Mercia, increased very little with increasing soil N, while other varieties, *e.g.* Apollo and Rialto, yielded > 1 t/ha more at R2 compared to R0.

[b]At Harper Adams in 1994-5 there was a soil N x variety interaction (*P*=0.005), but no fertilizer N x soil N x variety interaction. Some varieties, *e.g.* Apollo, Hunter, and Rialto, had relatively higher yields in the R1 treatment, compared to the R2 treatment.

Table 3.1.b Combine grain yield at F2 (t/ha at 85% dry matter).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**[a]	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**[b]	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	8.68	7.53	8.95	9.62	10.88	10.62	5.14	7.18	7.05	8.41
Avalon	9.20	7.46	9.37	8.56	8.84	10.03	4.76	6.37	6.62	7.91
Cadenza	9.60	7.55	8.47	10.15	10.60	9.94	4.92	6.85	7.43	8.39
Haven	8.75	7.68	9.54	9.54	10.71	11.42	5.77	8.16	7.53	8.79
Hereward	9.22	7.25	9.32	8.76	9.64	10.33	5.00	6.75	7.74	8.22
Hunter	9.24	7.73	9.91	9.51	9.78	10.84	5.20	7.82	8.21	8.69
Longbow	8.83	7.72	9.92	9.65	9.76	10.20	5.27	6.87	7.57	8.42
Mercia	8.92	7.34	9.06	9.30	9.36	9.92	5.30	7.52	7.09	8.20
Rialto	9.52	7.72	9.87	10.00	10.41	11.18	5.22	8.33	7.59	8.87
Riband	8.34	7.86	10.04	10.38	10.42	10.50	5.11	7.73	7.38	8.64
M.Huntsman	-	-	-		9.23	9.65	-	-	-	9.44
Soissons	-	-	-		9.31	10.49	-	-	-	9.90
significance	*0.500*	*0.311*	*0.129*	*<.001*	*0.001*	*<.001*	*0.214*	*0.648*	*0.269*	
e.s.e.	*0.225*	*0.109*	*0.137*	*0.218*	*0.188*	*0.153*	*0.165*	*0.208*	*0.312*	
R0	9.18	7.27	9.55	9.72	10.27	10.37	5.17	7.18	7.70	
R1	8.90	7.78	9.82	9.06	9.73	10.44	5.15	7.22	6.86	
R2	9.02	7.70	8.97	9.86	9.73	10.46	5.18	7.67	7.71	
significance	*<.001*	*<.001*	*<.001*	*0.148*	*0.597*	*<.001*	*0.211*	*0.138*	*0.116*	
e.s.e.	*0.193*	*0.167*	*0.115*	*0.376*	*0.472*	*0.123*	*0.322*	*0.165*	*0.376*	
c.v.	7.0	4.0	3.8	8.9	7.2	4.6	9.1	7.3	10.9	
mean	9.03	7.58	9.44	9.55	10.04	10.50	5.17	7.36	7.42	

[a]See table 3.1.a above.
[b]See table 3.1.a above.

3.2.1. Site Effects.

At Boxworth, in 1993-4, the mean yield for plots with no fertilizer applied to them was 6.7 t/ha, compared to 3.7 t/ha at both Harper Adams and Crossnacreevy (Table 3.1.a). This poor result at Harper Adams was probably an effect of drought stress on the crop; moisture availability may have been restricted during grain filling, due both to the light soil and the low summer rainfall at this site (see Appendix table 1). The low yield at Crossnacreevy is more likely a reflection of the low soil nitrogen availability in all the F0 treatments for this site-season; an effect that was repeated in 1994-5. The lower mean yield, compared to the other two seasons, at F0 at Boxworth in 1994-5 was probably due to the drought conditions that were prevalent that summer (see Appendix table 1).

The mean F0 yields at Harper Adams, in 1994-5 and 1995-6, appear quite high - at about 6.6 t/ha - particularly considering the mean F2 yields are less than a tonne more than this. These results at Harper Adams may have been influenced by ammonia deposition from a large poultry unit that was constructed 350 m upwind from the trial site before the 1994-5 season (a different area of the same field was used for the 1995-6 trial). Wheat plants can absorb ammonia directly from the atmosphere and atmospheric ammonia may also become available to plants through wet and dry deposition onto the soil. Hence the nil fertilizer plots at Harper Adams in 1994-5 and 1995-6 may have received sufficient nitrogen through these routes to produce a crop similar to that achieved with high levels of fertilizer N.

The effect of drought is also noticeable in the yields from the F2 plots (Table 3.1.b). As in the F0 treatment, Harper Adams is affected in 1993-4 and Boxworth in 1994-5. In 1993-4 and 1995-6, the mean grain yields from the F2 plots at Boxworth are what would be expected in East Anglia for a first wheat crop after oil seed rape. On the other hand, the F2 yields at Crossnacreevy, in all three seasons, are slightly higher than what would be expected for this site. High yields were probably encouraged by the level of fertilizer application at F2 being greater than normal for winter wheat in this area, combined with virtually no occurrence of lodging. Another factor probably involved was that, throughout the summers, the temperature was lower at Crossnacreevy than at the other two sites (see Appendix table 1), leading to a longer grain filling period.

3.2.2. Residue effects.

When no N fertilizer was applied (F0), increasing residual N levels caused an increase in yield for all site-seasons, except Harper Adams 1994-5 (Table 3.1.a). When analyzed, however, the differences were only statistically significant at Boxworth (all seasons) and Crossnacreevy in 1995-6. This pattern reflects that of the soil mineral nitrogen availability (Figures 3.1.1.-3.1.3.). In each year, large differences between the low and high soil residue treatments were seen at Boxworth compared to the other two sites, and at Crossnacreevy variation in the soil N levels between the treatments was only really noticeable in 1995-6. For each site-season, when high levels of fertilizer were added, grain yields were very similar in all R treatments (Table 3.1.b).

3.2.3. Variety differences.

When analyzed for F0 and F2 plots (Tables 3.1.a, 3.1.b), variety had no significant effect on yield at Boxworth and Harper Adams in all three experimental seasons. In contrast, there were significant varietal differences at Crossnacreevy in each season. For most of the site-seasons measured, at both F0 and F2, Rialto and Haven were noticeably high yielding, (relative to other variety means), while Riband often performed well when high levels of fertilizer had been applied. Avalon usually had a low yield at both F0 and F2, and Longbow was frequently a low ranking variety at F0. At Crossnacreevy, in 1994-5 and 1995-6, Soissons yielded poorly when no fertilizer N had been applied, and Maris Huntsman ranked low in the mean variety yields at F2.

3.3. Fertile shoot numbers throughout the season

Table 3.2.1. Fertile shoot numbers (per m^2) in early spring at F0.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4***	**94-5***	**95-6**	**mean**
date	-	-	-	10/3/94	15/2/95	-	-	4/3/95	6/3/96	
Apollo	-	-	-	1106	822	-	-	1021	1012	990
Avalon	-	-	-	742	771	-	-	1080	1085	920
Cadenza	-	-	-	686	651	-	-	929	924	798
Haven	-	-	-	812	1057	-	-	1298	2127	1324
Hereward	-	-	-	656	524	-	-	732	1478	848
Hunter	-	-	-	920	1153	-	-	1409	1460	1236
Longbow	-	-	-	624	620	-	-	791	1474	877
Mercia	-	-	-	834	723	-	-	769	1391	929
Rialto	-	-	-	857	922	-	-	1041	1647	1117
Riband	-	-	-	708	899	-	-	1193	1469	1067
M.Huntsman	-	-	-	-	705	-	-	-		705
Soissons	-	-	-	-	735	-	-	-		735
significance	-	-	-	*<.001*	*<.001*	-	-	*<.001*	*<.001*	
e.s.e.	-	-	-	*43.8*	*72.8*	-	-	*76.1*	*111.1*	
R0	-	-	-	833	696	-	-	1010	1230	
R1	-	-	-	770	719	-	-	-	1451	
R2	-	-	-	781	981	-	-	1043	1539	
significance	-	-	-	*0.655*	*0.118*	-	-	*0.456*	*0.314*	
e.s.e.	-	-	-	*46.5*	*57.8*	-	-	*20.5*	*107.6*	
mean	-	-	-	794.5	814.2	-	-	1026	1407	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1993-4 and 1994-5.*

Table 3.2.2. Fertile shoot numbers (per m^2) at GS 31 at F0.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5***	**95-6**	**mean**
date	26/4/94	25/4/95	15/4/96	12/4/94	3/5/95	24/4/96	-	24/4/95	24/496	
Apollo	1116	675	880	1134	703	599	-	693	1015	852
Avalon	949	605	1286	809	628	751	-	728	1177	867
Cadenza	967	831	864	843	613	653	-	792	1159	840
Haven	1147	733	1637	926	770	1093	-	891	1179	1047
Hereward	978	529	1262	692	523	848	-	781	1450	883
Hunter	1125	668	1310	953	728	749	-	875	1064	934
Longbow	847	593	1246	750	538	770	-	996	1050	849
Mercia	1037	717	1208	971	756	838	-	752	1141	928
Rialto	921	682	1114	792	680	748	-	706	1104	843
Riband	979	689	1480	1054	741	947	-	864	1273	1003
M.Huntsman	-	-	-	-	616	759	-	-	-	688
Soissons	-	-	-	-	712	708	-	-	-	710
significance	*0.002*	*0.005*	*<.001*	*<.001*	*0.231*	*<.001*	-	*0.099*	*0.154*	
e.s.e.	*47.5*	*43.8*	*54.2*	*47.5*	*70.6*	*41.5*	-	*68.1*	*98.6*	
R0	895	603	1138	896	669	664	-	795	1058	
R1	998	666	1186	879	608	763	-	-	1072	
R2	1126	748	1362	902	725	938	-	820	1353	
significance	*0.186*	*0.215*	*0.083*	*0.949*	*0.197*	*0.091*	-	*0.860*	*0.090*	
e.s.e.	*55.3*	*38.0*	*35.7*	*52.2*	*28.8*	*43.9*	-	*80.6*	*52.4*	
mean	1007	672	1229	892	668	800		808	1161	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

Table 3.2.3.a Fertile shoot numbers (per m^2) at GS 65 at F0.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6[a]	93-4	94-5	95-6	93-4	94-5*	95-6	mean
date	6/6/94	6/6/95	13/6/96	24/6/94	1/7/95	1/7/96	-	25/6/95	16/6/96	
Apollo	497	470	478	314	318	362	-	509	487	429
Avalon	459	376	492	339	308	367	-	417	550	414
Cadenza	485	449	569	317	319	401	-	479	535	444
Haven	454	398	554	309	380	436	-	447	571	444
Hereward	545	414	633	292	327	481	-	477	619	474
Hunter	500	401	580	299	349	438	-	506	516	449
Longbow	448	338	502	251	285	386	-	447	642	412
Mercia	546	464	706	335	378	545	-	510	595	510
Rialto	494	390	526	262	322	360	-	472	560	438
Riband	460	382	496	376	304	378	-	435	553	409
M. Huntsman	-	-	-	-	326	357	-	-	-	342
Soissons	-	-	-	-	336	525	-	-	-	431
significance	*0.010*	*0.080*	*0.202*	*0.001*	*0.088*	*0.623*	-	*0.636*	*0.359*	
e.s.e.	*19.8*	*29.8*	*24.4*	*24.0*	*29.7*	*28.5*	-	*37.0*	*43.2*	
R0	381	372	465	260	289	356	-	449	491	
R1	471	371	536	303	309	382	-	-	516	
R2	614	483	660	365	390	522	-	491	681	
significance	*0.009*	*0.057*	*0.011*	*0.761*	*0.472*	*0.055*	-	*0.197*	*0.055*	
e.s.e.	*10.9*	*15.8*	*15.4*	*39.5*	*21.19*	*24.4*	-	*9.4*	*24.9*	
mean	488.8	408.2	553.6	309.4	329	415.4	-	469.9	562.8	

**Only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

[a]At Boxworth in 1995-6 there was a fertilizer N x soil N x variety interaction (*P*=0.037).

Table 3.2.3.b Fertile shoot numbers (per m^2) at GS 65 at F2.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6[a]	93-4	94-5	95-6	93-4	94-5	95-6	mean
date	-	-	13/6/96	24/6/94	1/7/95	1/7/96	-	-	-	
Apollo	-	-	531	642	584	622	-	-	-	595
Avalon	-	-	544	575	387	591	-	-	-	524
Cadenza	-	-	657	670	545	675	-	-	-	637
Haven	-	-	608	664	497	696	-	-	-	616
Hereward	-	-	658	633	540	638	-	-	-	617
Hunter	-	-	643	704	518	673	-	-	-	634
Longbow	-	-	440	532	456	607	-	-	-	509
Mercia	-	-	711	714	487	762	-	-	-	668
Rialto	-	-	566	609	509	649	-	-	-	577
Riband	-	-	542	574	442	645	-	-	-	557
M.Huntsman	-	-	-	-	435	563	-	-	-	499
Soissons	-	-	-	-	485	780	-	-	-	633
significance	-	-	*0.202*	*0.001*	*0.088*	*0.623*	-	-	-	
e.s.e.	-	-	*24.4*	*24.0*	*29.7*	*28.5*	-	-	-	
R0	-	-	558	611	479	643	-	-	-	
R1	-	-	603	628	444	674	-	-	-	
R2	-	-	609	656	548	658	-	-	-	
significance	-	-	*0.011*	*0.761*	*0.472*	*0.055*	-	-	-	
e.s.e.	-	-	*15.4*	*39.5*	*21.2*	*24.4*	-	-	-	
mean	-	-	590	632	496	656	-	-	-	

[a] See above.

Table 3.2.4.a Ear numbers (per m²) at harvest at F0.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6[a]	93-4	94-5	95-6[b]	93-4	94-5	95-6	mean
date	16/8/94	28/7/95	9/8/96	29/8/94	17/8/95	3/9/96	-	3/8/95	16/8/96	
Apollo	380.7	341.2	440.7	244.4	287.8	336.1	-	468.7	405.7	363.2
Avalon	320.5	336.7	428.1	197.5	304.5	364.9	-	408.0	456.3	352.1
Cadenza	372.4	405.8	502.2	201.3	290.6	418.6	-	482.3	493.0	395.8
Haven	323.4	350.1	508.2	227.6	338.6	414.6	-	469.9	527.7	395.0
Hereward	407.9	338.4	580.6	259.7	292.3	433.5	-	431.0	575.3	414.8
Hunter	401.0	342.0	509.2	235.6	309.4	422.2	-	462.7	481.0	395.4
Longbow	321.6	293.9	429.7	167.4	242.9	401.0	-	398.0	504.0	344.8
Mercia	418.4	397.4	606.7	233.3	306.8	538.2	-	459.7	551.3	439.0
Rialto	351.6	330.4	481.1	241.0	285.8	358.9	-	440.0	460.7	368.7
Riband	324.0	345.0	414.5	201.8	269.0	380.1	-	429.7	497.3	357.7
M.Huntsman	-	-	-	-	299.6	359.6	-	-	-	329.6
Soissons	-	-	-	-	382.1	514.7	-	-	-	448.4
significance	*0.583*	*0.025*	*0.311*	*0.003*	*0.007*	*0.019*	-	*0.283*	*0.118*	
e.s.e.	*18.35*	*12.74*	*12.48*	*15.89*	*19.35*	*22.66*	-	*18.11*	*31.52*	
R0	299.6	313.4	415.9	170.7	278.6	349.4	-	433.2	430.6	
R1	325.8	342.7	468.0	222.6	280.3	382.5	-	401.9	464.4	
R2	461.0	388.2	586.5	269.6	343.4	503.7	-	499.9	590.7	
significance	*0.238*	*0.901*	*0.005*	*0.376*	*0.178*	*0.069*	-	*0.263*	*0.530*	
e.s.e.	*27.22*	*12.49*	*10.19*	*21.67*	*22.44*	*23.60*	-	*13.51*	*33.17*	
mean	362.1	348.1	490.1	220.9	292.8	406.8	-	445.0	495.2	

[a] See below.[b] See below.

Table 3.2.4.b Ear numbers (per m²) at harvest at F2.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6[a]	93-4	94-5	95-6[b]	93-4	94-5	95-6	mean
date	16/8/94	28/7/95	9/8/96	22/9/94	17/8/95	3/9/96	-	3/8/95	16/8/96	
Apollo	460.6	407.2	485.2	542.7	521.8	590.4	-	396.7	637.3	505.2
Avalon	437.1	362.6	500.2	519.7	387.8	574.2	-	411.3	604.3	474.6
Cadenza	483.3	385.3	554.6	451.3	507.4	640.8	-	450.0	631.7	513.0
Haven	464.9	363.3	554.5	442.2	466.5	685.6	-	428.0	637.7	505.3
Hereward	532.8	411.1	590.4	527.3	506.5	670.3	-	445.3	730.7	551.8
Hunter	531.4	376.7	573.0	472.6	467.3	653.1	-	438.0	638.7	518.8
Longbow	436.9	332.2	486.0	449.2	423.0	547.7	-	382.0	602.3	457.4
Mercia	590.3	449.2	678.0	544.2	562.8	753.5	-	486.0	744.7	601.1
Rialto	454.1	400.3	513.0	480.5	486.3	634.2	-	416.7	604.7	498.7
Riband	410.7	341.9	487.1	492.8	422.7	539.7	-	397.3	513.0	450.6
M.Huntsman	-	-	-	-	411.3	477.4	-	-	-	444.4
Soissons	-	-	-	-	563.9	743.2	-	-	-	653.6
significance	*0.583*	*0.025*	*0.311*	*0.003*	*0.007*	*0.019*	-	*0.283*	*0.118*	
e.s.e.	*18.35*	*12.74*	*12.48*	*15.89*	*19.35*	*22.66*	-	*18.11*	*31.52*	
R0	456.5	360.0	503.7	459.5	455.6	597.1	-	401.0	615.7	
R1	482.3	370.9	549.5	523.6	436.8	653.2	-	411.2	584.7	
R2	501.9	418.1	573.5	493.6	539.5	627.2	-	463.2	703.1	
significance	*0.238*	*0.901*	*0.005*	*0.376*	*0.178*	*0.069*	-	*0.263*	*0.530*	
e.s.e.	*27.22*	*12.49*	*10.19*	*21.67*	*22.44*	*23.60*	-	*13.51*	*33.17*	
mean	480.2	383.0	542.2	492.2	475.2	629.0		425.1	634.5	

[a] At Boxworth '96 soil N/var. interaction (P=0.001). Some varieties, *i.e.* Apollo, Haven, Longbow and Riband, showed no significant increase in ears per m² from R0 to R1, and two other varieties, Avalon and Cadenza, had similar numbers at R1 and R2. There was a fert N/soil N/var. interaction (P=0.05).

[b]At Crossnacreevy '96 soil N/var. interaction (P=0.022). Some varieties, Longbow, Mercia and Soissons, had > 150 more ears per m² in R2 than R0, and others, Avalon, Cadenza, Haven, Riband and M. Huntsman had similar numbers at R0, R1 and R2. There was a fert. N/soil N/var. interaction (P=0.033).

3.3.1. Site effects

Fertile shoot numbers were higher at Harper Adams than Crossnacreevy in early spring (Table 3.2.1), although measurements at the two sites only overlapped in 1994-5 (when there was a mean of 1407 shoots per m^2 at Harper Adams, compared to 814 at Crossnacreevy). The parameter was not assessed at Boxworth in early spring for any of the experimental seasons. At GS 31 (at F0) numbers had fallen at Harper Adams, but were still higher than at Crossnacreevy in 1994-5 and 1995-6 (Table 3.2.2.). Numbers at Boxworth were similar to Harper Adams in 1995-6, but lower in 1994-5. By GS 65, at F0, fertile shoot numbers decreased noticeably in all site-seasons, varying from 309 per m^2 at Crossnacreevy in 1993-4 to 563 at Harper Adams in 1995-6 (Table 3.2.3.a). When F2 plots were measured at Crossnacreevy, at GS 65, shoot numbers were considerably higher than when no fertilizer had been applied (Table 3.2.3.b.). Fertile shoot numbers, at F0, (measured as ear number per m^2) decreased slightly more by harvest, particularly at Boxworth and Crossnacreevy in 1993-4 (Table 3.2.4.a). There was a similar decrease, at harvest, in the F2 plots at Crossnacreevy in 1993-4 (Table 3.2.4.b.).

3.3.2. Residue effects

In early spring and at GS 31 (Tables 3.2.1, 3.2.2), there was a noticeable increase in shoot numbers (at F0) from R0 to R2 for all the site-seasons measured, except Crossnacreevy in 1993-4 and Harper Adams in 1994-5. These increases were, however not statistically significant. Similarly, at GS 65 in all seasons, at Crossnacreevy and Harper Adams (at F0) (Table 3.2.3.a), any increases in shoot numbers with residual soil N treatment were not significant. When counted in F2 plots at Crossnacreevy, at GS 65, shoot numbers were very similar for all three soil N treatments in all three years (Table 3.2.3.b). At Boxworth, at GS 65 (at F0, and F2 - when measured), there were more shoots in the R2 plots than the R0 plots in each season (statistically significant in 1993-4 and 1995-6). At harvest, at both F0 and F2 (Tables 3.2.4.a, 3.2.4.b), there were appreciably more ears per m^2 in R2 plots than R0 plots for all site-seasons measured, although this was only statistically significant at Boxworth in 1995-6.

3.3.3. Variety effects

There were varietal differences in shoot numbers at the four site-seasons measured in early spring (Table 3.2.1.). Relative to other variety means for each site-season, Cadenza,, Hereward and Longbow had low shoot numbers, except at Harper Adams in 1995-6 where only Cadenza had noticeably fewer shoots. Hunter had high shoot numbers in early spring at all site- seasons, while Haven produced over 2000 shoots per m^2 at Harper Adams in 1995-6 and had reasonably high numbers in other site-seasons.

In each experimental season, from GS 31 until harvest, shoot numbers (at F0) did not differ significantly between varieties at Harper Adams (Tables 3.2.2., 3.2.3.a, 3.2.4.a), indicating that those varieties with high shoot numbers in early spring had had a higher incidence of shoot death than those with low numbers. Ear numbers at harvest were also similar for all varieties in F2 plots at Harper Adams (Table 3.2.4.b).

At the other two sites, variety had a significant influence on shoot number at GS 31 (at F0) in all seasons except Crossnacreevy in 1994-5 (Table 3.2.2.). These effects were not always consistent, but it was noticeable that Longbow and Rialto often had low numbers of shoots, relative to other variety means, while Haven normally had a high shoot number. Other varieties, *e.g.* Apollo, had very fluctuating rankings. At GS 65 (at F0), at Boxworth and Crossnacreevy, there were statistical differences between varietal shoot numbers only in 1993-4 (Table 3.2.3.a). Longbow and Rialto, however, still usually had low numbers of shoots, and Avalon also performed poorly. The ranking of Haven had become more variable, but Mercia had a high mean shoot number in every site-season measured. Mercia also performed well at F2 at GS 65, as did Cadenza, while Avalon still had low shoot numbers (Table 3.2.3.b).

The fertile shoot numbers (measured as ears per m^2) for Mercia remained high at harvest in both F0 and F2 plots (Tables 3.2.4.a, 3.2.4.b). Longbow, on the other hand, usually had low numbers of ears at both fertilizer levels. At F0, Avalon was frequently also a low ranking variety, while Hereward quite often had high numbers of ears (relative to other variety means) in the nil fertilizer plots. At Crossnacreevy in 1994-5 and 1995-6 Soissons exhibited a high number of ears per m^2 in both F0 and F2 plots.

3.4. Crop resource capture

3.4.1. Nitrogen uptake throughout the season

Table 3.3.1. Nitrogen uptake in early spring at F0 (kg N/ha).

Site	**Boxworth**			**Crossnacreevy**			**Harper Adams**			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4***	**94-5***	**95-6**	**mean**
date	-	-	18/3/96	10/3/94	15/2/95	13/3/96	12/3/94	4/3/96	6/3/96	
Apollo	-	-	32.66	10.45	10.78	23.64	12.25	45.99	30.54	23.76
Avalon	-	-	50.90	10.00	10.65	35.80	10.19	47.88	33.07	28.36
Cadenza	-	-	50.53	7.53	9.72	33.89	8.80	38.98	39.76	27.03
Haven	-	-	43.65	8.01	10.84	40.53	10.47	43.70	45.26	28.92
Hereward	-	-	44.80	7.66	6.68	46.23	8.57	35.77	41.32	27.29
Hunter	-	-	44.59	8.52	11.83	33.25	12.03	42.66	38.30	27.31
Longbow	-	-	44.84	6.40	7.49	41.73	6.61	28.70	40.57	25.19
Mercia	-	-	44.91	7.95	11.26	37.18	11.34	42.09	41.92	28.09
Rialto	-	-	51.61	9.34	11.51	45.18	11.11	43.97	46.50	31.32
Riband	-	-	54.73	6.82	9.40	38.33	13.21	36.55	33.60	27.52
M.Huntsman	-	-	-	-	6.59	44.92	-	-	-	25.76
Soissons	-	-	-	-	10.63	31.53	-	-	-	21.08
significance	-	-	*<.001*	*<.001*	*<.001*	*<.001*	*0.001*	*<.001*	*0.014*	
e.s.e.	-	-	*2.711*	*0.526*	*0.772*	*2.250*	*0.852*	*2.368*	*3.057*	
R0	-	-	38.54	8.19	8.12	28.07	10.23	37.74	29.89	
R1	-	-	43.78	8.36	8.60	40.15	-	-	39.45	
R2	-	-	56.65	8.25	12.63	44.84	10.69	43.51	47.91	
significance	-	-	*0.019*	*0.989*	*0.086*	*0.038*	*0.015*	*0.398*	*0.041*	
e.s.e.	-	-	*1.309*	*0.796*	*0.761*	*1.719*	*0.008*	*2.950*	*1.855*	
mean			46.32	8.27	10.02	37.58	10.46	40.63	39.08	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1993-4 and 1994-5.*

Table 3.3.2. Nitrogen uptake at F0 at GS 31 (kg N/ha).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5***	**95-6**	**mean**
date	26/4/94	25/4/95	15/4/96	12/4/94	3/5/95	24/4/96	-	24/4/95	24/4/95	
Apollo	66.4	62.8	61.3	13.29	34.14	51.2	-	89.6	58.5	54.65
Avalon	70.2	63.2	83.1	14.65	31.87	56.4	-	93.7	59.2	59.04
Cadenza	61.9	57.5	84.6	12.28	30.19	55.9	-	87.0	59.5	56.11
Haven	59.0	51.6	70.9	13.00	32.40	63.8	-	82.4	53.6	53.34
Hereward	60.8	44.6	80.4	11.38	33.09	70.7	-	78.2	70.0	56.15
Hunter	58.1	53.8	77.8	13.62	37.66	62.1	-	88.7	57.1	56.11
Longbow	58.2	44.3	76.6	11.02	29.42	64.4	-	77.4	55.7	52.13
Mercia	64.2	63.1	77.6	13.59	30.17	61.0	-	84.7	60.9	56.91
Rialto	66.8	60.2	88.6	14.09	33.59	67.4	-	91.2	60.6	60.31
Riband	63.2	53.1	85.4	13.23	28.41	55.4	-	78.2	56.8	54.22
M.Huntsman	-	-	-	-	32.81	66.5	-	-	-	49.66
Soissons	-	-	-	-	27.54	58.2	-	-	-	42.87
significance	*0.677*	*<.001*	*0.032*	*0.151*	*0.522*	*0.025*	-	*0.867*	*0.702*	
e.s.e.	*4.75*	*3.32*	*5.04*	*0.889*	*2.906*	*3.72*	-	*8.43*	*5.27*	
R0	42.2	37.1	58.8	12.24	30.55	40.3	-	71.8	44.1	
R1	55.6	44.2	66.6	11.79	28.76	53.3	-	-	53.1	
R2	90.8	85.0	110.4	15.02	36.01	89.6	-	98.4	80.4	
significance	*0.105*	*<.001*	*0.017*	*0.279*	*0.143*	*0.081*	-	*0.135*	*0.054*	
e.s.e.	*8.61*	*0.40*	*3.62*	*1.087*	*1.540*	*7.59*	-	*4.05*	*4.54*	
mean	62.88	55.42	78.63	13.02	32.09	60.83	-	85.11	59.19	

**Only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

Table 3.3.3.a Nitrogen uptake at F0 at GS 65.

Site	Boxworth			Crossnacreevy			Harper Adams			
Season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6[b]**	**93-4**	**94-5***	**95-6**	**mean**
Date	6/6/94	6/6/95	13/6/96	24/6/94	1/7/95	1/7/96	-	25/6/95	16/6/96	
Apollo	106.1	109.3	158.1	35.1	50.4	89.3	-	154.8	126.6	103.7
Avalon	113.1	100.7	178.2	48.8	49.1	65.6	-	151.0	189.0	111.9
Cadenza	108.2	121.2	175.4	36.4	64.5	66.3	-	138.1	133.1	105.4
Haven	107.1	100.9	157.3	38.2	59.7	100.3	-	148.4	126.1	104.8
Hereward	113.7	85.2	191.2	39.7	60.1	86.1	-	131.0	165.3	109.0
Hunter	94.2	101.7	189.3	35.7	51.8	78.3	-	132.1	126.9	101.2
Longbow	100.2	99.0	186.7	35.7	52.3	71.6	-	132.7	160.0	104.8
Mercia	99.6	111.4	187.2	43.4	64.4	77.4	-	174.1	114.2	109.0
Rialto	112.9	105.6	176.8	33.5	55.6	81.6	-	198.4	141.1	113.2
Riband	110.4	100.2	184.8	39.0	57.6	87.0	-	139.6	140.6	107.4
M.Huntsman	-	-	-	-	41.3	87.1	-	-	-	64.2
Soissons	-	-	-	-	50.5	65.6	-	-	-	58.0
significance	*0.563*	*0.542*	*0.236*	*0.385*	*0.002*	*0.193*	-	*0.205*	*0.427*	
e.s.e.	*7.12*	*9.96*	*11.11*	*16.50*	*11.19*	*17.29*	-	*17.32*	*22.17*	
R0	64.1	58.9	118.0	29.2	44.1	60.8	-	143.0	98.5	
R1	80.1	77.1	145.2	38.7	51.7	68.5	-	-	118.9	
R2	175.4	174.5	272.3	47.7	68.6	109.8	-	157.1	209.4	
significance	*0.002*	*0.004*	*0.021*	*0.693*	*0.454*	*0.004*	-	*0.760*	*0.045*	
e.s.e.	*2.85*	*4.00*	*13.58*	*11.71*	*13.41*	*5.50*	-	*25.17*	*12.80*	
mean	106.5	103.5	178.5	38.5	56.6	80.4		150.0	142.3	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

[a]At Boxworth in 1995-6 there was a fertilizer N x soil N x variety interaction (*P*=0.012).

[b] At Crossnacreevy in 1995-6 there was a soil N x variety interaction (*P*=0.002). The N uptake of some varieties, *e.g.* Apollo, Hunter and Longbow, decreased as residual N level increased, while other varieties, *e.g.* Avalon, Cadenza, Hereward, Riband and Soissons had higher N uptakes in R2 plots compared to R0 plots. There was also a fertilizer N x soil N x variety interaction (*P*<.001).

Table 3.3.3.b Nitrogen uptake (kg N/ha) at F2 at GS 65.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6[b]**	**93-4***	**94-5**	**95-6**	**mean**
date	-	-	13/6/96	24/6/94	1/7/95	1/7/96	19/6/94	-	-	
Apollo	-	-	193.8	238.1	227.2	286.9	212.3	-	-	231.7
Avalon	-	-	229.3	212.0	177.3	247.0	190.6	-	-	211.2
Cadenza	-	-	222.3	262.4	201.2	271.3	168.0	-	-	225.0
Haven	-	-	218.6	231.8	241.5	330.6	227.6	-	-	250.0
Hereward	-	-	230.3	198.3	216.7	329.5	203.8	-	-	235.7
Hunter	-	-	265.5	255.4	234.7	308.6	222.5	-	-	257.3
Longbow	-	-	239.1	238.0	212.9	314.6	185.3	-	-	238.0
Mercia	-	-	231.6	255.0	163.0	277.8	209.8	-	-	227.4
Rialto	-	-	261.2	234.6	253.6	298.3	206.3	-	-	250.8
Riband	-	-	209.3	202.1	193.0	294.6	222.5	-	-	224.3
M.Huntsman	-	-	-	-	194.5	282.2	-	-	-	238.4
Soissons	-	-	-	-	188.1	204.8	-	-	-	196.4
significance	-	-	*0.236*	*0.385*	*0.002*	*0.193*	*0.141*	-	-	
e.s.e.	-	-	*11.11*	*16.50*	*11.19*	*17.29*	*14.04*	-	-	
R0	-	-	215.9	234.8	209.4	299.8	190.2	-	-	
R1	-	-	216.4	230.6	184.5	293.5	-	-	-	
R2	-	-	258.0	232.9	232.0	268.3	219.5	-	-	
significance	-	-	*0.021*	*0.693*	*0.454*	*0.004*	*0.316*	-	-	
e.s.e.	-	-	*13.58*	*11.71*	*13.41*	*5.50*	*11.22*	-	-	
mean	-	-	230.1	232.8	212.1	295.9	204.8	-	-	

**Only R0F2 and R2F2 treatments were measured at Harper Adams in 1993-4.* [a]See above.[b] See above.

Table 3.3.4.a Total nitrogen offtake at F0 (kgN/ha at 100% dry matter) at harvest.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	16/8/94	28/7/95	9/8/96	29/8/94	17/8/95	3/9/96	19/8/9	3/8/95	16/8/96	
Apollo	-	103.6	176.5	54.41	64.32	67.8	-	159.3	144.4	110.0
Avalon	-	122.1	187.5	55.24	62.84	75.9	-	156.9	153.1	116.2
Cadenza	-	111.9	177.2	52.20	62.56	77.7	-	164.1	143.4	112.7
Haven	-	110.5	190.1	63.69	64.38	81.3	-	171.3	157.9	119.8
Hereward	-	119.2	200.9	58.64	67.62	84.2	-	153.2	152.4	119.4
Hunter	-	115.8	184.9	57.06	69.10	81.6	-	179.5	147.5	119.3
Longbow	-	110.4	178.3	51.59	59.29	82.3	-	139.3	145.4	109.5
Mercia	-	120.2	184.9	59.73	63.77	89.9	-	161.9	144.7	117.8
Rialto	-	116.8	194.6	59.48	68.25	89.0	-	181.3	165.2	124.9
Riband	-	114.0	182.0	54.58	63.58	72.4	-	166.1	145.1	113.9
M.Huntsman	-	-	-	-	64.03	85.9	-	-	-	74.97
Soissons	-	-	-	-	66.32	80.9	-	-	-	73.61
significance	-	*0.200*	*0.246*	*0.671*	*0.076*	*<.001*	-	*0.986*	*0.424*	
e.s.e.	-	*3.68*	*4.78*	*5.247*	*4.198*	*5.51*	-	*7.27*	*8.78*	
R0	-	74.0	129.0	39.84	58.74	62.2	-	127.7	113.6	
R1	-	90.8	158.9	55.81	63.38	71.8	-	157.9	135.2	
R2	-	178.6	269.2	74.34	71.89	108.1	-	204.3	200.8	
significance	-	*<.001*	*<.001*	*0.433*	*0.831*	*0.126*	-	*0.362*	*0.141*	
e.s.e.	-	*3.60*	*5.38*	*7.121*	*12.122*	*9.51*	-	*14.18*	*14.14*	
mean	-	114.6	185.7	56.66	64.57	80.2	-	163.3	149.9	

[a] At Boxworth in 1995-6 there was a soil N x variety interaction (p<.001), but no fertilizer N x soil N x variety interaction. Differences between varieties in N offtake were much greater in R2 plots than in the lower residual N treatments.

Table 3.3.4.b Total nitrogen offtake at F2 (kg N/ha at 100% dry matter) at harvest.

Site	**Boxworth**			**Crossnacreevy**			**Harper Adams**			
season	**93-4***	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	16/8/94	28/7/95	9/8/96	22/9/94	17/8/95	3/9/96	-	3/8/95	16/8/96	
Apollo	220.05	175.1	221.6	216.16	234.00	243.7	-	206.2	202.6	214.9
Avalon	240.84	190.7	248.5	223.53	203.38	254.1	-	191.3	208.7	220.1
Cadenza	251.05	184.5	238.6	208.61	217.67	249.5	-	207.6	198.4	219.5
Haven	216.80	171.8	233.5	211.42	214.81	267.3	-	212.7	192.3	215.1
Hereward	235.25	181.6	247.7	208.90	212.08	282.9	-	196.2	210.6	221.9
Hunter	236.19	184.7	245.0	220.92	220.33	270.6	-	228.2	216.9	227.9
Longbow	235.94	175.8	237.4	209.30	207.67	234.9	-	192.1	192.5	210.7
Mercia	229.73	175.3	232.3	201.41	209.33	254.1	-	208.1	204.1	214.3
Rialto	238.25	190.7	258.3	211.63	218.87	282.9	-	221.2	191.9	226.7
Riband	220.10	176.3	239.5	197.84	216.51	226.3	-	211.8	194.0	210.3
M.Huntsman	-	-	-	-	212.39	245.9	-	-	-	229.1
Soissons	-	-		-	200.60	257.5	-	-	-	229.0
significance	-	*0.200*	*0.246*	*0.671*	*0.076*	*<.001*	-	*0.986*	*0.424*	
e.s.e.	-	*3.68*	*4.78*	*5.247*	*4.198*	*5.51*	-	*7.27*	*8.78*	
R0	230.05	170.8	214.6	193.15	216.42	229.0	-	190.4	202.2	
R1	-	181.2	244.2	221.93	219.43	275.7	-	208.6	180.0	
R2	234.78	190.0	261.9	217.84	206.06	262.7	-	223.6	221.4	
significance	-	*<.001*	*<.001*	*0.433*	*0.831*	*0.126*	-	*0.362*	*0.141*	
e.s.e.	-	*3.60*	*5.38*	*7.121*	*12.122*	*9.51*	-	*14.18*	*14.14*	
mean	232.42	180.7	240.2	210.97	215.46	256.6	-	207.5	201.2	

**only R0F2 and R2F2 treatments were measured at Boxworth in 1993-4; statistics could not be properly analysed.*

[a] See above.

3.4.1.1. Site effects

In March 1994 N uptake by the crop was low at both Crossnacreevy and Harper Adams (with means of approximately 8 and 10 kg N/ha respectively) (Table 3.3.1). This is probably a reflection of the low levels of SMN available at this time (see Figures 3.1.2., 3.1.3). N uptake was similarly low at Crossnacreevy in 1994-5 - again in line with SMN availability, but increased at Harper Adams to approximately 40 kg N/ha. This latter result was possibly due to the influence of ammonia deposition on the plots, as discussed in the yield results, as SMN was actually lower at this time than in 1993-4. In 1995-6, mean spring N uptake was around this magnitude for all sites. At GS 31, in nil fertilizer plots, crop N uptake was still low at Crossnacreevy in 1993-4, but was as high as 60 kg N/ha in 1995-6 (Table 3.3.2.). Levels were high at Boxworth in all three years, but the highest level recorded was 85 kg N/ha at Harper Adams in 1994-5.

At F0 N uptake remained low, at GS 65, at Crossnacreevy in 1993-4 and 1994-5 (Table 3.3.3.a). Although uptake increased at this site in 1995-6 - to a mean of 80.4 kg N/ha - it was still lower than that observed at the other two sites (particularly Harper Adams) at this growth stage. In contrast, plants with high levels of N fertilizer at Crossnacreevy in 1995-6 had the largest N uptakes (296 kg N/ha) of site-seasons measured at F2 at GS 65 (Table 3.3.3.b).

For most of the site-seasons measured there was little increase in total N offtake at F0 between GS 65 and harvest (Table 3.3.4.a). The largest increase was at Crossnacreevy in 1993-4 (an uptake of 38.5 kg N/ha at GS 65, compared to 56.7 kg N/ha at harvest), while no increase at all was observed at the same site in 1995-6. At F2 at harvest (Table 3.3.4.b.), at Crossnacreevy in 1993-4 and 1995-6, total N offtake actually appeared to be lower than at GS 65; a decrease of almost 40 kg N/ha was observed in 1995-6.

3.4.1.2. Residue Effects

In early spring, at GS 31 and at GS 65 (at F0) (Tables 3.3.1, 3.3.2 & 3.3.3.a), there was little difference in N uptake between residual N treatments at Crossnacreevy and Harper Adams in 1993-4 and 1994-5. In 1995-6, on the other hand, and in all three seasons at Boxworth, there were noticeable increases in N uptake from R0 to R2 plots; these increases were, however, not always statistically significant. In the F2 plots at GS 65 the residual N treatments did not have much effect on N uptake for most of the site seasons measured (Table 3.3.3.b). At Boxworth in 1995-6, however, N uptake was higher in the R2 treatment compared to the R0 and R1 treatments. In contrast, at Crossnacreevy in 1995-6, N uptake (at F2) was lower in the R2 plots than the other residual N treatments.

At harvest, at F0 (Table 3.3.4.a), there was a noticeable increase in total N offtake between R0 and R2 for most site-seasons measured; the increase was, however, only statistically significant at Boxworth in 1994-5 and 1995-6. A small (but usually not significant) increase between R0 and R2 was also observed at F2 for most site-seasons.

3.4.1.3. Variety Differences

In early spring variety had strong, but inconsistent, effects on N uptake (at F0) at the site-seasons measured (Table 3.3.1). Apollo, for example, had a high N uptake (relative to other variety means) at Crossnacreevy in 1993-4 and Harper Adams in 1993-4 and 1994-5, but a low uptake at all three sites in 1995-6. Mean variety N uptakes were also quite inconsistent at GS 31 (at F0), although differences were only significant at three out of eight site-seasons measured (Table 3.3.2.). One noticeable trend was that Longbow often had low N uptake values. Riband also, usually, performed poorly at Crossnacreevy and Harper Adams. In contrast, Avalon and Rialto were frequently high ranking varieties at all three sites.

By GS 65 variety only had a significant effect on N uptake at one of the site-seasons measured (Crossnacreevy in 1994-5). Variety ranking was very variable at F0 (Table 3.3.3.a), with Avalon, Hereward, Mercia and Rialto all performing well at some site-seasons and poorly at others. In the fertilised plots at GS 65 (Table 3.3.3.b.), Haven and Hunter frequently had high N uptakes in the site-seasons measured, while Soissons had a particularly low uptake (relative to other variety means) at Crossnacreevy in 1995-6.

At harvest varietal differences in total N offtake (at F0 and F2) (Tables 3.3.4.a, 3.3.4.b.) were not significant except at Crossnacreevy in 1995-6, but some trends were noticeable. Rialto usually had a high N offtake, relative to other variety means, particularly at F0. Cadenza and Longbow, on the other hand, often had low N offtakes at F0, relative to other varieties. Longbow also frequently had a low N offtake at F2, as did Haven, while Hunter usually had a high N offtake with high fertilizer input (relative

Table 3.4.a Grain nitrogen offtake at F0 (kgN/ha at 100% dry matter)

Site	**Boxworth**			**Crossnacreevy**			**Harper Adams**			
season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6[b]**	**93-4**	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	96.07	78.65	128.42	48.14	54.62	50.55	63.39	105.6	102.2	80.85
Avalon	100.02	89.40	136.08	48.98	51.77	59.32	61.10	107.4	96.5	83.4
Cadenza	100.70	84.00	126.74	45.23	52.71	57.24	66.96	108.4	98.5	82.28
Haven	86.74	86.54	137.95	51.84	52.67	58.68	69.59	116.9	101.5	84.71
Hereward	100.48	89.56	139.18	49.81	57.50	61.93	71.02	104.0	93.1	85.18
Hunter	94.68	86.95	134.65	45.53	56.37	57.20	63.77	124.8	91.6	83.95
Longbow	93.72	83.52	130.19	43.12	49.50	59.49	60.62	98.3	92.0	78.94
Mercia	95.91	89.97	129.47	53.10	53.54	63.77	64.33	110.6	95.2	83.99
Rialto	102.26	87.55	140.91	49.63	56.29	65.49	71.85	124.4	103.8	89.13
Riband	94.26	85.72	132.62	49.21	55.25	52.17	66.07	118.5	96.2	83.33
M.Huntsman	-	-	-		51.30	62.73			-	57.02
Soissons	-	-	-		53.46	58.59			-	56.02
significance	*0.157*	*0.103*	*0.514*	*0.113*	*0.020*	*<.001*	*0.255*	*0.902*	*0.427*	
e.s.e.	*4.192*	*2.788*	*2.986*	*4.136*	*3.330*	*2.604*	*3.441*	*5.40*	*6.11*	
R0	63.46	54.21	94.36	34.68	48.40	45.38	48.11	88.9	76.9	
R1	74.87	66.12	121.29	49.05	53.99	52.67	71.50	114.6	89.1	
R2	151.12	138.24	185.22	61.66	58.85	78.75	77.99	132.2	125.2	
significance	*<.001*	*<.001*	*<.001*	*0.585*	*0.494*	*0.065*	*0.111*	*0.400*	*0.214*	
e.s.e.	*3.060*	*2.617*	*2.128*	*5.653*	*8.498*	*2.677*	*5.869*	*12.10*	*10.36*	
mean	96.48	86.19	133.62	48.46	54.02	58.58	65.87	111.9	97.1	

[a]See below.[b] See below

Table 3.4.b. Grain nitrogen offtake at F2 (kgN/ha at 100% dry matter)

Site	**Boxworth**			**Crossnacreevy**			**Harper Adams**			
season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6[b]**	**93-4**	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/9	14/9/96	19/8/94	9/8/95	19/8/96	
	153.98	144.08	168.9	168.34	196.7	174.44	113.68	150.0	128.0	155.35
Avalon	173.76	154.85	183.4	159.48	172.2	177.85	106.51	134.5	119.2	153.53
Cadenza	177.46	148.57	169.4	171.35	184.3	174.53	104.37	147.9	125.9	155.98
Haven	157.27	138.56	177.2	163.21	179.6	192.23	114.84	159.5	118.2	155.62
Hereward	176.15	146.93	182.0	157.65	180.9	189.93	107.59	141.3	132.1	157.17
Hunter	172.51	144.07	183.8	174.61	187.6	190.86	115.19	169.4	137.0	163.89
Longbow	162.04	139.56	178.1	160.62	169.4	165.15	107.77	138.7	119.8	149.02
Mercia	164.44	141.07	173.1	156.79	169.9	177.54	108.31	149.3	118.1	150.95
Rialto	175.96	153.29	190.6	165.75	182.5	195.90	112.38	166.6	123.7	162.96
Riband	149.12	140.51	181.9	154.28	182.9	163.26	102.04	155.3	119.2	149.83
M.Huntsman	-	-	-	-	180.2	174.20	-	-	-	177.20
Soissons	-	-	-	-	168.7	187.96	-	-	-	178.33
significance	*0.157*	*0.103*	*0.514*	*0.113*	*0.020*	*<.001*	*0.255*	*0.902*	*0.427*	
e.s.e.	*4.192*	*2.788*	*2.99*	*4.136*	*3.330*	*2.604*	*3.441*	*5.40*	*6.11*	
R0	169.04	140.59	173.6	159.09	186.3	170.36	109.52	145.1	126.6	
R1	160.84	150.02	182.5	161.74	184.0	180.89	105.46	156.1	113.3	
R2	168.93	144.85	180.3	168.79	168.5	189.72	112.83	152.6	132.4	
significance	*<.001*	*<.001*	*<.001*	*0.585*	*0.494*	*0.065*	*0.111*	*0.400*	*0.214*	
e.s.e.	*3.060*	*2.617*	*2.13*	*5.653*	*8.50*	*2.677*	*5.869*	*12.10*	*10.36*	
mean	166.27	145.15	178.8	163.21	180.6	180.17	109.27	151.2	124.1	

[a]Boxworth '96 soil N/var. interaction ($p<0.001$), but no fert. N/soil N/var. interaction. Some varieties, *e.g.* Longbow and Mercia, had a smaller response to increasing soil N than others, *e.g.* Haven and Rialto.

[b] At Crossnacreevy '96 soil N/var. interaction ($p=0.038$), but no fert. N/soil N/var. interaction. Grain N offtake of all varieties higher in R2 than R0, but most varieties, except Avalon, Cadenza, Haven and Rialto, showed little increase from R0 to R1; most improvement occurred between R1 and R2 (except for Cadenza).

to other variety means). Avalon had a very variable ranking at F2, performing well at some sites and poorly at others. The two extra varieties grown at Crossnacreevy in 1994-5 and 1995-6 had intermediate rankings at both F0 and F2, except for Soissons at F2 in 1994-5, which had the lowest N offtake for that site-season (200.6 kg N/ha).

3.4.2. Grain nitrogen offtake

3.4.2.1. Site effects

In each experimental season mean grain nitrogen offtake in the F0 plots at Boxworth was much higher than that at Crossnacreevy (133.6 kg N/ha compared to 58.6 kg N/ha in 1995-6) (Table 3.4.a). This was probably a reflection of the lower soil nitrogen availability at the latter site. The amount of nitrogen removed in the grain at Harper Adams was intermediate between the two other sites in 1993-4 and 1995-6, but highest in 1994-5 at 111.9 kg N/ha.

The F2 plots at Harper Adams normally had lower mean grain N offtakes than the fertilized plots at Boxworth and Crossnacreevy (Table 3.4.b). This was particularly noticeable in 1993-4 (109.1 kg N/ha compared to 166.3 kg N/ha at Boxworth), probably because of the drought conditions apparent at Harper Adams in that year.

3.4.2.2. Residue effects

In the unfertilized plots, in all site-seasons, more N was taken off in the grain in the R2 treatment than the R0 treatment (Table 3.4.a). This effect was, however, only significant at Boxworth (in all three years), where grain in the R2 plots removed about twice the amount of N removed from R0 plots in 1995-6 (185.2 kg N/ha compared to 94.4 kg N/ha).

In the F2 treatment (Table 3.4.b), for each site-season, grain nitrogen offtake was quite similar at all three soil residual N levels, although, at Crossnacreevy in 1994-5, a slight decrease was noticeable in grain N offtake in the R2 plots compared to the R0 plots. Conversely, at Crossnacreevy in 1995-6, there was a slight increase in offtake with increasing residual N level.

3.4.2.3. Variety effects

At F0 differences between varieties in grain N offtake were small (Table 3.4.a) and only statistically significant at Crossnacreevy in 1994-5 and 1995-6. The ranking of varieties, in terms of their mean N offtakes, fluctuated between site-seasons. The most consistent variety was Rialto, which nearly always had one of the highest N offtakes, while Longbow frequently had a low offtake.

Varietal ranking was also very inconsistent in the highly fertilised treatment (Table 3.4.b). It could be seen, however, that Rialto was still, usually, a variety that removed large amounts of N, as was Hunter when fertilizer had been applied. Longbow, Mercia and Riband, on the other hand, all had low mean N offtakes, relative to other varieties, at several site-seasons (at F2).

3.5. Crop resource utilization

3.5.1. Green area index.

Table 3.5.1. GAI in early spring at F0.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6	93-4	94-5	95-6	93-4*	94-5*	95-6	mean
date	-	-	-	10/3/94	15/2/95	-	12/3/94	4/3/96	-	
Apollo	-	-	-	0.25	0.32	-	0.37	1.73	-	0.67
Avalon	-	-	-	0.26	0.32	-	0.33	1.53	-	0.61
Cadenza	-	-	-	0.15	0.25	-	0.27	1.41	-	0.52
Haven	-	-	-	0.18	0.31	-	0.34	1.36	-	0.55
Hereward	-	-	-	0.18	0.14	-	0.24	1.01	-	0.39
Hunter	-	-	-	0.19	0.36	-	0.40	1.58	-	0.63
Longbow	-	-	-	0.16	0.20	-	0.22	0.74	-	0.33
Mercia	-	-	-	0.21	0.36	-	0.37	1.55	-	0.62
Rialto	-	-	-	0.24	0.35	-	0.37	1.32	-	0.57
Riband	-	-	-	0.18	0.23	-	0.43	1.06	-	0.48
M.Huntsman	-	-	-	-	0.17	-	-	-	-	-
Soissons	-	-	-	-	0.27	-	-	-	-	-
significance	-	-	-	*<.001*	*<.001*	-	*0.003*	*<.001*	-	
e.s.e.	-	-	-	*0.016*	*0.026*	-	*0.033*	*0.094*	-	
R0	-	-	-	0.20	0.23	-	0.33	1.20	-	
R1	-	-	-	0.21	0.23	-	-	-	-	
R2	-	-	-	0.19	0.36	-	0.34	1.46	-	
significance	-	-	-	*0.855*	*0.035*	-	*0.126*	*0.353*	-	
e.s.e.	-	-	-	*0.021*	*0.015*	-	*.0004*	*0.116*	-	
mean				0.20	0.28		0.33	1.33		

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1993-4 and 1994-5.*

Table 3.5.2 GAI at GS 31 at F0.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6	93-4	94-5	95-6	93-4	94-5*	95-6	mean
date	26/4/94	25/4/95	15/4/96	12/4/94	3/5/95	-	-	24/4/95	-	
Apollo	3.14	2.80	1.99	0.35	1.33	-	-	3.73	-	2.22
Avalon	2.96	2.72	2.76	0.36	1.26	-	-	4.10	-	2.36
Cadenza	2.44	2.45	2.54	0.25	1.09	-	-	3.28	-	2.01
Haven	2.38	1.95	2.11	0.31	1.23	-	-	3.31	-	1.88
Hereward	2.38	1.75	2.46	0.24	1.44	-	-	3.14	-	1.90
Hunter	2.68	2.23	2.47	0.32	1.59	-	-	3.90	-	2.20
Longbow	2.27	1.80	2.50	0.27	1.23	-	-	2.90	-	1.83
Mercia	2.94	2.83	2.58	0.37	1.23	-	-	3.95	-	2.32
Rialto	2.80	2.42	2.60	0.38	1.10	-	-	3.45	-	2.13
Riband	2.68	2.23	2.72	0.36	0.89	-	-	3.17	-	2.01
M.Huntsman	-	-	-	-	1.54	-	-	-	-	-
Soissons	-	-	-	-	1.08	-	-	-	-	-
significance	*0.088*	*<.001*	*0.015*	*0.011*	*0.003*	-	-	*0.079*	-	
e.s.e.	*0.209*	*0.126*	*0.143*	*0.030*	*0.107*	-	-	*0.275*	-	
R0	2.02	1.84	2.02	0.30	1.20	-	-	3.15	-	
R1	2.43	2.11	2.15	0.30	1.11	-	-	-	-	
R2	3.55	3.01	3.24	0.37	1.44	-	-	3.84	-	
significance	*0.069*	*0.015*	*0.053*	*0.427*	*0.269*	-	-	*0.314*	-	
e.s.e.	*0.216*	*0.076*	*0.158*	*0.034*	*0.104*	-	-	*0.261*	-	
mean	2.67	2.32	2.47	0.32	1.24			3.49		

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

Table 3.5.3.a GAI at GS 65 at F0.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5[a]	95-6	93-4[b]	94-5	95-6	93-4	94-5*	95-6	mean
date	6/6/94	6/6/95	13/6/96	24/6/94	1/7/95	1/7/96	-	25/6/95	16/6/96	
Apollo	4.77	4.12	3.91	1.20	1.31	3.21	-	3.72	5.42	3.46
Avalon	5.31	4.00	4.36	1.66	1.75	2.76	-	3.53	7.31	3.83
Cadenza	4.65	3.70	3.99	1.26	1.30	2.58	-	3.31	5.71	3.31
Haven	4.43	3.66	4.78	1.62	1.07	3.38	-	3.91	6.32	3.65
Hereward	5.33	3.37	4.87	1.43	1.53	3.83	-	2.99	6.06	3.68
Hunter	5.23	3.88	5.58	1.39	1.40	3.53	-	4.51	5.64	3.89
Longbow	4.55	3.15	4.61	1.22	1.03	3.11	-	3.42	7.83	3.61
Mercia	5.26	4.01	5.09	1.71	2.01	3.36	-	4.05	5.83	3.92
Rialto	4.94	3.36	4.23	1.19	1.20	2.76	-	3.57	5.71	3.37
Riband	5.00	3.65	4.52	1.47	1.53	3.03	-	3.88	5.95	3.63
M.Huntsman	-	-	-	-	1.36	3.38	-	-	-	
Soissons	-	-	-	-	1.36	2.80	-	-	-	
significance	*0.281*	*0.002*	*0.671*	*0.011*	*0.301*	*0.150*	-	*0.473*	*0.120*	
e.s.e.	*0.293*	*0.160*	*0.188*	*0.229*	*0.230*	*0.278*	-	*0.426*	*0.589*	
R0	3.22	2.50	3.32	0.91	1.28	2.10	-	3.42	4.75	
R1	4.05	3.08	4.44	1.42	1.26	2.73	-	-	5.29	
R2	7.57	5.49	6.02	1.92	1.67	4.60	-	3.96	8.50	
significance	*0.007*	*0.015*	*0.026*	*0.457*	*0.494*	*0.143*	-	*0.473*	*0.061*	
e.s.e.	*0.191*	*0.197*	*0.327*	*0.432*	*0.497*	*0.509*	-	*0.354*	*0.516*	
mean	4.95	3.69	4.59	1.42	1.41	3.16		3.69	6.18	

**only R0F2 and R2F2 treatments were measured at Harper Adams in 1993-4.* [a] See below. [b] See below.

Table 3.5.3.b GAI at GS 65 at F2.

Site	Boxworth			Crossnacreevy			Harper Adams			
Season	93-4	94-5	95-6	93-4[b]	94-5	95-6	93-4*	94-5	95-6	mean
Date	-	-	13/6/96	24/6/94	1/7/95	1/7/96	19/6/94	-	-	
Apollo	-	-	4.98	5.77	4.52	7.68	4.76	-	-	5.54
Avalon	-	-	5.38	5.82	3.86	6.55	4.64	-	-	5.25
Cadenza	-	-	4.92	5.32	3.88	6.21	3.99	-	-	4.86
Haven	-	-	5.90	6.95	3.59	8.21	5.61	-	-	6.05
Hereward	-	-	5.56	6.84	4.64	7.38	4.93	-	-	5.87
Hunter	-	-	6.33	7.06	4.09	8.33	6.02	-	-	6.37
Longbow	-	-	5.34	5.94	3.69	6.98	4.48	-	-	5.29
Mercia	-	-	5.50	6.21	4.18	7.55	5.10	-	-	5.71
Rialto	-	-	5.31	6.16	4.18	7.33	4.58	-	-	5.51
Riband	-	-	5.54	6.25	4.36	7.34	5.02	-	-	5.70
M.Huntsman	-	-	-	-	3.86	8.20	-	-	-	6.03
Soissons	-	-	-	-	3.60	7.58	-	-	-	5.59
significance	-	-	*0.671*	*0.011*	*0.301*	*0.150*	*0.016*	-	-	
e.s.e.	-	-	*0.188*	*0.229*	*0.230*	*0.278*	*0.313*	-	-	
R0	-	-	5.40	5.79	3.88	6.51	4.69	-	-	
R1	-	-	5.55	6.78	3.28	8.28	-	-	-	
R2	-	-	5.47	6.121	4.95	7.55	5.14	-	-	
significance	-	-	*0.026*	*0.457*	*0.494*	*0.143*	*0.050*	-	-	
e.s.e.	-	-	*0.327*	*0.432*	*0.497*	*0.509*	*0.025*	-	-	
mean	-	-	5.48	6.23	4.1	7.36	4.91	-	-	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

[a]Boxworth '95 soil N/var. interaction (p=0.018), but no fert. N/soil N/var. interaction. Varieties. Hereward, Longbow and Rialto, showed less response to increasing soil N than others.

[b]Crossnacreevy '94 soil N/var. interaction (p=0.032), but no fertilizer x soil x variety interaction; varieties Apollo, Hereward and Riband, had higher GAIs in the R1 treatment than the R2 treatment.

3.5.1.1. Site effects.

In early spring (at F0) (Table 3.5.1), mean green area index (GAI) was much higher at Harper Adams in 1994-5, than at any of the other site-seasons measured; 1.33 compared to 0.28 at Crossnacreevy in the same year. At GS 31 (at F0) (Table 3.5.2.) GAIs at Boxworth were similar to each other in all three experimental seasons. The index was very low, compared to Boxworth, at Crossnacreevy in 1993-4, and mean GAI remained high for Harper Adams in 1994-5 (3.49). The latter had not increased much, however, by GS 65; the highest GAI recorded at GS 65 (at F0) was at Harper Adams in 1995-6 (6.18) (Table 3.5.3.a). Indices at Crossnacreevy (at GS 65) were low in 1993-4 and 1994-5, but increased in 1995-6 to be almost comparable with those found at Boxworth. When fertilizer had been added to the plots (Table 3.5.3.b), the GAI at Crossnacreevy (at GS 65), in each year, was greatly increased from the F0 situation (6.23 compared to 1.42 in 1993-4).

3.5.1.2. Residue effect.

In early spring (Table 3.5.1) the residual soil N treatments only had an effect (for the site-seasons measured) on GAIs (at F0) at Crossnacreevy in 1994-5, where plants growing in R2 plots had higher GAIs than those in the R0 and R1 treatments. At GS 31 (Table 3.5.2), the crops at Boxworth had increasing GAIs with increasing soil N, but this was only statistically significant in 1994-5. By GS 65 (at F0) (Table 3.5.3) these differences were significant for all years. Increases in GAIs from R0 to R2 were also noticeable (but not statistically significant) at Crossnacreevy in 1993-4 and 1995-6, and Harper Adams in 1995-6. At F2, at GS 65 (Table 3.5.3.a), differences were also noticeable (but not significant) at Crossnacreevy in 1994-5 and 1995-6, and Harper Adams in 1993-4.

3.5.1.3. Variety effect.

Variety had a strong influence on GAI early in the season. In early spring (at F0) (Table 3.5.1) Longbow and Hereward had low GAIs, relative to other variety means, for most of the site-seasons measured. Conversely, Apollo and Hunter usually had high GAIs, while Riband was very variable. At GS 31 (at F0) (Table 3.5.2) Longbow and Hereward usually still exhibited low GAIs, although Hereward had a high GAI, relative to other variety means, at Crossnacreevy in 1994-5. Avalon, Hunter and Mercia usually had high ranking GAIs at this growth stage, while Apollo had become more variable. By GS 65 there was a lot of variation in varietal ranking between site-seasons, and differences in GAI were mostly no longer significant. Longbow, however, still had a low ranking, at F0, at Boxworth in 1994-5 and Crossnacreevy in 1993-4 (Table 3.5.3.a). When fertilizer had been added (Table 3.5.3.b), Hunter had the highest GAI in four out of the five site-seasons measured (although this was not always statistically significant).

3.5.2. Canopy nitrogen requirement

Table 3.6.1. Canopy nitrogen requirement in early spring at F0 (g N/m²).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4***	**94-5***	**95-6**	**mean**
date	-	-	-	10/3/94	15/2/95	-	12/3/94	4/3/95	-	
Apollo	-	-	-	4.28	3.42	-	3.30	2.67	-	3.42
Avalon	-	-	-	3.88	3.36	-	3.08	3.13	-	3.36
Cadenza	-	-	-	5.03	3.97	-	3.36	2.83	-	3.80
Haven	-	-	-	4.30	3.50	-	3.04	3.21	-	3.51
Hereward	-	-	-	4.44	4.80	-	3.61	3.70	-	4.14
Hunter	-	-	-	4.48	3.32	-	3.03	2.70	-	3.38
Longbow	-	-	-	3.90	3.81	-	3.09	3.90	-	3.68
Mercia	-	-	-	3.88	3.17	-	3.25	2.77	-	3.27
Rialto	-	-	-	3.86	3.32	-	2.99	3.34	-	3.38
Riband	-	-	-	3.92	4.28	-	3.08	3.49	-	3.69
M.Huntsma	-	-	-	-	4.52	-	-	-	-	-
Soissons	-	-	-	-	4.15	-	-	-	-	-
significance	-	-	-	*0.002*	*<.001*	-	*0.518*	*0.001*	-	
e.s.e.	-	-	-	*0.184*	*0.223*	-	*0.201*	*0.190*	-	
R0	-	-	-	4.11	3.73	-	3.11	3.30	-	
R1	-	-	-	4.06	4.04	-	-	-	-	
R2	-	-	-	4.42	3.64	-	3.25	3.04	-	
significance	-	-	-	*0.414*	*0.300*	-	*0.297*	*0.205*	-	
e.s.e.	-	-	-	*0.164*	*0.137*	-	*0.051*	*0.061*	-	
mean	-	-	-	4.20	3.80	-	3.18	3.17	-	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1993-4 and 1994-5.*

Table 3.6.2. Canopy nitrogen requirement at GS 31 at F0 (g N/m²)

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5[a]**	**95-6**	**93-4**	**94-5***	**95-6**	**mean**
date	26/4/94	25/4/95	15/4/96	12/4/94	3/5/95	-	-	24/4/95	-	
Apollo	2.06	2.18	3.07	3.81	2.59	-	-	2.38	-	2.68
Avalon	2.35	2.25	3.02	4.06	2.61	-	-	2.27	-	2.76
Cadenza	2.46	2.26	3.31	4.94	2.76	-	-	2.66	-	3.07
Haven	2.45	2.59	3.35	4.18	2.65	-	-	2.48	-	2.95
Hereward	2.51	2.51	3.24	4.93	2.34	-	-	2.48	-	3.00
Hunter	2.14	2.33	3.11	4.45	2.38	-	-	2.25	-	2.78
Longbow	2.52	2.44	3.03	4.15	2.57	-	-	2.63	-	2.89
Mercia	2.11	2.19	2.98	3.79	2.45	-	-	2.13	-	2.61
Rialto	2.38	2.40	3.34	3.72	3.04	-	-	2.64	-	2.92
Riband	2.32	2.29	3.12	3.83	3.20	-	-	2.50	-	2.88
M.Huntsman	-	-	-	-	2.15	-	-	-	-	-
Soissons	-	-	-	-	2.58	-	-	-	-	-
significance	*0.002*	*<.001*	*0.367*	*0.001*	*<.001*	-	-	*0.237*	-	
e.s.e.	*0.085*	*0.061*	*0.130*	*0.210*	*0.096*	-	-	*0.151*	-	
R0	2.11	2.04	2.92	4.17	2.62	-	-	2.30	-	
R1	2.30	2.11	3.12	4.20	2.64	-	-	-	-	
R2	2.58	2.89	3.42	4.18	2.57	-	-	2.59	-	
significance	*0.228*	*0.014*	*0.056*	*0.970*	*0.920*	-	-	*0.209*	-	
e.s.e.	*0.131*	*0.056*	*0.061*	*0.084*	*0.122*	-	-	*0.071*	-	
mean	2.33	2.34	3.16	4.18	2.61	-	-	2.44	-	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

[a] At Crossnacreevy in 1994-5 there was a soil N x variety interaction (p=0.006), but no fertilizer N x soil N x variety interaction. The CNRs of most varieties did not differ significantly between the residual N treatments, but Haven had a lower, and Longbow a higher, CNR at R0 than R1 and R2.

Table 3.6.3.a Canopy nitrogen requirement at GS 65 at F0 (g N/m²).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4†	94-5†	95-6[a]	93-4	94-5	95-6[b]	93-4	94-5*	95-6	mean
date	6/6/94	6/6/95	13/6/96	24/6/94	1/7/95	1/7/96	-	25/6/95	16/6/96	
Apollo	2.13	2.51	3.57	2.20	2.07	2.19	-	3.49	1.90	2.51
Avalon	2.08	2.46	3.44	2.37	2.43	1.69	-	3.35	2.15	2.50
Cadenza	2.30	3.01	3.96	2.50	4.96	2.00	-	3.42	1.99	3.02
Haven	2.35	2.73	2.79	1.96	3.08	2.28	-	3.12	1.69	2.5
Hereward	2.05	2.46	3.35	2.24	2.14	1.80	-	3.53	2.36	2.49
Hunter	1.76	2.48	2.88	2.38	1.09	1.84	-	2.19	1.95	2.07
Longbow	2.13	2.90	3.44	2.06	2.00	1.74	-	3.25	1.76	2.41
Mercia	1.86	2.70	3.23	2.10	2.81	1.67	-	3.71	1.72	2.48
Rialto	2.27	3.07	3.71	2.11	1.08	2.23	-	4.75	2.17	2.67
Riband	2.14	2.62	3.36	2.10	2.80	2.18	-	3.35	1.96	2.56
M.Huntsman	-	-	-	-	1.40	1.96	-	-	-	1.68
Soissons	-	-	-	-	3.38	2.26	-	-	-	2.82
significance	*0.005*	*0.354*	*0.310*	*0.394*	*0.001*	*0.012*	-	*0.054*	*0.412*	
e.s.e.	*0.098*	*0.214*	*0.230*	*0.338*	*0.359*	*0.269*	-	*0.403*	*0.206*	
R0	2.00	2.37	3.16	2.61	1.78	2.07	-	3.83	1.79	
R1	1.98	2.50	2.79	2.12	2.69	1.92	-	-	1.96	
R2	2.34	3.22	4.18	1.88	2.84	1.96	-	3.00	2.15	
significance	*0.144*	*0.013*	*0.697*	*0.327*	*0.240*	*0.070*	-	*0.696*	*0.034*	
e.s.e.	*0.084*	*0.052*	*0.306*	*0.189*	*0.301*	*0.112*	-	*1.124*	*0.034*	
mean	2.11	2.70	3.37	2.20	2.45	1.96		3.42	1.97	

* *Only R0F2 and R2F2 treatments measured at Harper Adams '94.*[†] *See below.*[a] See below.[b] See below.

Table 3.6.3.b Canopy nitrogen requirement at GS 65 at F2 (g N/m²).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6[a]	93-4	94-5	95-6[b]	93-4*†	94-5	95-6	mean
date	-	-	13/6/96	24/6/94	1/7/95	1/7/96	19/6/94	-	-	
Apollo	-	-	3.39	4.07	3.97	3.31	4.62	-	-	3.87
Avalon	-	-	3.85	3.25	3.91	3.09	4.14	-	-	3.65
Cadenza	-	-	4.16	4.51	5.13	3.82	4.31	-	-	4.39
Haven	-	-	3.16	3.05	3.74	3.66	4.05	-	-	3.53
Hereward	-	-	3.68	2.70	3.06	4.01	4.14	-	-	3.52
Hunter	-	-	3.83	3.30	3.18	3.37	3.71	-	-	3.48
Longbow	-	-	4.15	3.53	4.48	4.07	4.11	-	-	4.07
Mercia	-	-	3.83	3.59	3.01	3.20	4.14	-	-	3.55
Rialto	-	-	4.53	3.50	4.08	3.48	4.50	-	-	4.02
Riband	-	-	3.36	2.85	3.88	3.60	4.74	-	-	3.69
M.Huntsman	-	-	-	-	4.18	2.94	-	-	-	3.56
Soissons	-	-	-	-	4.75	2.25	-	-	-	3.50
significance	-	-	*0.310*	*0.394*	*0.001*	*0.012*	*0.366*	-	-	
e.s.e.	-	-	*0.230*	*0.339*	*0.359*	*0.269*	*0.278*	-	-	
R0	-	-	3.53	3.77	3.90	3.90	4.20	-	-	
R1	-	-	3.50	3.08	4.17	3.23	-	-	-	
R2	-	-	4.35	3.46	3.77	3.07	4.29	-	-	
significance	-	-	*0.697*	*0.327*	*0.240*	*0.070*	*0.827*	-	-	
e.s.e.	-	-	*0.306*	*0.189*	*0.301*	*0.112*	*0.246*	-	-	
mean	-	-	3.79	3.44	3.84	3.56	4.25	-	-	

* *Only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

† *Boxworth '94, '95 and Harper Adams '94 (for F2), CNR at GS65 calculated as: (total N uptake/10)/total GAI. For other site-seasons, CNR at GS65 was calculated as: (non-ear N uptake/10)/non-ear GAI.*

[a] At Boxworth in 1995-6 there was a fertilizer N x soil N x variety interaction (p=0.018).

[b] Crossnacreevy '96 soil N/var. interaction (p=0.002). Varieties Cadenza, Hereward and M. Huntsman, had similar CNRs for R0, R1 and R2, while the CNRs of others, *e.g.* Apollo, Hunter and Riband, were inconsistent between soil N treatments. There was a fert N/soil N/var. interaction (p=0.003).

3.5.2.1. Site effects

Canopy nitrogen requirement (CNR) was only measured in early spring at Crossnacreevy and Harper Adams in 1993-4 and 1994-5 (at F0) (Table 3.6.1). In both years, the mean CNR at Crossnacreevy was slightly higher than that at Harper Adams (4.2 compared to 3.2 g/m^2 in 1993-4). By GS 31 (Table 3.6.2), in 1994-5, CNR was similar at these two sites (the parameter was not measured at Harper Adams in 1993-4). CNRs at Boxworth at GS 31 were also of a similar magnitude to those at the other sites; the highest CNR being 4.18 g/m^2 at Crossnacreevy in 1993-4. At GS 65 (at F0) (Table 3.6.3.a) the highest mean CNR measured was 3.42 g/m^2 at Harper Adams in 1994-5, and the lowest at Crossnacreevy and Harper Adams in 1995-6 (both about 1.96 g/m^2). In the F2 plots at GS 65 (Table 3.6.3.b), mean CNRs were slightly higher at Boxworth and Harper Adams (when measured) than at Crossnacreevy.

3.5.2.2. Residue effects

In early spring the residual N treatments did not appear to influence CNR (at F0) at the site-seasons measured (Table 3.6.1). At GS 31 (at F0) residual N treatments still had no effect on CNR at Crossnacreevy and Harper Adams in any of the years measured (Table 3.6.2). At Boxworth there was, however, a tendency for CNR to increase with increasing soil N level; this effect was statistically significant in 1994-5. This trend continued at Boxworth at GS 65 (at F0), and at this time was also noticeable at Crossnacreevy in 1994-5 and Harper Adams in 1995-6 (Table 3.6.3.a). At Crossnacreevy in 1993-4 and Harper Adams in 1994-5, however, CNR values decreased in R2 plots compared to R0 plots (although these differences were not statistically significant). In the F2 plots at GS 65 (Table 3.6.3.b), the effects of residual N treatment on CNR were also inconsistent (for the site-seasons measured). In 1995-6 (at F2), CNR values increased, from R0 to R2, at Boxworth and decreased at Crossnacreevy; these differences were, however, not statistically significant.

3.5.2.3. Variety effects

Variety frequently exerted a significant effect on CNR at site-seasons measured in early spring and at GS 31 (at F0) (Tables 3.6.1., 3.6.2.). These effects were quite inconsistent. It could be observed, however, that Mercia, (and, to a lesser extent, Hunter) usually had a low CNR, relative to other variety means, while Hereward often had a high value. Fluctuation in the ranking of variety means continued at GS 65, and differences were often not statistically significant. At this time Cadenza and Rialto frequently had high CNR values (at F0) (Table 3.6.3.a), while Hunter often still had a low ranking. Cadenza also had noticeably high CNR values at F2 (Table 3.6.3.b), as did Longbow. At Crossnacreevy, Soissons had a high CNR at F0 in 1994-5 and 1995-6, but a very low value (relative to other variety means) at F2 in 1995-6.

3.6. Biomass production

Table 3.7.1. Above ground biomass in early spring at F0 (DM t/ha).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4***	**94-5***	**95-6**	**mean**
date	-	-	18/3/96	10/3/94	15/2/95	13/3/96	12/3/94	4/3/95	6/3/96	
Apollo	-	-	0.66	0.23	0.22	0.54	0.22	1.10	0.62	0.51
Avalon	-	-	1.10	0.22	0.22	0.88	0.18	1.25	0.70	0.65
Cadenza	-	-	1.19	0.16	0.21	0.84	0.16	1.13	0.90	0.66
Haven	-	-	0.94	0.17	0.23	1.01	0.19	1.08	1.09	0.67
Hereward	-	-	1.01	0.17	0.14	1.17	0.16	0.87	0.97	0.64
Hunter	-	-	0.97	0.19	0.25	0.83	0.22	1.13	0.88	0.64
Longbow	-	-	0.97	0.13	0.15	0.98	0.12	0.73	0.95	0.58
Mercia	-	-	0.98	0.18	0.23	0.90	0.21	1.05	0.97	0.65
Rialto	-	-	1.12	0.21	0.24	1.11	0.21	1.09	1.05	0.72
Riband	-	-	1.19	0.14	0.19	0.95	0.24	0.89	0.76	0.62
M.Huntsman	-	-	-	-	0.14	1.10	-	-	-	0.62
Soissons	-	-	-	-	0.22	0.76	-	-	-	0.49
significance	-	-	*<.001*	*<.001*	*<.001*	*<.001*	*0.001*	*0.001*	*0.005*	
e.s.e.	-	-	*0.062*	*0.010*	*0.016*	*0.062*	*0.016*	*0.066*	*0.082*	
R0	-	-	0.86	0.18	0.17	0.74	0.19	0.97	0.66	
R1	-	-	0.96	0.18	0.18	1.07	-	-	0.94	
R2	-	-	1.22	0.18	0.26	0.96	0.19	1.10	1.07	
significance	-	-	*0.043*	*0.925*	*0.054*	*0.097*	*0.295*	*0.563*	*0.076*	
e.s.e.	-	-	*0.039*	*0.014*	*0.013*	*0.056*	*0.001*	*0.108*	*0.059*	
mean	-	-	1.01	0.18	0.21	0.92	0.19	1.03	0.89	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1993-4 and 1994-5.*

Table 3.7.2. Above ground biomass at GS 31 at F0 (DM t/ha).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5***	**95-6**	**mean**
date	26/4/94	25/4/95	15/4/96	12/4/94	3/5/95	24/4/96	-	24/4/95	24/4/96	
Apollo	2.57	2.44	1.36	0.45	1.73	1.78	-	3.60	1.74	1.96
Avalon	2.80	2.46	2.03	0.46	1.76	2.31	-	3.94	1.97	2.22
Cadenza	2.25	2.13	2.17	0.34	1.58	2.24	-	3.32	1.98	2.00
Haven	2.25	1.95	1.81	0.39	1.71	2.52	-	3.45	1.85	1.99
Hereward	2.10	1.68	1.98	0.32	2.05	2.82	-	3.06	2.18	2.02
Hunter	2.32	1.99	1.96	0.45	2.18	2.34	-	3.60	1.99	2.10
Longbow	2.06	1.60	1.92	0.33	1.68	2.48	-	2.77	1.93	1.85
Mercia	2.53	2.34	1.85	0.41	1.32	2.40	-	3.73	2.18	2.10
Rialto	2.74	2.47	2.16	0.47	1.47	2.78	-	3.94	2.05	2.26
Riband	2.59	1.92	2.04	0.41	1.15	2.19	-	2.99	1.68	1.87
M.Huntsman	-	-	-	-	1.95	2.51	-	-		2.23
Soissons	-	-	-	-	1.37	2.30	-	-		1.84
significance	*0.027*	*<.001*	*0.013*	*<.001*	*0.001*	*<.001*	-	*0.013*	*0.227*	
e.s.e.	*0.163*	*0.119*	*0.132*	*0.021*	*0.153*	*0.092*	-	*0.219*	*0.141*	
R0	2.00	1.89	1.63	0.39	1.59	1.73	-	3.08	1.53	
R1	2.40	1.99	1.76	0.38	1.42	2.38	-	-	1.86	
R2	2.87	2.42	2.40	0.44	1.96	3.06	-	3.81	2.48	
significance	*0.120*	*0.016*	*0.049*	*0.398*	*0.117*	*0.023*	-	*0.118*	*0.001*	
e.s.e.	*0.161*	*0.035*	*0.093*	*0.025*	*0.100*	*0.102*	-	*0.097*	*0.016*	
mean	2.42	2.10	1.93	0.40	1.66	2.39	-	3.44	1.95	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

[a] At Crossnacreevy in 1995-6 there was a soil N x variety interaction (p=0.009), but no fertilizer N x soil N x variety interaction. Some varieties *e.g.* Avalon and Cadenza showed little response to increasing soil N.

Table 3.7.3.a Above ground biomass at GS 65 at F0 (DM t/ha).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5[a]**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5***	**95-6**	**mean**
date	6/6/94	6/6/95	13/6/96	24/6/94	1/7/95	1/7/96	-	25/6/95	16/6/96	
Apollo	8.63	9.36	11.22	4.21	7.00	10.90	-	15.65	10.22	9.65
Avalon	9.36	8.93	11.51	5.74	6.61	9.68	-	14.50	10.83	9.64
Cadenza	8.83	8.67	12.50	4.39	8.07	10.51	-	15.35	10.18	9.81
Haven	8.04	8.04	11.72	4.98	8.59	11.67	-	15.10	11.35	9.94
Hereward	8.60	7.11	11.65	4.58	8.42	12.27	-	13.39	11.06	9.64
Hunter	8.09	7.87	12.29	4.40	8.25	11.23	-	14.68	10.83	9.71
Longbow	7.64	7.02	11.84	3.94	6.58	10.45	-	12.77	12.29	9.07
Mercia	8.27	8.74	12.51	5.02	7.46	11.57	-	15.03	9.41	9.75
Rialto	9.98	8.26	13.32	4.69	8.76	11.76	-	16.82	10.71	10.54
Riband	8.34	7.60	11.45	4.35	6.59	10.18	-	13.61	9.86	9.00
M.Huntsman	-	-	-	-	6.94	11.09	-	-	-	
Soissons	-	-	-	-	6.12	9.31	-	-	-	
significance	*0.033*	*<.001*	*0.747*	*0.085*	*<.001*	*0.185*	-	*0.026*	*0.187*	
e.s.e.	*0.434*	*0.296*	*0.310*	*0.414*	*0.501*	*0.483*	-	*0.699*	*0.659*	
R0	6.76	6.26	10.64	3.30	6.66	8.86	-	13.73	9.14	
R1	8.36	7.65	11.59	4.62	6.64	10.20	-	-	10.03	
R2	10.61	10.57	13.78	5.97	9.06	13.60	-	15.65	12.85	
significance	*0.004*	*0.030*	*0.015*	*0.328*	*0.898*	*0.032*	-	*0.125*	*0.061*	
e.s.e.	*0.119*	*0.389*	*0.221*	*0.586*	*0.871*	*0.584*	-	*0.270*	*0.492*	
mean	8.58	8.16	12	4.63	7.63	11.02		14.69	10.67	

**only R0F0 and R2F0 treatments were measured at Harper Adams in 1994-5.*

[a] At Boxworth in 1994-5 there was a soil N x variety interaction (p=0.032), but no fertilizer N x soil N x variety interaction. Some varieties, particularly Hereward, responded less to increasing soil N than others *e.g.* Cadenza, Haven and Hunter.

Table 3.7.3.b Above ground biomass at GS 65 at F2 (DM t/ha)

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4***	**94-5**	**95-6**	**mean**
date	-	-	13/6/96	24/6/94	1/7/95	1/7/96	19/6/94	-	-	
Apollo	-	-	11.54	11.50	15.16	16.34	10.81	-	-	13.07
Avalon	-	-	12.39	10.88	11.01	15.05	9.89	-	-	11.84
Cadenza	-	-	13.51	11.68	15.08	16.29	10.14	-	-	13.34
Haven	-	-	12.30	12.73	16.25	17.34	11.62	-	-	14.05
Hereward	-	-	12.35	10.95	15.52	15.58	9.49	-	-	12.78
Hunter	-	-	12.88	11.64	16.08	16.00	10.88	-	-	13.50
Longbow	-	-	12.14	11.03	13.02	16.29	9.03	-	-	12.30
Mercia	-	-	12.35	11.22	10.56	16.06	10.38	-	-	12.11
Rialto	-	-	14.26	12.36	16.56	17.95	9.70	-	-	14.17
Riband	-	-	12.11	11.35	12.32	16.10	11.77	-	-	12.73
M.Huntsman	-	-	-	-	13.33	16.39	-	-	-	14.86
Soissons	-	-	-	-	11.18	13.79	-	-	-	12.49
significance	-	-	*0.747*	*0.085*	*<.001*	*0.185*	*0.011*	-	-	
e.s.e.	-	-	*0.310*	*0.414*	*0.501*	*0.483*	*0.478*	-	-	
R0	-	-	11.98	11.13	13.20	16.91	9.59	-	-	
R1	-	-	12.58	11.64	12.56	14.40	-	-	-	
R2	-	-	13.18	11.84	15.75	16.98	11.15	-	-	
significance	-	-	*0.015*	*0.328*	*0.898*	*0.032*	*0.165*	-	-	
e.s.e.	-	-	*0.221*	*0.586*	*0.871*	*0.584*	*0.292*	-	-	
mean	-	-	12.58	11.53	14.16	16.3	10.37	-	-	

**only R0F2 and R2F2 treatments were measured at Harper Adams in 1993-4.*

Table 3.7.4.a Above ground biomass at harvest at F0 (DM t/ha).

Site	**Boxworth**			**Crossnacreevy**			**Harper Adams**			
season	**93-4**	**94-5**	**95-6**[a]	**93-4**	**94-5**	**95-6**[b]	**93-4**	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	29/8/94	17/8/95	3/9/96	-	3/8/95	16/8/96	
Apollo	11.84	10.39	14.01	5.76	7.52	10.89	-	14.39	14.74	11.19
Avalon	12.26	11.34	14.21	5.49	8.55	10.84	-	14.54	15.22	11.56
Cadenza	12.66	11.24	14.56	5.56	8.09	11.85	-	14.36	16.44	11.84
Haven	10.73	10.77	15.12	6.41	8.49	12.56	-	16.06	16.84	12.12
Hereward	12.68	10.52	15.36	6.09	8.11	12.79	-	13.61	16.34	11.94
Hunter	12.21	10.86	14.98	6.34	8.60	12.53	-	15.21	17.12	12.23
Longbow	11.32	10.37	14.72	4.84	7.32	12.54	-	13.31	16.81	11.4
Mercia	12.09	11.14	14.80	6.06	8.46	13.52	-	13.92	16.33	12.04
Rialto	12.62	11.13	15.53	6.55	8.53	12.17	-	15.89	17.57	12.5
Riband	11.51	10.96	14.48	5.72	8.33	12.01	-	14.74	16.51	11.78
M.Huntsman	-	-	-	-	8.18	12.20	-	-	-	10.19
Soissons	-	-	-	-	7.90	11.40	-	-	-	9.65
significance	*0.641*	*0.138*	*0.128*	*0.317*	*0.005*	*<.001*	-	*0.750*	*0.585*	
e.s.e.	*0.418*	*0.193*	*0.258*	*0.402*	*0.551*	*0.502*	-	*0.618*	*0.871*	
R0	9.47	8.49	13.06	4.02	7.54	9.62	-	14.05	14.15	
R1	10.72	10.14	14.57	5.87	7.34	11.38	-	13.39	15.10	
R2	15.79	13.98	16.70	7.75	9.65	15.32	-	16.37	19.93	
significance	*0.004*	*0.015*	*0.001*	*0.336*	*0.584*	*0.018*	-	*0.869*	*0.270*	
e.s.e.	*0.510*	*0.374*	*0.228*	*0.714*	*1.172*	*0.517*	-	*0.636*	*1.053*	
mean	11.99	10.87	14.78	5.88	8.20	12.17	-	14.60	16.39	

[a] At Boxworth '96 soil N/var. interaction (p=0.015). All varieties had greater biomass in R2 plots compared to the R0 plots, but for some, *e.g.* Apollo, Hereward and Rialto, the difference was much larger than for others, *e.g.* Avalon, Hunter and Longbow. There was a fert. N/soil N/ var. interaction (p=0.032).
[b]At Crossnacreevy '96 soilN/var. interaction (p=0.012), but no fertilizer N x soil N x variety interaction. The total biomass of Maris Huntsman and Riband increased very little with increasing soil N (meaned over fertilizer treatments), while that of some other varieties, *e.g.* Hunter, Longbow, Rialto and Soissons, increased by four tonnes or more.

Table 3.7.4.b Above ground biomass at harvest at F2 (DM t/ha).

Site	**Boxworth**			**Crossnacreevy**			**Harper Adams**			
season	**93-4**	**94-5**	**95-6**[a]	**93-4**	**94-5**	**95-6**[b]	**93-4***	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	22/9/94	17/8/95	3/9/96	19/8/94	3/8/95	16/8/96	
Apollo	15.48	13.23	15.22	15.94	18.68	20.82	12.85	12.66	21.15	16.23
Avalon	16.61	13.36	16.25	16.12	14.44	19.31	12.63	12.45	20.77	15.77
Cadenza	17.25	14.07	16.20	15.74	18.12	19.55	12.85	14.95	20.29	16.56
Haven	15.45	12.76	15.71	15.35	18.21	21.56	13.21	14.04	21.33	16.4
Hereward	17.05	12.97	16.60	15.35	17.73	20.02	12.64	13.61	20.76	16.3
Hunter	16.65	13.18	16.58	15.48	16.84	19.26	12.81	14.94	21.71	16.38
Longbow	15.77	12.98	16.32	15.91	18.10	20.00	12.74	12.26	21.69	16.2
Mercia	16.76	13.15	16.17	14.84	17.32	19.45	12.65	13.37	21.57	16.14
Rialto	17.18	13.69	17.11	16.27	18.31	21.00	12.41	15.21	20.28	16.83
Riband	14.73	13.14	16.29	15.66	17.36	19.02	13.78	13.96	19.47	15.93
M.Huntsman	-	-	-	-	16.40	17.33	-	-	-	16.86
Soissons	-	-	-	-	16.15	20.08	-	-	-	18.12
significance	*0.641*	*0.138*	*0.128*	*0.317*	*0.005*	*<.001*	*0.918*	*0.438*	*0.585*	
e.s.e.	*0.418*	*0.193*	*0.258*	*0.402*	*0.551*	*0.502*	*0.609*	*0.618*	*0.871*	
R0	16.16	12.30	15.82	15.36	16.71	19.33	12.33	13.07	20.56	
R1	16.23	13.14	16.63	15.69	15.94	20.01	-	12.92	19.72	
R2	16.49	14.33	16.28	15.95	19.26	20.01	13.38	15.25	22.42	
significance	*0.004*	*0.015*	*0.001*	*0.336*	*0.584*	*0.018*	*0.133*	*0.869*	*0.270*	
e.s.e.	*0.510*	*0.374*	*0.228*	*0.714*	*1.172*	*0.517*	*0.157*	*0.636*	*1.053*	
mean	16.29	13.26	16.24	15.67	17.51	20.00	12.86	13.75	20.90	

**only R0F2 and R2F2 treatments were measured at Harper Adams in 1993-4.* [a] See above.[b] See above.

3.6.1. Site effects.

On the occasions when biomass was measured in early spring (at F0) (Table 3.7.1), it was much lower at Crossnacreevy in 1993-4 and 1994-5, and Harper Adams in 1993-4 (approximately 0.2 t/ha), than at other site-seasons (a mean of 0.96 t/ha). At GS 31 dry matter (at F0) (Table 3.7.2.) was still low at Crossnacreevy in 1993-4, and remained so until harvest. Biomass at Crossnacreevy in 1994-5 was also lower than other site-seasons, but higher than in 1993-4. When total dry matter was measured at F2 at harvest (Table 3.7.4), the highest value was recorded at Harper Adams in 1995-6 (around 21 t/ha), and the lowest at Harper Adams in 1993-4 (12.9 t/ha).

3.6.2. Residue effects

In early spring (Table 3.7.1.) residual N treatments only had a significant effect on biomass production at Boxworth in 1995-6 (for the site-seasons measured), where greater amounts of dry matter were recorded for R2 plots compared to R0 plots. At GS 31 (at F0) (Table 3.7.2.) there was a noticeable increase in biomass from R0 to R2 plots in all site-seasons measured, except at Crossnacreevy in 1993-4. These increases, however, were not always statistically significant. At GS 65 and harvest (at F0) (Tables 3.7.3.a, 3.7.4.a), more dry matter was produced in R2 plots for all site-seasons measured, although, again, this was not always statistically significant. At F2, at GS 65 (Table 3.7.3.b), differences in biomass production between residual N treatments were not as appreciable as at F0, and by harvest (Table 3.7.4.b) were only noticeable at Boxworth and Crossnacreevy in 1994-5. There was, however, a 1 to 2 t/ha increase in dry matter from F2R0 to F2R2 plots at Harper Adams each year.

3.6.3. Variety effects

Variety had a strong effect on biomass production in early spring (at F0) (Table 3.7.1.), but the ranking of varieties was very inconsistent over the site-seasons measured. At GS 31 (at F0) (Table 3.7.2.), it became apparent that, at most of the site-seasons measured, Rialto and Avalon produced large amounts of dry matter (relative to other variety means), while Longbow was often one of the lower ranking varieties. Hereward fluctuated from being a low ranking variety to having the greatest biomass production at Harper Adams in 1995-6 (at GS 31).

At GS 65 varietal differences were not always statistically significant but, at F0 (Table 3.7.3.b), Rialto continued to have high dry matters at most site-seasons, while Longbow still performed poorly. Avalon was not as noticeably high ranking at this time. Rialto also had high levels of biomass production (relative to other variety means) when fertilizer had been added to the plots, as did Haven (Table 3.7.3.b). Avalon, on the other hand, was one of the lower ranking varieties at F2, for most site-seasons measured. At Crossnacreevy in 1994-5 and 1995-6, Soissons produced some of the lowest dry matter values, at both F0 and F2.

By harvest varietal differences in dry matter were only significant at Crossnacreevy in 1994-5 and 1995-6 (Tables 3.7.4.a, 3.7.4.b). At these two site-seasons, Soissons had low biomass values at F0, and Maris Huntsman had a low value at F2 in 1995-6. In general, however, over all site-seasons, Rialto performed well, both and without fertilizer, while Haven was often high ranking at F0, and Cadenza at F2. Longbow and Apollo frequently still had low levels of biomass at F0. The ranking (of dry matter production levels) of most other varieties at harvest was inconsistent between site-seasons.

3.7. Harvest indices and grain weight

3.7.1. Harvest index

Table 3.8.a Harvest index at F0 (%).

Site	Boxworth			Crossnacreevy			Harper Adams			
Season	93-4[a]	94-5[b]	95-6[c]	93-4	94-5	95-6	93-4*	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	-	9/8/95	19/8/96	
Apollo	46.87	45.93	48.04	55.90	53.58	50.47	-	37.85	42.30	47.62
Avalon	44.72	41.18	49.56	53.36	46.86	48.36	-	38.68	41.42	45.52
Cadenza	47.51	43.52	42.93	54.07	54.99	46.73	-	35.68	37.71	45.39
Haven	49.28	47.53	51.22	52.04	53.37	47.56	-	42.80	43.02	48.35
Hereward	45.12	44.74	45.66	50.84	51.59	46.89	-	40.20	40.44	45.68
Hunter	47.65	47.02	48.79	51.50	54.23	46.51	-	41.53	43.45	47.59
Longbow	49.65	48.65	50.14	54.45	56.35	49.96	-	42.70	41.86	49.22
Mercia	47.18	45.34	46.81	55.38	54.33	48.40	-	40.38	41.72	47.44
Rialto	46.96	46.29	47.56	51.13	54.17	48.63	-	40.75	40.11	46.95
Riband	49.36	48.38	51.47	57.29	56.06	50.83	-	43.41	45.17	50.25
M.Huntsman	-	-	-	-	53.88	46.63	-	-	-	50.26
Soissons	-	-	-	-	49.68	45.27	-	-	-	47.48
significance	*0.002*	*<.001*	*0.126*	*<.001*	*<.001*	*<.001*	-	*0.262*	*0.236*	
e.s.e.	*0.487*	*0.331*	*0.490*	*0.927*	*0.772*	*0.736*	-	*1.282*	*0.864*	
R0	46.75	45.90	47.88	54.52	53.47	48.72	-	40.30	42.23	
R1	47.33	45.10	49.42	54.32	54.14	48.09	-	41.84	41.38	
R2	48.22	46.57	47.36	51.96	52.17	47.24	-	39.06	41.56	
significance	*0.509*	*<.001*	*0.002*	*0.064*	*0.333*	*0.016*	-	*0.594*	*0.707*	
e.s.e.	*1.05*	*0.413*	*0.327*	*1.127*	*0.955*	*0.329*	-	*1.459*	*1.501*	
mean	47.43	45.86	48.22	53.60	53.55	48.43	-	40.40	41.72	

Table 3.8.b Harvest index at F2 (%).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4[a]	94-5[b]	95-6[c]	93-4	94-5	95-6	93-4*	94-5	95-6	Mean
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	47.60	48.59	50.10	51.49	56.63	47.97	34.35	40.32	40.54	46.4
Avalon	47.15	47.56	49.04	45.58	56.59	50.67	32.17	37.34	40.89	45.22
Cadenza	47.34	45.62	44.51	54.87	57.78	46.67	31.74	40.60	39.11	45.36
Haven	48.12	51.34	51.57	52.94	60.61	49.83	38.58	41.60	41.94	48.5
Hereward	46.01	47.64	47.86	48.71	56.53	47.62	33.88	40.45	40.68	45.49
Hunter	47.21	49.98	50.80	52.31	57.75	48.59	34.45	42.70	42.03	47.31
Longbow	47.96	50.63	51.68	51.76	59.38	49.05	37.51	40.58	42.79	47.93
Mercia	45.27	47.59	47.65	53.54	55.99	48.41	35.72	40.74	39.19	46.01
Rialto	47.14	48.06	49.17	52.31	57.29	48.43	36.17	42.40	41.03	46.89
Riband	48.15	51.01	52.32	56.27	60.56	49.19	31.73	44.47	42.91	48.51
M.Huntsman	-	-	-	-	54.70	43.40	-	-	-	49.05
Soissons	-	-	-	-	57.21	50.39	-	-	-	53.80
significance	*0.002*	*<.001*	*0.126*	*<.001*	*<.001*	*<.001*	*0.376*	*0.262*	*0.236*	
e.s.e.	*0.487*	*0.331*	*0.490*	*0.927*	*0.772*	*0.736*	*2.205*	*1.282*	*0.864*	
R0	48.30	50.34	51.32	54.18	59.39	50.46	35.89	42.33	42.75	
R1	46.61	50.39	50.19	49.02	56.50	46.49	-	40.82	41.05	
R2	46.67	45.68	46.91	52.73	56.88	48.10	33.37	40.21	39.53	
significance	*0.509*	*<.001*	*0.002*	*0.064*	*0.333*	*0.016*	*0.274*	*0.594*	*0.707*	
e.s.e.	*1.05*	*0.413*	*0.327*	*1.127*	*0.955*	*0.329*	*0.817*	*1.459*	*1.501*	
mean	47.20	48.80	49.47	51.98	57.91	48.64	34.63	41.12	41.11	

**At Harper Adams in 1993-4 HI could only be calculated for R0F2 and R2F2 plots.*

[a]Boxworth '94 soil N/var. interaction (p<.001), but no fert. N/soil N/var. interaction. Some varieties had stable HI over R0, R1 and R2, while others, particularly Avalon, increased with increasing soil N.

[b] Boxworth '95 fert. N/soil N/var. interaction (p=0.004). [c] Boxworth '96 soil N/var. interaction (p<.001). Apollo, Cadenza, Hunter, and Rialto had no significant change in HIs in R2 plots compared to R0 plots; others decreased as soil N levels increased. There was a fert. N/soil N/var. interaction (p=0.004).

3.7.1.1. Site effects

In 1993-4 and 1994-5, mean biomass harvest indices (HI), for F0 and F2 (Tables 3.8.a, 3.8.b.), were slightly higher at Crossnacreevy than Boxworth, which in turn were higher than at Harper Adams (when measured). In 1995-6 HIs were similar at Boxworth and Crossnacreevy, but still lower at Harper Adams.

3.7.1.2. Residue effects

Except at F0 at Boxworth (in all three years), there was a tendency for HI to decrease with increasing residual N level (Tables 3.8.a., 3.8.b.). This was particularly noticeable in F2 plots and was statistically significant for three out of nine site-seasons.

3.7.1.3. Variety effects

Variety had a significant effect on HI (for F0 and F2) at Boxworth in 1993-4 and 1994-5, and Crossnacreevy in all three years (Tables 3.8.a & b). For most site-seasons, at both F0 and F2, Riband had a appreciably high HI, relative to other variety means. Longbow was also frequently a high ranking variety, while Haven performed well at F2 in particular. Hereward had a low HI, at both F0 and F2, for most site seasons, while Avalon and Cadenza were often low ranking, particularly at F2. At Crossnacreevy in 1994-5 and 1995-6, Soissons had low HIs at F0, while M. Huntsman performed poorly at F2.

3.7.2. Grain weight (mg)

3.7.2.1. Site effects

Similarly to harvest index, at both F0 and F2, mean grain weight was highest at Crossnacreevy in each year; the highest mean weight was 50 mg at F0 in 1994-5 (Tables 3.9.a, 3.9.b). For most site-seasons mean grain weight was quite similar at F0 and F2.

3.7.2.2. Residue effects

Residual N treatments had a small but inconsistent effect on grain weight, with significant differences in weight (meaned over variety treatment) occurring at three site-seasons (Tables 3.9.a, 3.9.b). At Boxworth in 1995-6 grain weight was higher in R0 plots than R2 plots (at F0 and F2), while the opposite was true at Crossnacreevy in 1995-6 (at F0). At Boxworth in 1993-4, on the other hand, grain was heaviest in the R1 plots.

3.7.2.3. Variety effects

Variety effects on grain weight were quite variable between site-seasons (although differences were not always statistically significant) (Tables 3.9.a, 3.9.b). It was noticeable, however, that, at both F0 and F2, Longbow nearly always had a high grain weight, relative to other varieties. Avalon frequently had high grain weights at F0, while Cadenza performed quite well at F2. Mercia usually had low grain weights at both F0 and F2, while Apollo was often a low ranking variety at F0, and Hereward one at F2. At Crossnacreevy in 1994-5 and 1995-6, Soissons had low grain weights both with and without fertilizer, while Maris Huntsman had high weights in both situations. The highest mean variety grain weight recorded was, in fact, 60.2 mg for Maris Huntsman at F2 in 1994-5.

Table 3.9.a Grain weight (mg) at F0 at harvest.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5[a]	95-6[b]	93-4[c]	94-5	95-6	93-4	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	29/8/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	38.57	34.84	38.76	41.40	48.33	43.20	37.81	37.07	39.67	39.96
Avalon	46.54	39.94	39.20	48.32	54.25	51.19	42.11	42.29	42.93	45.2
Cadenza	38.95	38.63	41.82	46.22	48.46	44.80	43.49	39.08	41.06	42.5
Haven	39.18	38.67	38.33	47.05	55.12	48.80	42.06	40.62	42.33	43.57
Hereward	38.83	36.45	35.57	43.82	48.41	45.15	37.63	38.97	38.04	40.32
Hunter	35.72	35.48	36.39	43.55	47.78	42.44	40.96	38.99	40.29	40.18
Longbow	42.88	42.28	42.15	46.76	52.02	52.14	43.63	41.45	44.74	45.34
Mercia	35.88	36.97	36.13	42.06	44.63	41.64	38.17	37.49	39.10	39.12
Rialto	39.90	38.38	38.92	40.88	47.98	44.32	41.28	39.92	41.24	41.42
Riband	41.01	38.66	41.19	48.91	53.31	49.62	38.96	39.30	41.78	43.64
M.Huntsman	-	-	-	-	53.28	48.73	-	-	-	51.00
Soissons	-	-	-	-	44.12	40.15	-	-	-	42.14
significance	*0.090*	*0.008*	*0.201*	*<.001*	*<.001*	*<.001*	*0.031*	*0.161*	*0.600*	
e.s.e.	*0.578*	*0.663*	*0.518*	*0.676*	*0.631*	*0.556*	*0.609*	*0.663*	*0.653*	
R0	39.57	37.65	40.46	44.32	49.46	44.48	38.06	39.98	42.28	
R1	40.84	38.22	39.94	45.55	50.67	45.86	41.53	40.52	41.82	
R2	38.83	38.22	36.13	44.82	49.30	47.70	42.24	38.05	39.25	
significance	*0.050*	*0.162*	*0.048*	*0.105*	*0.926*	*0.004*	*0.448*	*0.083*	*0.540*	
e.s.e.	*0.467*	*0.530*	*0.214*	*0.668*	*0.975*	*0.229*	*1.042*	*0.450*	*0.720*	
mean	39.75	38.03	38.84	44.90	50.03	46.33	40.61	39.52	41.12	

Table 3.9.b Grain weight (mg) at F2 at harvest.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5[a]	95-6[b]	93-4[c]	94-5	95-6	93-4	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	22/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	36.57	33.20	39.91	48.15	49.53	44.65	41.48	37.09	40.13	41.19
Avalon	42.94	39.58	38.84	48.41	51.38	46.73	44.40	41.92	41.66	43.98
Cadenza	36.29	42.15	41.78	51.72	50.56	42.55	44.35	38.52	39.16	43.01
Haven	36.78	39.98	36.42	54.39	52.59	45.30	42.88	37.65	40.77	42.97
Hereward	34.41	35.93	34.14	46.49	47.55	42.23	37.11	36.50	38.05	39.16
Hunter	33.84	36.42	36.90	48.09	48.27	41.27	41.13	39.02	38.87	40.42
Longbow	39.32	41.79	41.31	51.65	51.41	46.70	43.75	38.94	43.35	44.25
Mercia	34.14	38.13	35.06	44.61	44.48	39.51	39.44	37.43	36.88	38.85
Rialto	37.57	39.03	37.35	47.01	47.72	44.64	43.46	38.40	40.66	41.76
Riband	37.40	40.69	39.08	50.76	52.51	43.24	41.45	38.63	40.47	42.69
M.Huntsman	-	-	-	-	60.18	51.77	-	-	-	55.98
Soissons	-	-	-	-	44.96	41.52	-	-	-	43.24
significance	*0.090*	*0.008*	*0.201*	*<.001*	*<.001*	*<.001*	*0.031*	*0.161*	*0.600*	
e.s.e.	*0.578*	*0.663*	*0.518*	*0.676*	*0.631*	*0.556*	*0.609*	*0.663*	*0.653*	
R0	36.71	38.63	39.19	49.89	49.68	44.39	41.04	38.82	40.25	
R1	37.39	39.66	38.78	47.63	50.55	44.13	41.99	38.13	40.85	
R2	36.68	37.78	36.27	49.87	50.05	44.00	42.80	38.28	38.90	
significance	*0.050*	*0.162*	*0.048*	*0.105*	*0.926*	*0.004*	*0.448*	*0.083*	*0.540*	
e.s.e.	*0.467*	*0.530*	*0.214*	*0.668*	*0.975*	*0.229*	*1.042*	*0.450*	*0.720*	
mean	36.92	38.69	38.08	49.13	49.60	43.68	41.94	38.41	40.00	

[a] Boxworth '95 soil N/var. interaction (p<.001), but no fert. N/soil N/var. interaction. All the varieties, except Avalon, had no significant difference in grain weight between the residual N treatments; grain weight of Avalon, however, decreased from 41.28 mg at R0 to 36.11 mg at R2.

[b] Boxworth '96 soil N/var. interaction (p<.001), but no fert. N/soil N/var. interaction. For all varieties, except Longbow, no significant difference in grain weight between R0 and R1, but all varieties decreasedin grain weight between the lower residual N levels and the R2 treatments.

[c] Crossnacreevy '94 soil N/var. interaction (p=0.019), but no fert. N/soil N/var. interaction. Varieties Apollo and Cadenza had similar grain weight at R0, R1 and R2 while others, *e.g.* Longbow and Riband, were more variable.

3.8. Efficiency of nitrogen utilization

3.8.1. Apparent recovery of fertilizer nitrogen

Using the results from the F2 treatment, % fertilizer recovery at the three sites was estimated using the formula:

((N offtake at F2 - N offtake at F0)/total N fertilizer applied at F2) x 100

As this calculation was carried out on means generated by the Genstat anovas for grain N uptakes, no statistical analysis has been performed on the results.

Table 3.10.a Apparent recovery of fertilizer N, at F2, at R0 (%).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6	93-4	94-5	95-6	93-4	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	37.28	34.59	35.41	44.22	50.82	44.82	24.90	22.84	17.73	34.73
Avalon	43.95	42.74	39.69	43.15	43.63	42.39	23.33	22.91	16.85	35.40
Cadenza	50.96	40.86	37.38	46.22	49.31	42.58	21.18	17.27	18.31	36.01
Haven	38.92	32.55	40.45	41.23	50.07	46.68	25.49	19.53	21.62	35.17
Hereward	43.46	35.71	35.35	43.16	45.17	42.62	19.13	23.67	14.46	33.64
Hunter	47.12	33.34	42.64	50.67	49.81	49.30	24.53	17.71	23.08	37.58
Longbow	46.67	32.52	39.10	45.03	48.85	41.94	29.25	27.93	24.96	37.36
Mercia	43.52	31.89	35.67	43.15	47.96	43.40	23.96	15.27	18.31	33.68
Rialto	43.41	37.76	39.87	44.89	48.78	43.01	23.57	18.51	15.85	35.07
Riband	35.63	33.51	41.23	50.70	48.81	39.29	20.81	18.65	20.15	34.31
Mean	43.09	35.55	38.68	45.24	48.32	43.60	23.62	20.43	19.13	

Table 3.10.b Apparent recovery of fertilizer N, at F2, at R1 (%).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6	93-4	94-5	95-6	93-4	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	23.25	36.29	31.15	47.00	49.31	44.38	19.93	20.69	12.00	31.56
Avalon	43.01	42.46	31.17	33.76	41.18	41.36	20.03	6.18	12.48	30.18
Cadenza	41.67	37.91	27.22	47.78	46.72	45.29	14.10	14.47	14.62	32.20
Haven	37.11	33.17	32.04	39.71	46.16	49.99	17.26	16.15	0.48	30.23
Hereward	42.23	34.21	30.36	34.24	46.67	50.88	11.51	11.49	15.33	30.77
Hunter	40.80	35.80	30.36	47.20	48.35	47.18	20.74	23.13	25.43	35.44
Longbow	32.86	36.04	30.65	43.26	38.28	39.87	12.79	11.27	6.86	27.99
Mercia	40.23	32.87	31.08	37.43	40.98	40.54	11.23	17.56	10.14	29.12
Rialto	44.31	39.71	38.75	44.93	43.62	49.04	12.93	16.18	12.57	33.56
Riband	28.34	34.76	31.05	34.49	39.03	40.45	13.83	13.64	4.90	26.72
Mean	37.38	36.32	31.38	40.98	44.03	44.90	15.44	15.08	11.48	

Table 3.10.c Apparent recovery of fertilizer N, at F2, at R2 (%).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4	94-5	95-6	93-4	94-5	95-6	93-4	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	20.64	71.05	-30.00	42.20	52.28	46.07	23.48	4.95	3.21	25.99
Avalon	10.44	-14.03	-0.73	46.15	44.33	45.85	17.51	0.36	-0.89	16.55
Cadenza	6.84	17.15	-4.68	46.10	44.71	39.78	14.52	11.35	1.95	19.75
Haven	22.05	0.87	-69.00	42.89	39.17	49.07	17.49	10.73	-3.89	12.15
Hereward	16.71	15.80	-8.03	42.56	40.00	46.10	19.24	5.49	24.84	22.52
Hunter	17.31	19.13	1.78	45.42	41.97	49.42	24.92	7.67	12.05	24.41
Longbow	10.75	14.55	9.25	42.19	41.15	32.87	20.70	4.84	2.16	19.83
Mercia	4.61	-0.32	-7.12	34.41	35.13	40.02	24.98	9.35	-0.47	15.62
Rialto	9.16	34.35	-20.45	39.00	36.52	50.55	17.70	11.35	-4.16	19.34
Riband	8.65	6.65	6.85	31.13	49.26	41.57	12.98	7.85	3.26	18.69
Mean	12.72	16.52	-12.21	41.21	42.45	44.13	19.35	7.39	3.81	

3.8.1.1. Site effects and residue effects

It can be seen from Tables 3.10.a - 3.10.c that the calculation of apparent fertilizer recovery produced extremely variable values both between and within site-seasons, indicating, perhaps, that this is not a very reliable estimate of fertilizer recovery. While taking this into account, however, some general points can still be made about the results. When fertilizer recoveries were meaned over variety the values at Crossnacreevy were quite similar for all years and residual N treatments. Values were also quite consistent at Boxworth in the R0 and R1 treatments and slightly lower than at Crossnacreevy. In the R2 plots at Boxworth, however, fertilizer recovery was noticeably decreased compared to the other residual N treatments, particularly in 1995-6 when a negative mean recovery value was calculated. Recoveries at Harper Adams were generally much lower than at the other two sites, but were reasonably consistent between years for both the R0 and R1 treatments. In the R2 plots at Harper Adams (similarly to the situation at Boxworth) mean fertilizer recovery was very variable between years.

3.8.1.2. Variety effects

Due to the inconsistency of the calculated varietal fertilizer recovery values, particularly at Harper Adams for all three residual N treatments, and at Boxworth in the R2 plots (Tables 3.10.a - 3.10.c), it was difficult to observe any trends in varietal ranking. It was noticeable, however, that Hunter often had a high value for recovery (relative to other variety means), especially in R0 and R1 plots. Mercia, on the other hand, was frequently one of the varieties with the poorest recovery in any site-season. The recoveries calculated for some varieties were very inconsistent. Apollo, for example, had an apparent fertilizer recovery of 83% in the R2 plots at Boxworth in 1994-5, compared to -44% the following year.

3.8.2. Grain N%

Table 3.11.a Grain N% at F0 at harvest.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4[a]	94-5[b]	95-6[c]	93-4	94-5	95-6	93-4[d]	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	1.70	1.58	1.87	1.53	1.45	1.18	2.07	2.03	1.85	1.7
Avalon	1.74	1.80	1.91	1.69	1.67	1.29	2.22	2.08	1.77	1.8
Cadenza	1.58	1.62	1.99	1.52	1.42	1.21	2.22	2.12	1.74	1.71
Haven	1.60	1.62	1.75	1.57	1.46	1.13	1.94	1.89	1.59	1.62
Hereward	1.69	1.82	1.96	1.62	1.66	1.25	2.17	2.02	1.75	1.77
Hunter	1.57	1.62	1.81	1.49	1.52	1.20	2.05	1.98	1.64	1.65
Longbow	1.61	1.60	1.75	1.66	1.45	1.08	2.11	1.89	1.60	1.64
Mercia	1.60	1.72	1.85	1.60	1.38	1.24	2.00	2.02	1.72	1.68
Rialto	1.65	1.62	1.85	1.52	1.45	1.20	2.07	1.94	1.70	1.67
Riband	1.61	1.56	1.76	1.52	1.44	1.02	2.02	1.90	1.68	1.61
M.Huntsman	-	-	-	-	1.47	1.27	-	-	-	1.37
Soissons	-	-	-	-	1.69	1.38	-	-	-	1.54
significance	*0.005*	*<.001*	*0.629*	*0.008*	*0.001*	*0.006*	*<.001*	*0.785*	*0.914*	
e.s.e.	*0.026*	*0.025*	*0.024*	*0.045*	*0.037*	*0.022*	*0.034*	*0.056*	*0.047*	
R0	1.44	1.40	1.52	1.60	1.53	1.17	1.93	1.71	1.57	
R1	1.48	1.45	1.69	1.58	1.50	1.19	2.15	1.95	1.60	
R2	1.99	2.13	2.34	1.55	1.49	1.25	2.18	2.30	1.95	
significance	*<.001*	*<.001*	*<.001*	*0.430*	*0.483*	*0.144*	*0.253*	*0.174*	*0.238*	
e.s.e.	*0.023*	*0.024*	*0.015*	*0.051*	*0.055*	*0.026*	*0.077*	*0.152*	*0.084*	
mean	1.64	1.66	1.85	1.57	1.49	1.18	2.09	1.99	1.70	

Table 3.11.b Grain N% at F2 at harvest.

Site	Boxworth			Crossnacreevy			Harper Adams			
season	93-4[a]	94-5[b]	95-6[c]	93-4	94-5	95-6	93-4[d]	94-5	95-6	mean
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	19/8/94	9/8/95	19/8/96	
Apollo	2.09	2.25	2.22	2.06	2.13	1.93	2.61	2.46	2.12	2.21
Avalon	2.22	2.44	2.31	2.20	2.30	2.08	2.64	2.49	2.11	2.31
Cadenza	2.18	2.32	2.35	1.99	2.05	2.06	2.50	2.54	1.97	2.22
Haven	2.12	2.12	2.19	2.01	1.97	1.98	2.34	2.31	1.82	2.1
Hereward	2.25	2.38	2.30	2.12	2.21	2.16	2.53	2.47	2.00	2.27
Hunter	2.19	2.19	2.19	2.16	2.25	2.07	2.61	2.54	1.96	2.24
Longbow	2.13	2.13	2.12	1.97	2.04	1.89	2.40	2.37	1.86	2.1
Mercia	2.17	2.26	2.25	1.98	2.13	2.10	2.40	2.33	1.95	2.17
Rialto	2.18	2.34	2.27	1.95	2.06	2.05	2.53	2.35	1.91	2.18
Riband	2.11	2.10	2.14	1.75	2.07	1.83	2.36	2.38	1.90	2.07
M.Huntsman	-	-	-	-	2.30	2.12	-	-	-	2.21
Soissons	-	-	-	-	2.13	2.10	-	-	-	2.12
significance	*0.005*	*<.001*	*0.629*	*0.008*	*0.001*	*0.006*	*<.001*	*0.785*	*0.914*	
e.s.e.	*0.026*	*0.025*	*0.024*	*0.045*	*0.037*	*0.022*	*0.034*	*0.056*	*0.047*	
R0	2.17	2.28	2.14	1.93	2.14	1.92	2.49	2.39	1.94	
R1	2.13	2.27	2.19	2.11	2.23	2.04	2.42	2.54	1.92	
R2	2.20	2.22	2.37	2.02	2.04	2.13	2.57	2.34	2.02	
significance	*<.001*	*<.001*	*<.001*	*0.430*	*0.483*	*0.144*	*0.253*	*0.174*	*0.238*	
e.s.e.	*0.023*	*0.024*	*0.015*	*0.051*	*0.055*	*0.026*	*0.077*	*0.152*	*0.084*	
mean	2.16	2.26	2.23	2.02	2.12	2.02	2.49	2.42	1.96	

[a] Boxworth '94 soil N/var. interaction (p=0.016), but no fert. N/soil N/var. interaction. All varieties had little difference in grain N% between R0 and R1 and increased level in R2.

[b] At Boxworth in 1994-5 there was a fertilizer N x soil N x variety interaction (p=0.019).

[c] Boxworth '96 soil N/var. interaction (p<0.001), but no fert. N/soil N/variety interaction. All varieties, except Haven, had a small difference in grain N % between R0 and R1 and then increased level in R2.

[d] Harper Adams '94 soil N/var. interaction (p=0.001), but no fert. N/soil N/var. interaction. Some varieties, *e.g.* Longbow and Riband, had higher grain N% at R1 than R2.

3.8.2.1. Site effects

Mean grain nitrogen concentrations, at F0, were lower at Crossnacreevy than the other two sites in all three years (Tables 3.11.a, 3.11.b). Harper Adams had the highest grain N%s in 1993-4 and 1994-5, but the mean decreased slightly in 1995-6 when the highest value was recorded at Boxworth. The mean at Crossnacreevy in 1995-6 (1.18%) was particularly low compared to other site seasons. When mean grain N% was calculated for F2 plots, Boxworth and Crossnacreevy had similar values for all three years. The grain N concentrations (at F2) at Harper Adams were higher than the other two sites in 1993-4 and 1994-5, and slightly lower than them in 1995-6.

3.8.2.2. Residue effects

In each year grain N concentration, at F0, increased with increasing residual N level at Boxworth (Table 3.11.a). Concentrations also increased slightly at Harper Adams, but differences were not statistically significant at that site. Residual N treatment had virtually no effect on grain N% at Crossnacreevy, at F0. When the plots were highly fertilised there was little difference in grain N% between residual N plots for any site-season (Table 3.11.b).

3.8.2.3. Variety effects

Varietal differences in grain N concentration were statistically significant at six out of nine site-seasons (Tables 3.11.a, 3.11.b). With nil fertilizer N the differences were quite inconsistent, but Avalon had a noticeably high N concentration, relative to other variety means, at most sites, and Hereward was also often a high ranking variety (particularly at Boxworth and Crossnacreevy). Haven, Longbow and Riband, on the other hand all, frequently, had low grain N%s. Cadenza had a fluctuating ranking; the variety had a high grain N% at Harper Adams in 1993-4 and 1994-5, and Boxworth in 1995-6, but a low N concentration at Boxworth in 1993-4 and Crossnacreevy in 1993-4 and 1994-5.

In the F2 plots Avalon still had a high grain N concentration at most sites. Hereward (especially at Boxworth and Crossnacreevy) and Hunter (particularly at Crossnacreevy and Harper Adams) were also often high ranking varieties. Similarly to the situation at F0, Haven, Longbow and Riband all frequently had low N concentrations, relative to other variety means. At Crossnacreevy in 1994-5 and 1995-6 Soissons had the highest grain N% when no fertilizer was applied, while Maris Huntsman was high ranking in the F2 treatment.

3.8.3. Nitrogen harvest index

Table 3.12.a Nitrogen harvest index at F0 (%).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4***	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	-	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	-	9/8/95	19/8/96	
Apollo	-	74.85	73.44	88.66	84.67	74.52	-	66.76	70.37	76.18
Avalon	-	72.38	73.28	88.94	82.75	77.87	-	68.20	64.27	75.38
Cadenza	-	73.71	71.67	87.45	84.21	73.31	-	66.20	68.53	75.01
Haven	-	77.49	73.65	81.17	81.60	71.89	-	68.22	65.11	74.16
Hereward	-	74.38	71.67	85.20	84.90	73.70	-	68.96	61.59	74.34
Hunter	-	74.36	73.59	81.91	81.81	70.23	-	70.00	63.24	73.59
Longbow	-	76.06	73.73	83.94	83.49	73.13	-	70.19	62.59	74.73
Mercia	-	74.08	70.44	88.75	84.05	71.47	-	70.02	66.29	75.01
Rialto	-	73.98	73.16	84.06	82.54	73.45	-	69.50	63.32	74.29
Riband	-	74.68	73.56	90.29	86.77	72.02	-	72.38	66.60	76.61
M.Huntsman	-	-	-	-	80.57	72.40	-	-	-	76.48
Soissons	-	-	-	-	80.96	73.42	-	-	-	77.19
significance	-	*0.312*	*0.441*	*<.001*	*0.078*	*0.167*	-	*0.689*	*0.371*	
e.s.e.	-	*1.191*	*1.075*	*1.304*	*1.374*	*1.491*	-	*1.663*	*2.453*	
R0	-	73.30	73.12	87.35	82.60	73.04	-	69.55	67.35	
R1	-	72.95	76.42	87.72	84.84	73.24	-	72.78	65.91	
R2	-	77.54	68.92	83.05	82.13	73.07	-	64.80	62.31	
significance	-	*0.075*	*0.178*	*0.162*	*0.034*	*0.314*	-	*0.641*	*0.944*	
e.s.e.	-	*1.751*	*2.079*	*2.044*	*1.020*	*2.287*	-	*2.549*	*4.239*	
mean	-	74.60	72.82	86.04	83.68	73.16	-	69.04	65.19	

Table 3.12.b Nitrogen harvest index at F2 (%).

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4***	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	26/9/94	19/8/95	14/9/96	-	9/8/95	19/8/96	
Apollo	73.99	82.44	76.64	78.23	84.14	71.51		72.98	63.17	75.39
Avalon	71.93	81.20	74.59	71.51	83.47	70.26		71.01	57.80	72.72
Cadenza	72.94	80.56	71.18	82.60	84.72	69.81		71.71	63.87	74.67
Haven	72.67	80.90	76.24	77.61	83.83	72.03		75.55	60.93	74.97
Hereward	72.86	81.12	74.20	76.13	85.37	67.50		72.44	62.55	74.02
Hunter	74.78	78.11	75.36	79.33	85.23	70.79		73.83	63.82	75.16
Longbow	71.16	79.60	75.70	77.19	81.89	70.29		72.47	63.02	73.91
Mercia	71.89	80.67	75.55	78.39	81.33	69.95		72.27	58.04	73.51
Rialto	73.80	80.54	74.35	78.69	83.28	70.01		74.40	64.43	74.94
Riband	69.84	79.81	76.58	77.64	84.45	71.94		73.37	62.04	74.46
M.Huntsman	-	-	-	-	84.90	71.38		-	-	78.14
Soissons	-	-	-	-	84.28	73.19		-	-	78.74
significance	-	*0.312*	*0.441*	*<.001*	*0.078*	*0.167*	-	*0.689*	*0.371*	
e.s.e.	-	*1.191*	*1.075*	*1.304*	*1.374*	*1.491*	-	*1.663*	*2.453*	
R0	73.06	82.44	81.44	82.63	86.15	73.61	-	76.27	62.85	
R1	-	82.78	74.78	72.87	83.84	66.23	-	74.59	62.38	
R2	72.11	76.26	68.90	77.70	81.73	72.32	-	68.15	60.67	
significance	-	*0.075*	*0.178*	*0.162*	*0.034*	*0.314*	-	*0.641*	*0.944*	
e.s.e.	-	*1.751*	*2.079*	*2.044*	*1.020*	*2.287*	-	*2.549*	*4.239*	
mean	72.59	80.49	75.04	77.73	83.77	70.41	-	73.00	61.97	

**At Boxworth in 1993-4 NHI could only be calculated for R0F2 and R2F2 plots.*

[a] Boxworth '96 soil N/variety interaction (p=0.011), but no fert. N/soil N/var. interaction. All varieties, except Mercia, had similar NHIs in R0 and R1and then exhibited a decrease from R1 to R2. NHI of Mercia, in contrast, was lower in R1 than R0, but did not show a significant decrease from R1 to R2.

3.8.3.1. Site effects

At F0, for the seasons measured, nitrogen harvest indices (NHIs) were lower at Harper Adams than at the other two sites, and higher at Crossnacreevy than Boxworth in 1994-5 (Table 3.12.a). Mean NHI at F2 was also highest at Crossnacreevy in 1994-5, and lowest at Harper Adams in 1995-6 (Table 3.12.b). Mean NHIs were higher at F2 than F0 at Boxworth (in 1994-5 and 1995-6), but this observation was more variable at the other two sites.

3.8.3.2. Residue effects

Residual N treatment only had a significant effect on NHI at Crossnacreevy in 1994-5, when there was a noticeable decrease in NHI, at F2, in R2 plots compared to R0 plots. Other than this, NHIs were quite inconsistent between residual N treatments, at both F0 and F2, with indices for R1 plots often being either higher or lower than those for both R0 and R2 plots (Tables 3.12.a, 3.12.b).

3.8.3.3. Variety effects

At both F0 and F2, differences in varietal NHIs were very variable between site-seasons and no consistent trends in varietal ranking were observed (Tables 3.12.a, 3.12.b). Differences were only significant at Crossnacreevy in 1993-4 when Riband had a high NHI at F0 and Cadenza performed well at F2 (relative to other variety means).

4. DISCUSSION

4.1. Comparisons with the Levington data set

Since nitrogen has a major influence on crop growth, productivity and profitability, growers' objective is to maximise the efficiency of utilisation of nitrogen applied to their crops. It would be helpful to ascertain if there are differences between varieties in their requirements for nitrogen, which could then be taken into account in decision-making on farms. Foulkes *et al.* (1998) examined varietal differences in requirement for nitrogen fertilizer using results from experiments conducted by Levington Agriculture in England which included twenty-two varieties, varying in age of introduction according to year of first harvest in National List trials from 1969 to 1988. In each year over the period 1982-92, six or seven varieties, selected because they were of interest commercially in that year, were grown at seven fertilizer nitrogen amounts at each of two sites. Grain yield (t/ha at 85%DM) from the combine and grain %N (100%DM) were determined on each plot.

Several parameters were derived from the data describing the recovery of nitrogen from the soil and from fertilizer by the varieties and their efficiency in using this nitrogen in producing grain yield. For each variety at each site in each year, the response to fertilizer nitrogen was estimated by fitting a linear plus exponential function to the grain yield data. The economic optimum amount of nitrogen (Nopt) was calculated using the parameters of this model and assuming that 3 kg of grain were produced per kg of nitrogen applied. Yield at Nopt was then derived. The response in nitrogen offtake to applied nitrogen was determined by fitting a two-line function to each dataset. Nitrogen offtake in grain when no nitrogen was applied and at Nopt and the apparent recovery of fertilizer nitrogen at Nopt were derived from this function. The requirement for nitrogen for a crop being grown to produce maximum economic yield was calculated from yield at Nopt and grain %N. The requirement for fertilizer *nitrogen* was then calculated from this requirement for nitrogen taking into account recovery of nitrogen available in the soil and recovery of nitrogen supplied as fertilizer.

The Levington programme, the conclusions of which were summarised in the Introduction, included twenty-two varieties varying in age by nineteen years. However some comparisons between varieties were indirect, as individual varieties were only examined in from four to thirteen experiments, so producing an incomplete data matrix. In the Soil N programme, ten varieties, varying in age by fourteen years, were compared. Although the treatments in the two programmes were not the same, it is possible to compare results from the two data sets.

4.1.1. Comparison of varieties common to both programmes

Seven varieties were common to both the Soil N experiments and the Levington programme, the older Avalon, Longbow and Mercia and the newer Apollo, Riband, Haven and Hereward. Results from the two programmes for the parameters discussed by Foulkes *et al.* (1998) are presented in Table 4.1.

In the Soil N programme yield at F2, i.e. with an intended total nitrogen supply from soil and fertilizer of 300 kg/ha, is considered to be equivalent to yield at Nopt in the Levington programme. Yields at F2 of the older varieties in Soil N experiment were similar to their yields at Nopt in the Levington programme. Yields of the newer varieties were lower in the Soil N experiments than in the Levington programme.

Grain %N was generally lower in the Levington dataset than in the Soil N programme. In the Levington dataset this was grain %N at Nopt. In the Soil N programme, N rates were probably above optimum. Yields would therefore have been similar (in the Levington dataset maximum yields and yields at Nopt were very similar) but grain %N was likely to be higher in the Soil N programme.

Grain N offtakes when no fertilizer N was applied were similar in most of the older varieties in both data sets with the exception of Longbow, which had a higher grain N offtake in the Levington programme. The newer varieties had higher grain N offtakes in the Soil N experiments than in the Levington programme.

Recovery of fertilizer N in the Soil N experiments was calculated in two ways, from the F1 treatments at Boxworth and Crossnacreevy where 40 kg/ha N were applied in early spring, there being no F1 treatment in the Harper Adams experiments, and from the F2 treatments at all three sites. Recovery of F1 fertilizer N was usually lower in the Soil N experiments than in the Levington programme, particularly in the newer varieties. Longbow was again the exception, having a high recovery of soil N in the Soil N experiments and a low recovery in the Levington programme. Recovery of F2 fertilizer N was much lower in all varieties in the Soil N experiments.

Requirements for fertilizer N, calculated using recovery of F1 fertilizer, were similar in most varieties in the two programmes, although Mercia required 215 kg/ha fertilizer N in the Soil N experiments compared with 183 kg/ha in the Levington programme, while Haven required less in the Soil N experiments, 174 kg/ha as compared with 213 kg/ha in the Levington programme.

The older varieties, Avalon and Mercia, tended to behave similarly whilst the newer varieties, Apollo, Riband, Haven and Hereward, tended to behave differently in the two programmes. Longbow stood out from other varieties in having contrasting behaviour in the two programmes. Its yields and grain N offtakes at Nopt/with fertilizer N were similar in both data sets. Compared to the other varieties Longbow was better at recovering Soil N but poorer in recovering F1 Fertilizer N in the Levington programme. The opposite was true in the Soil N programme.

Table 4.1. Comparison of characteristics of varieties in the Soil N experiments (all sites and Soil Ns) and the Levington programme

Year first in NL trials	Avalon 1977	Longbow 1979	Mercia 1983	Apollo 1985	Riband 1985	Haven 1987	Hereward 1988	Hunter 1990	Cadenza 1990	Rialto 1991
Grain yield at F2 (t/ha)	7.90	8.44	8.20	8.39	8.65	8.83	8.19	8.63	8.36	8.86
Levington	*7.99*	*8.49*	*8.34*	*9.11*	*9.43*	*9.73*	*9.23*	-	-	-
Grain N at F2 (%)	2.36	2.16	2.22	2.25	2.12	2.15	2.32	2.31	2.28	2.24
Levington	*1.98*	*1.75*	*1.89*	*1.94*	*1.80*	*1.81*	*1.93*	-	-	-
Grain N at F2 (kg/ha)	153.8	149.5	152.3	155.9	151.0	158.1	156.5	164.6	156.2	164.9
Levington	*158*	*146*	*157*	*177*	*169*	*178*	*179*	-	-	-
Grain N at F0 (kg/ha)	82.0	77.6	83.1	78.9	82.9	84.1	84.4	84.3	81.2	88.5
Levington	*73.7*	*90.1*	*81.8*	*80.9*	*76.8*	*69.5*	*73.5*	-	-	-
N from fertilizer = grain N at F2 - grain N at F0 (kg/ha)	71.8	71.9	69.2	77.0	68.1	74.0	72.1	80.3	75.0	76.4
Levington	*84.3*	*55.9*	*75.2*	*96.1*	*92.2*	*108.5*	*105.5*	-	-	-
Recovery at F1(%) (((Total N in F1-Total N in F0)*100)/40) Boxworth and Crossnacreevy only	41.8	50.0	32.3	47.9	38.5	42.5	32.3	46.8	44.9	40.8
Levington	*45*	*37*	*41*	*52*	*49*	*51*	*51*	-	-	-
Fertilizer N required = (N from fertilizer*100/Recovery) (kg/ha) Boxworth and Crossnacreevy only	172	144	215	161	177	174	224	172	167	187
Levington	*187*	*151*	*183*	*185*	*188*	*213*	*207*	-	-	-
Recovery at F2(%) (((Total N in F2-T F0)*100)/Total N applied at F2)	34.6	35.6	30.7	33.6	30.9	28.5	31.1	36.3	35.1	35.5

4.1.2. Age effects on characteristics of the varieties in the two programmes

The summary of the findings from the Levington programme has been tabulated in Table 4.2 along with results from the Soil N programme, meaned for the three sites and regressed against the year of entry of the varieties into National List trials.

Table 4.2. Changes in characteristics of varieties over a ten-year period

	Levington data	**Soil N Results 1993-96**
Grain Yield (t/ha at 85% DM)	+0.96	**+ 0.39**
- at F2		(± 0.180)
Grain N%	zero	**+ 0.0082**
- at F2		(± 0.05938)
Grain N offtake (kg/ha)	+21.1	**+ 8.3**
- at F2		(± 2.57)
N recovered from soil (kg/ha)	-7.7	**+ 3.9**
- grain N offtake at F0		(± 1.83)
N required from fertilizer (kg/ha) -	+28.8	**+ 4.34**
grain N offtake at F2 - grain N offtake at F0		(± 2.323)
Recovery of fertilizer (%)	+9.2	**- 1.14**
- at F1, Boxworth and Crossnacreevy only		(± 4.538)
Requirement for fertilizer (kg/ha) -	+28.2	**+ 13.7**
(N required from fertilizer x 100)/recovery		(± 17.28)

The Levington data set showed significant varietal differences in nitrogen offtake when no fertilizer nitrogen was applied. The implication of these findings was that older varieties such as Longbow and Mercia were slightly better at acquiring soil nitrogen than more modern varieties. This contrasts with the results of the Soil N experiments where more modern varieties had similar ability to recover soil nitrogen. There is little indication, therefore, from the results in the Soil N programme that some varieties would be more suitable for growing in low soil nitrogen environments than others on the basis of their ability to take up soil nitrogen.

The Levington findings indicated that yield and N offtake at Nopt were higher for modern varieties. If the F2 treatment is taken to approximate to Nopt, there is some indication that this is also the case in the Soil N experiments, the increase in yield being very similar to that of 0.038 t/ha per year determined by Austin *et al.* (1989). Results in the Soil N programme indicate that fertilizer requirement was higher for more recent varieties than older ones, although the difference was less than in the Levington data set. This was related to relatively lower N offtakes at Nopt, better Soil N offtakes and poorer F1 Fertilizer N recovery by modern varieties in the Soil N programme than in the Levington trials. Recovery of Fertilizer N in the F2 treatment increased slightly in modern varieties by 1.96 (±1.420) kg/ha/decade so that their requirement for fertilizer N decreased by 2.04 (±8.41) kg/ha/decade.

Generally age-related effects were less marked in the Soil N experiments than in the Levington results.

4.1.3. Comparison of the Levington parameters at the three sites

The three sites used in the Soil N programme differed greatly in availability of nitrogen in the soil, in weather and in crop growth. The Levington hypothesis was used to examine differences in the behaviour of the varieties between the sites (Tables 4.3 and 4.4).

Table 4.3. Comparison of characteristics at the three sites (mean of the ten varieties)

	Soil N Results 1993-96		
	Boxworth	Crossnacreevy	Harper Adams
Grain Yield (t/ha at 85% DM)	8.69	10.06	6.62
(± 0.686, p<0.001, CV=9.7%)			
Grain N%	2.22	2.05	2.46
(± 0.063, p<0.001, CV=6.3%)			
Grain N offtake (kg/ha)	163.4	175.1	130.3
(± 11.86, p<0.001, CV=11.2%)			
N recovered from soil (kg/ha)	105.5	53.7	89.0
(± 11.86, p<0.001, CV=11.2%)			
N required from fertilizer (kg/ha)	58.0	121.4	41.4
Recovery of F1 fertilizer (%)	46.7	38.4	N/A
Requirement for fertilizer (kg/ha)	136	339	101*
Recovery of F2 fertilizer (%)	25.3	57.9	16.5

*Based on mean recovery of F1 fertilizer at Crossnacreevy and Boxworth

Grain N offtakes were similar in most varieties at Boxworth and Crossnacreevy but yields were higher and grain N% lower at Crossnacreevy than at Boxworth. The longer grain-filling period at Crossnacreevy would have allowed the crop to continue to produce dry matter resulting in both higher yields and greater dilution of the nitrogen in the grain to give lower grain N% than at Boxworth.

At Harper Adams grain N% was much higher and yields and grain N offtakes were much lower than at the other two sites. Both the uptake of nitrogen by the crop and photosynthetic activity during grain-filling may have been curtailed by drought at this site so that nitrogen in the grain was not diluted and yields of grain were low relative to the other two sites.

Recovery of soil N, i.e. grain N offtake without fertilizer N, was highest at Boxworth and lowest at Crossnacreevy, reflecting the abundance of soil N at Boxworth and the paucity of soil N at Crossnacreevy. Therefore more nitrogen had to be supplied as fertilizer at Crossnacreevy than at Boxworth. Lower grain N offtakes at Harper Adams resulted in less nitrogen needing to be supplied as fertilizer than at Boxworth and Crossnacreevy.

Recovery of fertilizer N in the F1 treatment was slightly higher at Boxworth than at Crossnacreevy. In the F2 treatment recovery at Crossnacreevy was better than in the F1 treatment and much higher than at Boxworth and Harper Adams. Drought at Harper Adams would account for the poorer recovery of the later applied fertilizer N at this site. At Boxworth continued supply of nitrogen by the soil may have reduced the need for fertilizer N by the crop later in the growing season.

Greater variation from variety to variety in recovery of F1 fertilizer N than in other characteristics resulted in very variable amounts of fertilizer N being required by the varieties, those in some varieties at Crossnacreevy being surprisingly high (Table 4.4).

Table 4.4. Comparison of characteristics of varieties at the three sites

		Avalon	Longbow	Mercia	Apollo	Riband	Haven	Hereward	Hunter	Cadenza	Rialto
Grain yield at F2 (t/ha)	Boxworth	8.68	8.82	8.44	8.39	8.75	8.66	8.60	8.96	8.54	9.04
	Crossnacreevy	9.18	9.89	9.56	10.41	10.47	10.59	9.61	10.08	10.27	10.56
	Harper Adams	5.88	6.63	6.62	6.42	6.78	7.30	6.38	6.88	6.30	7.01
Grain N at F2 (%)	Boxworth	2.32	2.13	2.22	2.19	2.13	2.14	2.31	2.19	2.28	2.26
	Crossnacreevy	2.19	1.97	2.07	2.04	1.88	1.98	2.16	2.16	2.03	2.02
	Harper Adams	2.56	2.39	2.37	2.53	2.37	2.33	2.50	2.57	2.52	2.44
Grain N at F2 (kg/ha)	Boxworth	170.7	159.8	159.6	155.6	157.2	157.7	168.4	166.8	165.1	173.3
	Crossnacreevy	170.3	165.4	168.5	180.3	167.3	178.8	176.6	184.8	177.2	181.8
	Harper Adams	120.5	123.2	128.8	131.9	128.7	137.8	124.5	142.3	126.2	139.5
Grain N at F0 (kg/ha)	Boxworth	108.5	102.5	105.1	101.1	104.2	103.7	109.6	105.4	104.3	110.2
	Crossnacreevy	53.4	50.7	56.8	51.1	52.2	54.4	56.4	53.0	51.7	57.1
	Harper Adams	84.3	79.5	87.5	84.5	92.3	94.1	87.2	94.5	87.7	98.1
N from fertilizer (kg/ha)	Boxworth	62.2	57.3	54.5	54.5	53.0	54.0	58.8	61.4	60.8	63.1
	Crossnacreevy	116.9	114.7	111.7	129.2	115.1	124.4	120.2	131.8	125.5	124.7
	Harper Adams	36.2	43.7	41.3	47.4	36.4	43.7	37.3	47.8	38.5	41.4
Recovery at F1 (%)	Boxworth	31.0	59.8	43.3	41.5	39.8	53.0	28.8	46.0	60.8	63.1
	Crossnacreevy	52.5	40.3	21.3	54.3	37.3	32.0	35.8	47.5	29.0	33.5
	Harper Adams	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fertilizer N required (kg/ha)	Boxworth	201	96	126	131	133	102	205	133	100	131
	Crossnacreevy	223	285	526	238	309	389	336	277	433	372
	Harper Adams*	87	87	128	99	95	103	116	102	87	102
Recovery at F2 (%)	Boxworth	29.4	32.0	20.6	26.5	24.1	12.6	16.8	28.8	30.6	31.5
	Crossnacreevy	58.6	55.0	54.1	61.1	54.1	58.2	59.3	60.5	58.1	59.5
	Harper Adams	16.4	19.8	17.4	13.3	14.3	14.9	17.2	19.7	16.8	15.4

*Based on mean recovery of F1 fertilizer at Crossnacreevy and Boxworth

4.1.4. Age effects on characteristics of the varieties at the three sites

The differences between the sites in their supply of soil nitrogen and in growing conditions have marked effects when behaviour of the varieties is related to their age (Table 4.5).

Table 4.5. Changes in characteristics of varieties over a ten-year period at the three sites

	Soil N Results 1993-96		
	Boxworth	Crossnacreevy	Harper Adams
Grain Yield	**+ 0.11**	**+ 0.64**	**+ 0.43**
(t/ha at 85% DM)	(± 0.15)	(± 0.28)	(± 0.26)
Grain N%	**+ 0.013**	**- 0.011**	**+0.020**
	(± 0.055)	(± 0.073)	(± 0.66)
Grain N offtake	**+ 3.0**	**+ 11.0**	**+10.8**
(kg/ha)	(± 4.6)	(± 3.2)	(± 4.0)
N recovered from soil	**+ 1.27**	**+ 1.53**	**+ 8.89**
(kg/ha)	(± 2.23)	(± 1.71)	(± 2.86)
N required from fertilizer	**+ 1.69**	**+ 9.49**	**+ 1.89**
(kg/ha)	(± 2.78)	(± 3.75)	(± 3.13)
Recovery of F1 fertilizer	**+ 4.74**	**- 7.03**	**N/A**
(%)	(± 7.88)	(± 7.46)	
Requirement for fertilizer	**- 16.9**	**+ 66.5**	**+ 6.68***
(kg/ha)	(± 27.94)	(± 65.89)	(± 9.60)
Recovery of F2 fertilizer	**+ 1.66**	**+ 2.40**	**-0.53**
(%)	(± 4.953)	(± 1.728)	(± 1.608)
Requirement for fertilizer	**- 31.8**	**+ 7.63**	**+18.4**
(kg/ha)	(± 59.00)	(± 3.379)	(± 31.80)

*Based on mean recovery of F1 fertilizer at Crossnacreevy and Boxworth.

Both yield and grain N% increases in newer varieties were low at Boxworth so that increase in grain N offtake was also low. Crossnacreevy and Harper Adams had higher increases in their grain N offtakes, because of greater increases in yield in newer varieties. Although Boxworth and Crossnacreevy differed greatly in the availability of soil nitrogen, increases in recovery of this nitrogen in newer varieties were similar at both sites. At Harper Adams, however, newer varieties recovered much more nitrogen relative to older varieties than at the other sites. Relatively more nitrogen was required and less F1 fertilizer nitrogen was recovered by newer varieties at Crossnacreevy than at Boxworth and Harper Adams, resulting in a much higher relative requirement for fertilizer nitrogen in newer varieties at Crossnacreevy compared to the other sites.

Conclusions

- Similar results would have been expected in the two programmes because of the commonality in age of introduction of the varieties, 1969 to 1988 in the Levington trials and 1977 to 1991 in the Soil N experiments, and in the varieties included, seven being common to both. However in the Soil N experiments there were smaller differences between older and newer varieties than in the Levington data set. This may be simply because some of the varieties used were different. Although ten is a large number of varieties to include in any experimental programme, varieties are peculiarly unique and therefore an even larger number may have been required to provide a more sound test of the effect of age. In the Soil N programme eight of the ten varieties, and in the Levington programme, 16 of the 22 varieties had been bred at PBIC (formerly the Plant Breeding Institute, Cambridge). In both programmes therefore the genetic base was probably less diverse than it would have been if varieties from a larger number of breeders had been used.

- In the Soil N experiments, newer varieties required more fertilizer N than older varieties but not as much as was indicated by results from the Levington programme.

- Timing of N fertilizer applications may need to take account of variation in recovery during the growing season. Indications that fertilizer N should be applied early at Boxworth and Harper Adams to take advantage of better recovery of fertilizer N earlier in the growing season need to be verified. Availability of non-soil and non-fertilizer N at Harper Adams in the 1994-5 and 1995-6 experiments will have affected the recovery of soil and fertilizer N (see section 4.2.1). At Crossnacreevy, on the other hand, fertilizer N should be applied later when recovery appears to be higher.

- Differences in behaviour of the varieties at the three sites suggests that they do interact with environment. Therefore knowing the features of the site, for example, a long grain-filling period, proneness to drought, or availability of soil nitrogen, might enable variety choice to be tailored more appropriately.

    - ♦ Varieties responded to differences in availability of soil nitrogen at Boxworth and Crossnacreevy, not by varying in their ability to take up soil nitrogen, but by showing differences in their recovery of fertilizer nitrogen applied in early spring. The tendency at Crossnacreevy for older varieties to recover fertilizer N applied early in the spring better than newer varieties needs to be verified.

    - ♦ Where the grain filling period was longer, i.e. at Crossnacreevy, newer varieties showed a greater increase in yield than older varieties and decreased in grain N%, i.e. nitrogen was used more efficiently in yield production.

    - ♦ Where drought curtailed photosynthesis and advanced maturity, i.e. at Harper Adams, newer varieties produced higher yields than older varieties but were less efficient in using nitrogen, improvements in grain N% for newer varieties being greater than at the other two sites.

4.2. Variety interactions with soil residue levels

Varietal differences in uptake and utilisation of nitrogen under conditions of contrasting soil nitrogen availability were initially examined by looking for variety interactions with Soil N residue over all characteristics in all site-seasons at each of the four growth stages when crop processes were measured i.e. early spring, GS 31, GS 65 and harvest (Tables 4.6 and 4.7). In early spring variety x Soil N interactions did not occur on any of the 25 occasions when such interactions could have arisen. At GS 31, two interactions out of a possible 36 between variety and Soil N were obtained, both at Crossnacreevy. At GS 65 five interactions out of a possible 40 between variety and Soil N were obtained, two of these at Boxworth and three at Crossnacreevy. Out of a possible 20 interactions between variety, Soil N and Fertilizer N at GS 65, five occurred, three at Boxworth and two at Crossnacreevy. At harvest, ten out a possible 51 interactions between variety and Soil N were obtained, seven at Boxworth, two at Crossnacreevy and one at Harper Adams. Out of a possible 47 interactions between variety, Soil N and Fertilizer N at harvest, four were obtained, three at Boxworth and one at Crossnacreevy.

Table 4.6. Number of possible interactions = No. site-seasons x No. interactions (early spring and GS 31: SN x Var only)

	early spring	GS31	GS65	Harvest
Shoot no/m^2	4	8	20 (SN x Var: 8, FN x SN x Var: 4)	32 (SN x Var: 8, FN x SN x Var: 8)
N uptake	7	8	21 (SN x Var: 8, FN x SN x Var: 4)	29 (SN x Var: 8, FN x SN x Var: 7)
GAI	4	6	21 (SN x Var: 8, FN x SN x Var: 4)	N/A
CNR	4	6	21 (SN x Var: 8, FN x SN x Var: 4)	N/A
Biomass	7	8	21 (SN x Var: 8, FN x SN x Var: 4)	33 (SN x Var: 9, FN x SN x Var: 8)
Grain yield	N/A	N/A	N/A	36 (SN x Var: 9, FN x SN x Var: 9)
Harvest index	N/A	N/A	N/A	33 (SN x Var: 9, FN x SN x Var: 8)
Nitrogen harvest index	N/A	N/A	N/A	29 (SN x Var: 8, FN x SN x Var: 7)

Table 4.7. Summary of incidence of interactions for all traits in all site-seasons

	Boxworth	Crossnacreevy	Harper Adams
N uptake	GS65 FNxSN '96 **GS65 FNxSNxVar '96** Harv FNxSN '95 Harv FNxSN '96 **Harv SNxVar '96**	GS65 FNxVar '95 **GS65 SNxVar '96** **GS65 FNxSNxVar '96** GS65 FNxSN '96 Harv FNxVar '96	
GAI	**GS65 SNxVar '95** GS65 FNxSN '96	GS65 FNxVar '94 **GS65 SNxVar '94**	
CNR	**GS65 FNxSNxVar '96**	**GS31 SNxVar '95** GS65 FNxVar '95 **GS65 SNxVar '96** **GS65 FNxSNxVar '96**	
Shoot no/m^2	GS65 FNxSN '96 **GS65 FNxSNxVar '96** Harv FNxVar '95 Harv FNxSN '96 **Harv SNxVar '96**	GS65 FNxVar '94 Harv FNxVar '94 Harv FNxVar '95 Harv FNxVar '96 **Harv SNxVar '96** **Harv FNxSNxVar '96**	
Biomass	**GS65 SNxVar '95** GS65 FNxSN '96 **Harv SNxVar '96** **HarvFNxSNxVar '96** Harv FNxSN '94 Harv FNxSN '95 Harv FNxSN '96	**GS31 SNxVar '96** GS65 FNxVar '95 GS65 FNxSN '96 Harv FNxVar '95 Harv FNxVar '96 **Harv SNxVar '96** Harv FNxSN '96	
Grain yield	FNxSN '94 FNxSN '95 FNxSN '96 **SNxVar '96**	FNxVar '94 FNxVar '95 FNxVar '96 FNxSN '96	**SNxVar '95**
Harvest index	**SNxVar '94** FNxVar '94 FNxVar '95 **FNxSNxVar '95** FNxSN '95 FNxSN '96 **SNxVar '96** **FNxSNxVar '96**	FNxVar '94 FNxVar '95 FNxVar '96 FNxSN '96	
NHI	**SN xVar '96**	FNxVar '94 FNxSN '95	

Thus, generally, there were few interactions between variety and Soil N residue levels. Of those that were obtained, more occurred early in the growing season at Crossnacreevy than at Boxworth whilst later, at GS 65 and at harvest, more interactions were obtained at Boxworth than at Crossnacreevy. At Crossnacreevy eight of the ten variety x Soil N interactions occurred in 1995-6, the only experiment at this site in which soil N levels in the autumn differed between the three pre-treatments. At Harper Adams drought in 1993-4 and high levels of external N supply in 1994-5 and 1995-6 (see Section 4.2.1) would have diminished the likelihood of interactions occurring and only one was in fact obtained.

At Boxworth where differences between the Soil N treatments in Soil N levels were quite marked, more interactions would have been expected. Data for the traits from all three years at Boxworth were combined and tested for variety x Soil N interactions (Table 4.8). On no occasion for any trait was there a consistent difference between the varieties in their response to Soil N.

Table 4.8. Significance of effects of variety, Soil N, Fertilizer N and their interactions on traits at Boxworth (mean of three years)

GS 31

	Soil N	Variety	SN x Var
N uptake	<0.001	0.18	0.95
GAI	<0.001	<0.001	0.68
CNR	<0.001	0.35	1.00
Shoot No.	0.002	0.10	1.00
Biomass	<0.001	<0.001	0.86

GS 65

	Soil N	Variety	SN x Var
N uptake	<0.001	1.00	1.00
GAI	<0.001	0.17	0.98
CNR	<0.001	0.24	0.97
Shoot No.	<0.001	<0.001	0.91
Biomass	<0.001	0.42	1.00

Harvest

	Soil N	Fertilizer N	Variety	SN x Var	FN x Var	FN x SN	FN x SN x Var
N uptake	<0.001	<0.001	0.49	1.00	1.00	<0.001	1.00
Shoot No.	<0.001	<0.001	<0.001	1.00	1.00	0.003	1.00
Biomass	<0.001	<0.001	0.019	1.00	1.00	<0.001	1.00
Grain yield	<0.001	<0.001	0.044	1.00	1.00	<0.001	1.00
Harvest Index	<0.001	<0.001	<0.001	0.34	0.72	<0.001	1.00
Nitrogen Harvest Index	<0.001	<0.001	0.063	0.57	0.88	<0.001	0.99

At Crossnacreevy in 1995-6, different responses of the varieties in their biomass production at GS 31 and in their N uptake and CNR at GS 65 to Soil N resulted from the differences in available N under the three Soil N treatments over the winter (Tables 4.9 -

4.11). However differences at harvest in 1995-6 between the varieties in their biomass production and ear populations were not accompanied by significant differences in their grain yields at the three Soil N levels (Tables 4.12 - 4.14).

Table 4.9. Effect of Soil N on biomass production of winter wheat varieties at Crossnacreevy at GS 31 in 1995-6

	R0	R1	R2
Apollo	1.26	1.74	2.34
Avalon	1.95	2.32	2.65
Cadenza	1.81	2.46	2.46
Haven	1.68	2.44	3.43
Hereward	2.12	2.76	3.57
Hunter	1.43	2.42	3.16
Longbow	1.83	2.56	3.05
Mercia	1.91	2.27	3.02
Rialto	2.00	2.78	3.56
Riband	1.39	2.36	2.83
s.e. (variety x SN)		0.183	
Sig. (variety x SN)		0.009	
CV%		9.4	

Table 4.10. Effect of Soil N on N uptake of winter wheat varieties at Crossnacreevy at GS 65 in 1995-6

	R0	R1	R2
Apollo	200.3	205.5	158.5
Avalon	113.3	151.3	204.4
Cadenza	137.5	191.8	177.2
Haven	238.3	197.6	210.5
Hereward	181.4	210.7	231.3
Hunter	223.0	199.3	158.1
Longbow	231.6	169.6	178.2
Mercia	194.5	158.3	179.9
Rialto	155.5	245.4	168.9
Riband	175.4	144.5	252.4
s.e. (variety x SN)		21.2	
Sig. (variety x SN)		0.002	
CV%		23.1	

Table 4.11. Effect of Soil N on CNR of winter wheat varieties at Crossnacreevy at GS 65 in 1995-6

	R0	R1	R2
Apollo	3.57	2.71	1.97
Avalon	1.94	2.50	2.72
Cadenza	2.65	3.08	2.01
Haven	3.62	2.44	2.86
Hereward	3.00	2.71	3.00
Hunter	3.35	2.61	1.85
Longbow	3.80	2.42	2.50
Mercia	2.94	2.33	2.04
Rialto	2.60	3.62	2.34
Riband	3.04	2.04	3.59
s.e. (variety x SN)		0.329	
Sig. (variety x SN)		0.002	
CV%		24.4	

Table 4.12. Effect of Soil N on shoot number/m² of winter wheat varieties at Crossnacreevy at harvest in 1995-6

	R0	R1	R2
Apollo	419	462	509
Avalon	443	480	486
Cadenza	516	539	534
Haven	541	530	579
Hereward	512	521	622
Hunter	468	546	599
Longbow	402	454	567
Mercia	577	620	741
Rialto	448	506	535
Riband	444	489	446
s.e. (variety x SN)		31.4	
Sig. (variety x SN)		0.22	
CV%		10.7	

Table 4.13. Effect of Soil N on biomass production of winter wheat varieties at Crossnacreevy at harvest in 1995-6

	R0	R1	R2
Apollo	14.9	15.6	17.1
Avalon	14.1	14.5	16.7
Cadenza	14.5	15.8	16.8
Haven	16.5	15.9	18.8
Hereward	14.5	16.4	18.3
Hunter	13.8	15.6	18.3
Longbow	14.1	15.2	19.6
Mercia	15.0	15.9	18.6
Rialto	14.6	16.7	18.5
Riband	14.5	16.2	15.8
s.e. (variety x SN)		0.69	
Sig. (variety x SN)		0.012	
CV%		7.7	

Table 4.14. Effect of Soil N on grain yield of winter wheat varieties at Crossnacreevy in 1995-6

	R0	R1	R2
Apollo	7.39	7.51	8.57
Avalon	7.00	7.52	8.62
Cadenza	7.20	7.81	8.22
Haven	8.12	8.34	9.74
Hereward	7.48	7.52	9.20
Hunter	7.73	7.84	9.10
Longbow	7.71	8.06	9.18
Mercia	7.24	7.99	8.67
Rialto	7.88	8.54	9.92
Riband	7.68	7.98	9.12
s.e. (variety x SN)		0.200	
Sig. (variety x SN)		0.278	
CV%		4.6	

Overall the lack of consistent differences between varieties in their response to Soil N at Boxworth and the absence of differential yield responses to Soil N at Crossnacreevy in 1995-6 suggests that soil nitrogen residue status does not differentially affect maximum yield potential of the varieties.

At Boxworth, where differences in the residual soil nitrogen treatments were well established, the high soil nitrogen treatment exerted an obvious influence on crop growth, with a 3.7 t/ha difference in yield between R0 and R2 when no fertilizer was applied. A high residual soil nitrogen level could, therefore, be of appreciable benefit to crop growth in a situation where the rate of fertilizer nitrogen application is much reduced.

There may be detrimental effects of supra-optimal N levels resulting from application of fertilizer N to soils with high levels of mineral N. Weaker stems, greater weed competition and higher levels of disease could lead to higher chemical costs, and/or a reduced yield. Some of the effects (e.g. higher stem and ear numbers) may be beneficial to crop performance. Variety characteristics therefore need to be selected with these points in mind. For example the tendency towards weak stems with super-optimal N levels should be counteracted by choosing a strong stemmed variety (ideally one that retains a high tillering capacity). Varieties with high shoot numbers and large canopies will be more competitive with weeds.

Savings in fertilizer costs may be achieved where soil mineral N levels are high. For example, 100 kg/ha soil N, 60% of which is recovered by the crop, would lead to savings of £40/ha in fertilizer costs. However there is some doubt as to whether the saving in fertilizer costs through uptake of soil N will be greater than the detrimental effects on yield that may arise from the same response. In general, however, it can be probably be concluded that recovery of large amounts of soil N only has a significant detrimental financial effect on yield in the presence of fertilizer N when the crop has been grossly over-fertilised. Thus soil N recovery by wheat in high soil N situations is of value and will also have beneficial environmental effects through restricting leachable nitrate residues in wheat fields.

Choice of variety does not need to take into account Soil N environment given that at Crossnacreevy Haven and Rialto were the highest yielding varieties in all three Soil N treatments (Table 4.14) and at Boxworth, Haven, Hunter Longbow, Rialto and Riband all produced high yields in the three Soil N treatments (Table 4.15).

Table 4.15. Effect of Soil N on grain yield of winter wheat varieties at Boxworth (mean of three years)

	R0	R1	R2
Apollo	6.83	7.26	8.44
Avalon	7.01	7.65	8.51
Cadenza	6.95	7.44	8.56
Haven	7.38	8.02	8.62
Hereward	7.03	7.48	8.51
Hunter	7.46	7.87	8.94
Longbow	7.46	7.96	8.65
Mercia	7.05	7.42	8.44
Rialto	7.27	7.99	9.19
Riband	7.50	7.91	8.58
s.e. (variety x SN)		0.284	
Sig. (variety x SN)		1.00	
CV%		15.4	

4.2.1. Results of the F0 treatment at Harper Adams

The reduction in the response to fertilizer N at Harper Adams in the two years after 1993-4 occurred after a large increase in the number of poultry upwind of the field site had taken place. Up to summer 1994, i.e. for the 1993/94 season, there were 44,000 birds about 450m from the field site in a WSW direction. In summer 1994 the old poultry houses were emptied and a new house was built housing 83,000 birds. This house was closer to the field site, 350m away in a WSW direction. There is likely to be an annual emission of 14 t of nitrogen as ammonia from this number of birds. The prevailing wind is westerly and this, combined with the proximity of the new houses, would have resulted in the emissions of ammonia having an effect on the field site for the second and third seasons, 1994-5 and 1995-6. The quantities of N deposited could easily have supplied the N requirements of the crops at the field site (R. Sylvester-Bradley, pers.comm.).

Conclusions

- Varieties responded similarly to Soil N at Boxworth when results from all three years were combined. At Crossnacreevy, relative yields of the varieties were not affected by Soil N although other characteristics responded differently throughout the growing season. **The amount of available N in the soil does not influence choice of variety.**

- All characteristics of varieties responded differently to Fertilizer N on some occasions at Crossnacreevy. Generally, responses to Fertilizer N were similar in all varieties at Boxworth and Harper Adams. These differences between sites in the responses of varieties to fertilizer N need to be verified.

- Drought and supply of N from non-soil and non-fertilizer sources, i.e. poultry emission, did not affect variety performance differentially. Indeed these factors tended to mask or over-ride responses of varieties, and of the crop in general, to differences in availability of N in the soil or from fertilizer. Therefore with soils where there is a high risk of drought, variety choice should be based on characteristics playing a role in drought resistance (see Section on Water Availability), availability of soil N and supply of fertilizer N having no differential effect on variety performance.

4.3. Candidate physiological traits

Variation amongst the varieties for each trait was examined using means for the fertilizer treatments over all Soil N treatments from all experiments. Whilst differences between varieties are observed in individual treatments and at individual sites and interactions are also detected in over-site-years analyses, it has been recognised that the best estimate of a variety's expression of a trait is obtained by examining its mean over as many trials/experiments as is possible (Scott *et al.*, 1994 and Holbook *et al*,. 1983). Although we are concerned with identifying suitability of varieties for contrasting soil N environments, the traits are examined with and without fertilizer to maximise the likelihood of detecting differences in variety behaviour. Trends with age of the variety for each trait were examined using regression analysis, year of first harvest in National List trials being used to represent age of the varieties.

Grain Yield

Since grain yield is the primary varietal trait of value to growers, variation in grain yield and relationships between grain yield and other traits are of prime importance.

At **F2** grain yield varied between **7.9** t/ha in Avalon and **8.9** t/ha in Rialto (Table 4.16). With the exception of Rialto, the most modern of the bread wheats, the bread-making varieties were lower-yielding as would be expected. Grain yield of more modern varieties at F2 increased by 0.042 ±0.017t/ha/year ($p = 0.037$, $R^2 = 44.0\%$) (Figure 4.1).

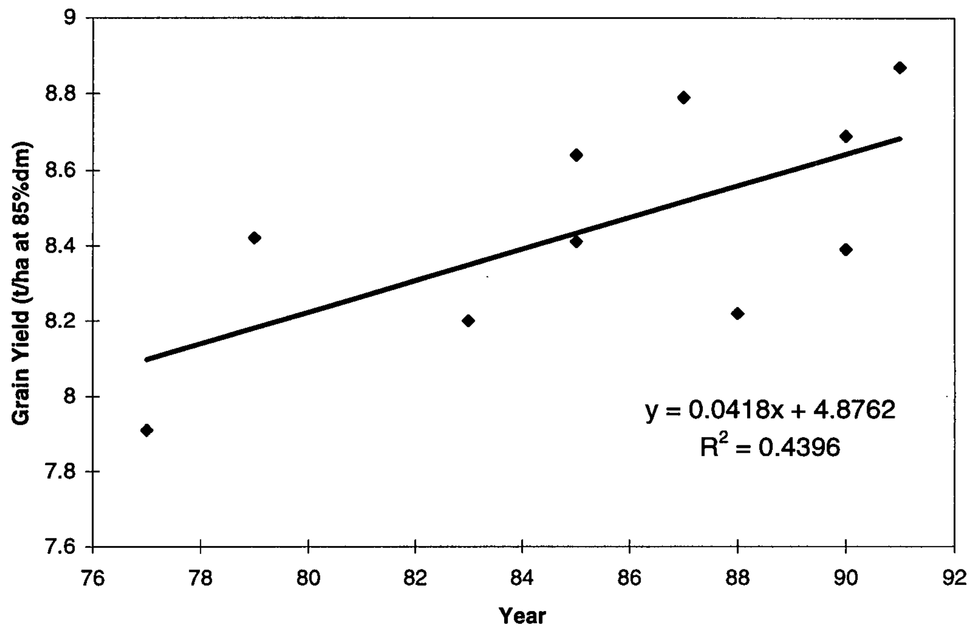
Table 4.16. Grain yield (t/ha at 85%DM) - mean of all site-years and Soil N treatments

	F2		F0
Apollo	8.41		5.47
Avalon	7.91		5.38
Cadenza	8.39		5.52
Haven	8.79		6.04
Hereward	8.22		5.57
Hunter	8.69		5.83
Longbow	8.42		5.64
Mercia	8.20		5.76
Rialto	8.87		6.12
Riband	8.64		5.99
s.e. (variety x FN)		0.084	
Sig. (variety x FN)		<0.001	
CV%		7.1	

At **F0** grain yield was on average 2.7 t/ha lower than at F2 (Table 4.16). Avalon was again the lowest yielding variety with **5.4** t/ha and Rialto the highest with **6.1** t/ha.

Most varieties were ranked similarly in both treatments with the exception of Mercia which was higher yielding at F0 than at F2 and Apollo which was higher yielding at F2 than at F0 relative to other varieties. In the UK Recommended List trials (HGCA, 1995-6) Rialto outyielded Mercia by 1.2 t/ha, a much greater margin than that of 0.7 t/ha at F2 in this programme. Yields in the UK trials were higher than those in the F2 treatment, that of Rialto being 9.9t/ha. Therefore it would appear that Mercia performs better relative to other varieties at lower than at higher fertility levels.

Figure 4.1
Grain yield at F2 v Year of first harvest in NL trials



Ability to yield without fertilizer N was not as closely related to age of the variety as yield at F2, the increase being 0.026 ±0.0169t/ha/year (p = 0.164, R^2 = 22.7%). This may reflect the variation in availability of soil N amongst the site-years at F0 in this programme whereas at F2 total availability of nitrogen from both soil and fertilizer was very similar in all site-years.

Nitrogen uptake

One of the primary mechanisms by which varieties may be able to either exploit high soil N availability or minimise the disadvantages of low soil N availability is through their recovery of nitrogen. Although growth over the winter months in winter wheat crops is very limited and development is slow, differences between varieties in N uptake during the winter could be of significance in enabling plants to produce green area and increase growth more rapidly once conditions become favourable in spring.

At F0 Rialto had higher N uptakes than other varieties consistently throughout the growing season when meaned over site-years and soil N treatments (Table 4.17). However high N uptake cannot be assumed to lead to high grain yields because Avalon, which had the lowest yields, also had high N uptakes, ranking second to Rialto at GS 31 and GS 65 at F0. At F2, Hunter had the highest N uptakes at both GS 65 and harvest. Mercia, along with Haven and Riband, had lower N uptakes at F2 than at F0 at harvest relative to other varieties whilst Cadenza and Hunter had better N uptakes relative to other varieties at F2 than at F0 at harvest.

If greater N uptake over winter was advantageous to subsequent growth of the crop by enabling increased uptake of nitrogen and producing a larger canopy earlier in the growing season, then differences obtained in early growth would become even larger as the season progressed. N uptake between early spring and harvest at F0 increased over four-fold and at F2 increased eight-fold but the ranges amongst the varieties of 15.5 kg/ha at F0 and 16.4 kg/ha at F2 at harvest were not much greater in absolute terms than the range of 7.5 kg/ha in N uptake in early spring and in percentage terms were much smaller. This suggests that early advantages in N uptake were not influential in determining growth during the remainder of the season.

Table 4.17. Total Nitrogen uptake (kg/ha) - mean of all site-years and Soil N treatments

	Early spring F0	GS 31 F0	GS 65 F0	Harvest F0	GS 65 F2	Harvest F2
Apollo	23.8	54.7	103.7	110.1	231.7	214.9
Avalon	28.4	59.0	111.9	116.2	211.2	220.1
Cadenza	27.0	56.1	105.4	112.7	225.0	219.5
Haven	28.9	53.3	104.8	119.9	250.0	215.1
Hereward	27.3	56.2	109.0	119.5	235.7	221.9
Hunter	27.3	56.1	101.2	119.4	257.3	227.9
Longbow	25.2	52.1	104.8	109.5	238.0	210.7
Mercia	28.1	56.9	109.0	117.9	227.4	214.3
Rialto	31.3	60.3	113.2	125.0	250.8	226.7
Riband	27.5	54.2	107.4	114.0	224.3	210.3
s.e. (variety x FN)				2.47		2.47
Sig. (variety x FN)				<0.001		<0.001
CV%				7.8		7.8

More modern varieties were not able to recover nitrogen any better than older varieties over the winter or in the absence of fertilizer (Table 4.18). When fertilizer was applied there was some indication that more modern varieties recovered more nitrogen than older varieties, particularly at GS 65.

Table 4.18. Relationships between N uptake and variety age

Comparison of N uptake with variety age at:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0			
Early spring	0.138 ± 0.1445	10.3	0.367
GS 31	0.098 ± 0.1830	3.5	0.606
GS 65	-0.142 ± 0.2773	3.2	0.623
Harvest	0.516 ± 0.3150	25.1	0.140
F2			
GS65	1.872 ± 0.8387	38.4	0.056
Harvest	0.742 ± 0.3780	32.5	0.085

Differences between winter wheat varieties in their capacity to recover nitrogen applied as fertilizer may be linked to differences in rooting pattern both in terms of the rate of root extension and the amount and distribution of roots in the soil. It is possible that more modern varieties have a greater proportion of their root biomass in the upper part of the soil profile where most fertilizer nitrogen is available (in the top 20 cm), while older varieties may have roots more evenly distributed down the soil profile. Where the varieties would have access to soil N only, the influence of such differences in pattern of rooting on the amount of nitrogen taken up will depend on the vertical distribution of nitrogen in the soil and on how distribution of both roots and nitrogen change over time relative to one another. However, as little recent work has been carried out to investigate these possibilities, any theories must be very speculative.

At F0 varieties differed consistently in their N uptake between early spring and GS 31 and between GS 31 and GS 65 (Table 4.19). N uptakes at harvest, however, were less well correlated with N uptakes at GS 65. At F2 N uptakes of the varieties were not correlated with their N uptakes at F0 earlier in the growing season. There was poor correlation between N uptakes at harvest with those at GS 65 in the F2 treatment.

Varieties with high N uptake early in the life cycle would be expected to continue to have high N uptake subsequently and *vice versa*. Rialto, with very high N uptakes, Mercia and Hereward, with average N uptakes, Apollo and Longbow, both with low N uptakes, constitute such types when their behaviour without fertilizer nitrogen is examined. With fertilizer, Rialto continues to be a high N uptake type and Hereward an average N uptake type but Mercia appears to be a low N uptake type along with Apollo. Longbow, whilst having a low N uptake at harvest at F2, had a relatively high N uptake at GS 65 at F2. The other varieties were intermediate in their N uptake but tended to be variable during the growing season and with fertilizer N application relative to the full set of varieties.

Table 4.19. Relationships within the trait during the growing season

Comparison of N uptake at:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0 at GS 31	F0 in early spring	0.795 ± 0.3276	42.4	0.041
F0 at GS 65	F0 at GS 31	1.098 ± 0.3681	52.6	0.018
F0 at harvest	F0 at GS 65	0.608 ± 0.4030	22.2	0.170
F2 at GS 65	F0 in early spring	1.668 ± 2.4051	5.7	0.508
F2 at GS 65	F0 at GS 31	-0.675 ± 2.0141	1.4	0.746
F2 at harvest	F2 at GS 65	0.192 ± 0.1364	19.8	0.197

Green area index

The magnitude of the green area of the crop determines its capacity to intercept and provide light energy for production of biomass. A green area index of about 3 is needed to intercept most, i.e. 95%, of the incoming radiation. Early in the growing season, when GAI is less than 3, varieties with higher GAI will be able to intercept more light and therefore provide more energy for biomass production than those with lower GAI. In addition, varieties with higher GAI will reach the optimum GAI of 3 earlier than those with lower GAI and will therefore begin to fully intercept available light earlier. Where nitrogen is in short supply, varieties with high GAI would have an advantage over varieties with low GAI. In this project senescence of the canopy, which determines the capacity of the crop to continue light interception and biomass production at the end of the growing season, was not assessed.

GAI at GS 65 at F2 varied between **4.86** in Cadenza and **6.37** in Hunter (Table 4.20). Under the F0 treatment at GS 65, Cadenza again had the lowest value of **3.31** and Hunter, along with Mercia, the highest GAI of **3.9**. Mercia, Avalon and Longbow produced more green area without fertilizer than at F2, relative to other varieties. Haven and Rialto, on the other hand, produced less green area without fertilizer N, relative to other varieties.

Table 4.20. Green area index - mean of all site-years and Soil N treatments

	Early spring F0	GS 31 F0	GS 65 F0	GS 65 F2
Apollo	0.67	2.22	3.46	5.54
Avalon	0.61	2.36	3.83	5.25
Cadenza	0.52	2.01	3.31	4.86
Haven	0.55	1.88	3.65	6.05
Hereward	0.39	1.90	3.68	5.87
Hunter	0.63	2.20	3.89	6.37
Longbow	0.33	1.83	3.61	5.29
Mercia	0.62	2.32	3.92	5.71
Rialto	0.57	2.13	3.37	5.51
Riband	0.48	2.01	3.63	5.70

Based on the early spring and GS 31 assessments, Apollo, Avalon, Hunter and Mercia produced their green area earlier than other varieties while Hereward, Longbow and Riband were slower in producing their green area (Table 4.20).

More modern varieties were no better than older varieties in producing green area at any stage or in either treatment (Table 4.21).

Table 4.21. Relationships between GAI and variety age

Comparison of GAI with variety age at:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0			
Early spring	0.0033 ± 0.0812	2.0	0.70
GS 31	-0.008 ± 0.0138	4.2	0.57
GS 65	-0.019 ± 0.0142	17.9	0.22
F2			
GS65	0.028 ± 0.031	9.7	0.38

Production of GAI at GS 31 was strongly related to GAI in early spring (Table 4.22). There was poor correlation of GAI at GS 65 in both fertilizer treatments with GAI at GS 31.

Rapid production of green area, i.e. high GAI early in the life cycle, might be expected to lead to a high GAI at GS 65. Conversely slow production of green area, i.e. low GAI early in the life cycle, might be expected to be associated with low GAI at GS 65. In this group of varieties, both these types were found: early GA production was associated with high GAI at GS 65 in Hunter, Mercia, Cadenza and Riband, and late GA production was associated with low GAI at GS 65 in Longbow. However the counter-intuitive combination of early GA production with low GAI at GS 65 was found in Apollo and Avalon, and of late GA production with high GAI at GS 65 was found in Haven, Hereward and Riband.

Table 4.22. Relationships within the trait during the growing season

Comparison of GAI at:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0 at GS 31	F0 in early spring	1.42 ± 0.342	68.2	0.003
F0 at GS 65	F0 at GS 31	0.423 ± 0.364	14.4	0.279
F2 at GS 65	F0 at GS 31	-0.029 ± 0.810	0.16	0.972

Canopy nitrogen requirement

Canopy nitrogen requirement is the efficiency with which a crop utilises the nitrogen taken up in production of green area. Varieties with low CNR will produce more green area per g of nitrogen than those with high CNR and will therefore be able to produce more green area earlier with beneficial consequences for light interception and biomass production. Where nitrogen is in short supply, varieties with low CNR would have an advantage over varieties with high CNR.

In early spring more nitrogen was needed to produce green area than at GS 31 or, alternatively, canopy expansion was slower than N uptake in early spring than at GS 31 (Table 4.23). At F0 most varieties improved in their efficiency in using nitrogen to produce green area between GS 31 and GS 65, CNR decreasing over this period. At F2, the varieties were less efficient at using nitrogen to produce green area than at F0, the CNR being much higher, 3.48 to 4.39 g/m^2 at F2 compared with 2.07 to 3.02 g/m^2 at F0.

Table 4.23. Canopy nitrogen requirement (g/m^2) - mean of all site-years and Soil N treatments

	Early spring F0	GS 31 F0	GS 65 F0	GS 65 F2
Apollo	3.42	2.68	2.51	3.87
Avalon	3.36	2.76	2.50	3.65
Cadenza	3.80	3.07	3.02	4.39
Haven	3.51	2.95	2.50	3.53
Hereward	4.14	3.00	2.49	3.52
Hunter	3.38	2.78	2.07	3.48
Longbow	3.68	2.89	2.41	4.07
Mercia	3.27	2.61	2.48	3.55
Rialto	3.38	2.92	2.67	4.02
Riband	3.69	2.88	2.56	3.69

Cadenza had high CNR's relative to other varieties at all growth stages and at both F0 and F2 at GS 65. Hereward had a very high CNR relative to other varieties in early spring which declined at subsequent growth stages and was also low at F2 at GS 65 relative to other varieties. Longbow also had a high CNR coming out of the winter which declined subsequently but at F2 at GS 65, its CNR was high relative to other varieties. Hunter, Mercia and Avalon had low CNR relative to other varieties at all growth stages and also at F2 at GS 65. The CNR of Rialto and Apollo increased relative to other varieties during the season and, in these varieties, were highest at F2 at GS 65.

Modern varieties were no more efficient than older varieties at utilising nitrogen to produce green area at any growth stage with or without fertilizer nitrogen (Table 4.24).

Table 4.24. Relationships between CNR and variety age

Comparison of CNR with variety age at:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0			
Early spring	0.115 ± 0.01943	4.2	0.570
GS 31	0.0136 ± 0.00965	19.9	0.196
GS 65	0.0095 ± 0.01719	3.7	0.594
F2			
GS 65	0.0074 ± 0.02246	1.3	0.750

CNR of the varieties at GS 31 were strongly correlated with those in early spring but there was a much poorer correlation between CNR at GS 31 and GS 65 (Table 4.25). At F2 CNR of the varieties at GS 65 bore little relation to CNR at GS 31 at F0.

Table 4.25. Relationships within the trait during the growing season

Comparison of CNR at:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0 at GS 31	F0 in early spring	0.403 ±0.1289	54.9	0.014
F0 at GS 65	F0 at GS 31	0.827 ±0.4942	25.9	0.133
F2 at GS 65	F0 at GS 31	0.895 ±0.6702	18.2	0.219

Shoot numbers

Production of shoots is one process by which crops increase their green area, along with production of more and/or larger leaves. In low N environments varieties with higher shoot populations will produce their green area earlier and more rapidly than those with lower shoot populations. When nitrogen is more abundant varieties producing higher shoot populations will be at greater risk of lodging than those with lower shoot populations.

In this programme shoot number declined progressively from GS 31 to harvest. Therefore the GS 31 data are being taken as defining maximum shoot number. Shoot numbers at GS 31 at F0 are considered to be representative of the varieties when grown with fertilizer in the F2 treatment at this stage since little, i.e. 40 kg/ha, fertilizer N would have been applied to the F2 treatment before GS 31.

At GS 31, shoot numbers varied between **840** per m^2 in Cadenza and **1047** per m^2 in Haven (Table 4.26). At GS 65, shoot numbers at F0 had declined to between 409 shoots/m^2 in Riband and 510 shoots/m^2 in Mercia. At F2, the decrease in shoot numbers was much smaller than at F0, to between 509 shoots/m^2 in Longbow and 668 shoots/m^2 in Mercia. Cadenza lost less shoots than other varieties between GS 31 and GS 65 in both treatments, 396 shoots/m^2 at F0 and 203 shoots/m^2 at F2. Haven lost more shoots than other varieties between GS 31 and GS 65 in both treatments, 603 shoots/m^2 at F0 and 431 shoots/m^2 at F2.

Table 4.26. Shoot numbers per m^2 - mean of all site-years and Soil N treatments

	Early spring F0	GS 31 F0	GS 65 F0	Harvest F0	GS 65 F2	Harvest F2	% survival F0	% survival F2
Apollo	990	852	429	363	595	505	42.6	59.3
Avalon	920	867	414	352	524	475	40.6	54.8
Cadenza	798	840	444	396	637	513	47.1	61.1
Haven	1324	1047	444	395	616	505	37.7	48.3
Hereward	848	883	474	415	617	552	47.0	62.5
Hunter	1236	934	449	395	634	519	42.3	55.6
Longbow	877	849	412	345	509	457	40.6	53.9
Mercia	929	928	510	439	668	601	47.3	64.8
Rialto	1117	843	438	369	577	499	43.7	59.1
Riband	1067	1003	409	358	557	451	35.6	44.9

At both F0 and F2 shoot numbers continued to decline between GS 65 and harvest, decreases of between 48 and 71 shoots/m^2 in the F0 treatment and 49 and 124 shoots/m^2 in the F2 treatment being observed (Table 4.26). Therefore ear number at harvest in the F2 treatment is taken as defining final shoot number and as being most applicable to farming practice. Comparing this number with shoot number at GS 31 enabled % survival to be calculated.

At harvest at F2, ear number varied between **451** per m^2 in Riband and **601** per m^2 in Mercia (Table 4.26). At F0 at harvest, final shoot numbers varied between **345** per m^2 in Longbow and **439** per m^2 in Mercia. Most varieties behaved similarly in both treatments with the exception of Riband which had more ears at F0 than at F2 relative to other varieties and Apollo which had more ears at F2 than at F0 relative to other varieties.

Shoot survival at F2 varied between **45%** in Riband and **65%** in Mercia (Table 4.26). At F0 shoot survival varied between **36%** in Riband and **47%** in Cadenza, Hereward and Mercia. Most varieties behaved similarly in both treatments with the exception of Longbow in which shoot survival was greater at F0 than at F2 and Haven in which shoot survival at F2 than at F0 relative to other varieties.

At F2 at GS 65 more modern varieties tended to have more shoots present than older varieties (Table 4.27). At other times of measurement, however, more modern varieties were no more prolific in producing shoots than older varieties nor were their shoots any more likely to survive to become ears.

Table 4.27. Relationships between shoot number and variety age

Comparison of shoot numbers with variety age at:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0			
Early spring	12.6 ± 12.14	11.9	0.33
GS 31	1.35 ± 5.40	0.77	0.81
GS 65	1.91 ± 2.217	8.5	0.41
Harvest	2.62 ± 2.07	16.7	0.24
F2			
GS65	6.74 ± 3.019	38.4	0.056
Harvest	2.67 ± 3.193	8.1	0.43
Shoot survival			
F0	0.250 ± 0.285	8.8	0.41
F2	0.243 ± 0.461	3.3	0.61

Shoot production in the varieties at GS 31 was strongly dependent on their shoot production in early spring (Table 4.28). Shoot production of the varieties at GS 65 in both fertilizer treatments was not dependent on their shoot production at GS 31 in the F0 treatment. At harvest shoot numbers of the varieties both with and without fertilizer nitrogen were very strongly related to their shoot numbers at GS 65 but were not related to their shoot numbers at GS 31 in the F0 treatment.

As with green area it would be expected that varieties which have high shoot numbers early in the life cycle would continue to have high shoot numbers during the remainder of the growing season and *vice versa*. Both these types are found, Hunter had high and Longbow had low shoot numbers throughout their life cycle. However types were also found which did not behave in these ways. Haven, Rialto and Riband, which had high shoot numbers relative to other varieties early in the life cycle, had relatively low shoot numbers at harvest. Conversely Cadenza, Hereward and Mercia, which had low shoot numbers relative to other varieties early in the life cycle, had relatively high shoot numbers at harvest.

Table 4.28. Relationships within the trait during the growing season

Comparison of shoot numbers at:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0 at GS 31	F0 in early spring	0.289 ± 0.107	47.7	0.027
F0 at GS 65	F0 at GS 31	0.033 ± 0.151	0.5	0.83
F2 at GS 65	F0 at GS 31	0.158 ± 0.244	5.9	0.53
F0 harvest	F0 at GS 65	0.939 ± 0.097	92.1	<0.001
F2 harvest	F2 at GS 65	0.734 ± 0.163	71.7	0.002
F0 harvest	F0 at GS 31	0.097 ± 0.144	5.4	0.52
F2 harvest	F0 at GS 31	-0.0014±0.217	0.0005	0.99

Biomass

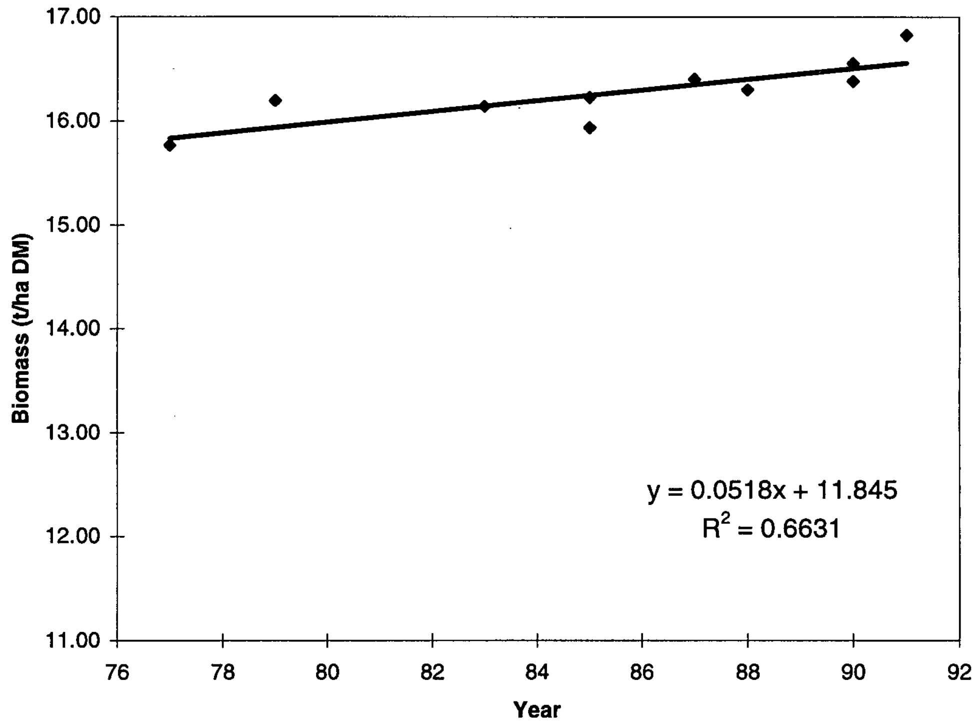
Biomass at harvest is the end result of the processes of expansion, duration and activity of the canopy in intercepting radiation and conversion of light energy to chemical energy in the form of dry matter.

At F2 at harvest biomass production of the ten varieties was very similar, ranging from **15.8**t/ha in Avalon to **16.8**t/ha in Rialto (Table 4.29). Compared with the range in other traits this variation in harvest biomass is small. Despite this, there was an age-related increase of 0.052 ±0.0131t/ha/year ($p = 0.004$, $R^2 = 66.3\%$) in biomass amongst the varieties (Figure 4.2).

Table 4.29. Biomass (t/ha DM) - mean of all site-years and Soil N treatments

	Early spring	GS 31	GS 65	Harvest	GS 65	Harvest
	F0	F0	F0	F0	F2	F2
Apollo	0.51	1.96	9.65	11.19	13.07	16.23
Avalon	0.65	2.22	9.64	11.56	11.84	15.77
Cadenza	0.66	2.00	9.81	11.84	13.34	16.56
Haven	0.67	1.99	9.94	12.12	14.05	16.40
Hereward	0.64	2.02	9.64	11.94	12.78	16.30
Hunter	0.64	2.10	9.71	12.23	13.50	16.38
Longbow	0.58	1.85	9.07	11.40	12.30	16.20
Mercia	0.65	2.10	9.75	12.04	12.11	16.14
Rialto	0.72	2.26	10.54	12.50	14.17	16.83
Riband	0.62	1.87	9.00	11.78	12.73	15.93
s.e. (variety x FN)				0.219		0.219
Sig. (variety x FN)				<0.001		<0.001
CV%				9.1		9.1

Figure 4.2
Biomass at harvest at F2 v Year of first harvest in NL trials



Biomass at F0 at harvest was on average 3.4 t/ha less in all varieties than in the F2 treatment (Table 4.29). Apollo had the smallest biomass of **11.2** t/ha and Rialto the highest of **12.5** t/ha, again a relatively small range. The differences between the varieties were again age-related although less strongly so than in the F2 treatment. A similar increase in biomass to that at F2 of 0.056 ±0.0221 t/ha/year ($p = 0.036$, $R^2 = 44.3\%$) was obtained.

Compared with traits discussed previously the varieties did not behave in so similar a way in the F0 and F2 treatments at harvest. Apollo and Cadenza both had much higher biomass production at F2 than at F0 relative to other varieties while Mercia produced more biomass at F0 than at F2 relative to other varieties.

On average 3 t/ha dry matter were produced by all varieties between GS 65 and harvest at F2 (Table 4.29). The variation amongst the varieties at F2 was much greater at GS 65 than at harvest. At GS 65 Avalon had the smallest biomass of **11.8** t/ha and Rialto the largest of **14.2** t/ha. Some of this variation may be attributable to the date on which biomass at GS 65 was determined, which depended on development.

On average almost 8t/ha dry matter were produced by all varieties between GS 31 and GS 65 at F0 (Table 4.29). At GS 31 Longbow had the smallest biomass of **1.9** t/ha and Rialto the largest of **2.3** t/ha.

The biomasses of the varieties at later stages in the growing season were strongly related to their age, particularly when fertilizer nitrogen was applied (Table 4.30).

Table 4.30. Relationships between biomass and variety age

Comparison of biomass with variety age at:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0			
Early spring	0.0046 ± 0.00388	15.2	0.266
GS 31	0.0043 ± 0.01000	2.2	0.681
GS 65	0.051 ± 0.0267	31.3	0.093
Harvest	0.056 ± 0.0221	44.3	0.036
F2			
GS65	0.140 ± 0.0324	69.8	0.003
Harvest	0.052 ± 0.0131	66.3	0.004

As with GAI and shoot production, biomass of the varieties at GS 31 was dependent on their biomass production in early spring (Table 4.31). Biomass of the varieties at F0 but not at F2 at GS 65 was strongly dependent on their biomass production at GS 31 at F0. At harvest biomass of the varieties in both fertilizer treatments was strongly dependent on their biomass in the corresponding treatments at GS 65.

Some of the varieties behaved consistently from growth stage to growth stage, namely Rialto, which had high biomass production relative to other varieties, and Apollo, Longbow and Riband, which had low biomass production relative to other varieties throughout the growing season. However other varieties, such as Avalon, had high biomass production at GS 31 but at harvest had low biomass production relative to other varieties.

Table 4.31. Relationships within the trait during the growing season

Comparison of biomass at:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
F0 at GS 31	F0 in early spring	1.50 ± 0.662	39.2	0.053
F0 at GS 65	F0 at GS 31	2.47 ± 0.715	59.8	0.009
F2 at GS 65	F0 at GS 31	0.83 ± 2.044	2.0	0.690
F2 at GS 65	F0 in early spring	5.24 ± 4.597	13.9	0.287
F0 harvest	F0 at GS 65	0.60 ± 0.246	42.6	0.041
F2 harvest	F2 at GS 65	0.32 ± 0.075	69.2	0.003

Harvest index

Varieties in which a higher proportion of the biomass is partitioned to the grain, i.e. those with higher harvest indices, will perform better than varieties with low harvest indices in low N environments where biomass production is poor.

At F2 harvest index varied between **46.9%** in Avalon and Hereward and **50.6%** in Riband (Table 4.32). Variation in harvest index amongst the varieties at F2 was not related to their age (regression coefficient = +0.017 ±0.0975%/year, p = 0.87, R^2 = 0.4%).

Table 4.32. Harvest index (%) - mean of all site-years (excluding Harper Adams 1993-4) and Soil N treatments

	F2		F0
Apollo	47.9		47.6
Avalon	46.9		45.5
Cadenza	47.1		45.4
Haven	49.7		48.4
Hereward	46.9		45.7
Hunter	48.9		47.6
Longbow	49.2		49.2
Mercia	47.3		47.4
Rialto	48.2		47.0
Riband	50.6		50.2
s.e. (variety x FN)		0.034	
Sig. (variety x FN)		<0.001	
CV%		4.6	

At F0 harvest indices were on average about 1% lower than at F2 (Table 4.32). Apollo, Longbow, Mercia and Riband had very similar harvest indices in the two treatments while those of the other varieties were 1.2-1.7% lower at F0. As at F2, variation in harvest index amongst the varieties at F0 was not related to their age (regression coefficient = -0.055 ±0.1185%/year, p = 0.66, R^2 = 2.6%).

Nitrogen harvest index

The efficiency with which nitrogen taken up by the crop is partitioned to the grain, nitrogen harvest index (NHI), will, in part, determine the %N in the grain which affects its marketability. In bread wheats, varieties with high NHI will be more likely to produce grain with acceptable %N than those with low NHI.

At F2 nitrogen harvest index varied between **72.7%** in Avalon and **75.4%** in Apollo (Table 4.33). There was a strong age-related increase in NHI in more modern varieties (regression coefficient = 0.133 ±0.0410%/year, p = 0.012, R^2 = 56.8%). At F0 nitrogen harvest index was higher in most varieties than at F2, ranging between **73.6%** in Hunter and **76.6%** in Riband. Unlike at F2 variation in NHI amongst the varieties was not related to their age (regression coefficient = -0.080 ±0.0637%/year, p = 0.25, R^2 = 16.4%). Thus modern varieties appear to be more efficient at partitioning nitrogen to the grain than older varieties when nitrogen is readily available. Nitrogen Harvest Index appears to be a very conservative trait. Relative to the means of the varieties, variation amongst the varieties at both F0 and F2 was much smaller than variation in any other trait.

Table 4.33. Nitrogen harvest index (%) - mean of all site-years and Soil N treatments

	F2		F0
Apollo	75.4		76.2
Avalon	72.7		75.4
Cadenza	74.7		75.0
Haven	75.0		74.2
Hereward	74.0		74.3
Hunter	75.2		73.6
Longbow	73.9		74.7
Mercia	73.5		75.0
Rialto	74.9		74.3
Riband	74.5		76.6
s.e. (variety x FN)		0.057	
Sig. (variety x FN)		<0.001	
CV%		4.4	

Conclusions

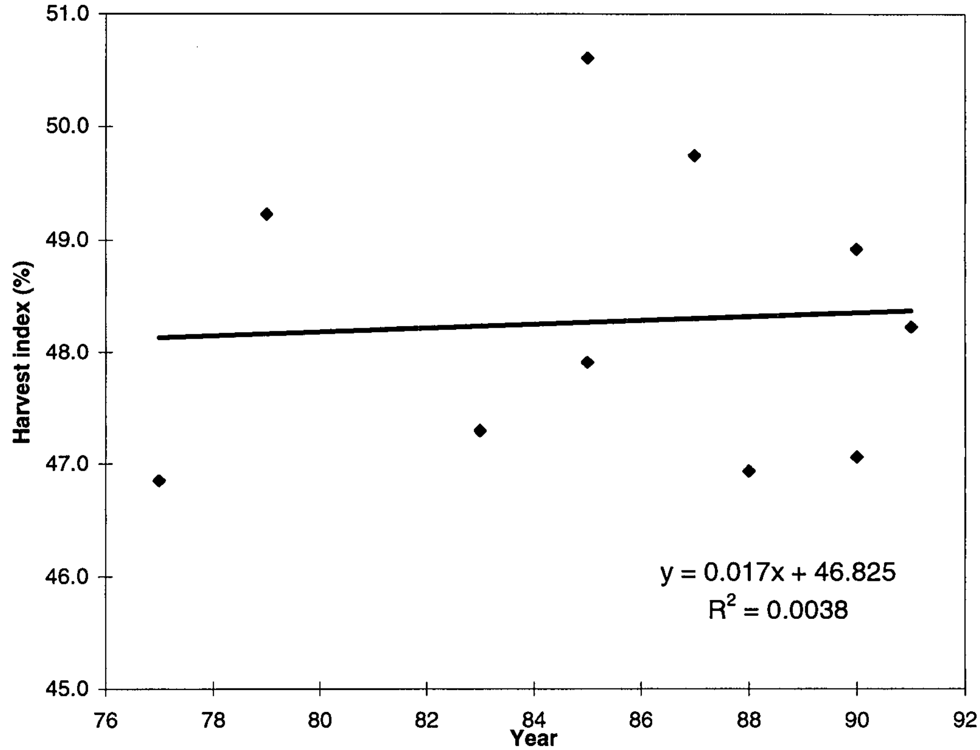
Age-related effects

- Age-related variation amongst the varieties was evident in grain yield and in NHI at F2 but not at F0, in biomass at GS 65 at F2 but not at F0 and at harvest in both F0 and F2. However age-related variation amongst the varieties was not observed in biomass in early spring or at GS 31, in green area index, CNR, shoot production, shoot survival or in harvest index.

- Austin *et al.* (1980) concluded that yield improvement in winter wheat varieties introduced during the first eighty years of the 20th century was mainly attributable to greater harvest index. However in a more recent paper, Austin *et al.* (1989) included varieties introduced during the 1980's. Unfortunately none of the varieties in Austin *et al.*'s programme were included in this programme, but the most modern were of a very similar vintage to Longbow. Grain yields, biomass production and harvest indices reported in both papers were similar to those in this programme. Austin *et al.* (1989) found that biomass of the modern varieties was only significantly greater than that of older varieties in a high-yielding year, on average biomass of varieties of all ages was similar.

  In the set of ten varieties introduced over the period 1977 to 1991 included in this programme the increase in grain yield of 40 kg/ha/year (Figure 4.1) was similar to that of 38 kg/ha/year calculated by Austin *et al.* (1989). An increase in biomass of 52 kg/ha/year (p = 0.004) in this set of ten varieties was found (Figure 4.2). However variation in harvest index showed no age-related increase (Figure 4.3).

Figure 4.3
Harvest index at F2 v Year of first harvest in NL trials



The mechanism by which yields of winter wheat varieties improved up until 1980 was harvest index. However the results in this programme indicate that in varieties introduced since 1980 harvest index did not contribute to yield increases but rather that biomass accounted for yield improvement.

- Biomass of the varieties at F2 was age-related both at GS 65 and at harvest. In addition their biomass at harvest and at GS 65 were correlated in both fertilizer treatments. Therefore it would appear that differences in biomass at harvest were determined at or before GS 65. When no fertilizer N was applied in the F0 treatment, biomass of the varieties at GS 65 was correlated with their biomass at GS 31 and in early spring. However when fertilizer N was applied, there were no correlations between biomass of the varieties in early spring and at GS 31 with their biomass at GS 65. Therefore the effect of fertilizer N on growth during stem elongation over-rode earlier differences in biomass production amongst the varieties and determined the age-related variation in biomass found at GS 65 which was sustained at harvest and influenced their grain yield.

Variation in the traits

- Varieties differed in their expressions of all the traits. Ranges in values amongst the varieties at all growth stages were usually at least 10% of the mean of all varieties at each growth stage.
- The varieties tended to be more variable earlier in the life cycle than later.
- Variation amongst the varieties at F2 was similar to that in the F0 treatment across all traits.

- There were significant correlations in N uptake, GAI, CNR, shoot number and biomass of the varieties between GS 31 and early spring.
- However neither GAI, CNR nor shoot numbers of the varieties at GS 65 were correlated with those at GS 31. Biomass and N uptake of the varieties at F0 at GS 65 was significantly correlated with their biomass and N uptake at GS 31 but at F2 there were no correlations between the expressions of these traits at GS 65 with their expressions at earlier stages in the life cycle.
- Shoot numbers and biomass of the varieties at both F0 and F2 at harvest were significantly correlated with their magnitudes at GS 65. However N uptake of the varieties at harvest was not related to their N uptake at GS 65 in either treatment.

- At growth stages other than harvest many of the traits were assessed over a period of about two weeks. Unlike at harvest, when the rate of change of many of the traits is minimal if not zero, at other growth stages the traits will be changing rapidly. Thus although traits were assessed as nearly as possible at the same growth stage, some of the variation between varieties may be attributable to the date on which the assessment was conducted.

- For many of the traits ranking of the varieties changed significantly between GS 31 and GS 65 whereas there was greater similarity of ranking amongst the varieties between early spring and GS 31 and between GS 65 and harvest. Since the period between GS 31 and GS 65 is most significant for growth and productivity of the crop, prediction of the crop status at GS 65 is of greatest value. Results from this programme suggest that it is not possible to predict crop status of individual varieties at GS 65 from their status at GS 31.

- If certain expressions of the traits are deemed to be desirable, it is possible to choose varieties with these expressions. However since location, fertilizer treatment and growth stage influence expression of the traits, careful consideration has to be given to assessment of the traits, in particular, the number of trials required, the management involved and the growth stage when the trait is to be assessed.

Variety differences

- Rialto produced the highest yields both with and without fertilizer. Its superior performance is associated with high N uptake and biomass production throughout the growing season, GAI, CNR and shoot production being average compared with other varieties.

- Avalon gave the lowest yields both with and without fertilizer. There was no indication from its expressions of the traits during most of the growing season that it would produce lower yields than other varieties. It was only at GS 65 and at harvest that its biomass production was lower compared with other varieties at F2, its biomass at F0 being average.

- Mercia produced higher grain yields relative to other varieties under lower fertility conditions than under high fertility conditions. GAI at GS 65 and N uptake and biomass at harvest were lower at F2 than at F0 in Mercia relative to other varieties. Mercia stood out because survival of its shoots was greater than in other varieties so that it had highest shoot populations in both fertilizer treatments at GS 65 and at harvest. Such high shoot populations may have been a disadvantage at high fertilizer N levels but an advantage at low fertilizer N levels.

- Apollo performed better relative to other varieties at higher than at lower fertility. Its shoot production was better at F2 than at F0 relative to other varieties. Thus high shoot populations at F2 were not disadvantageous in Apollo, although they were much lower than those of Mercia. Biomass production in Apollo was poorer at F0 relative to other varieties. There was no apparent reason for this when its expressions of the traits were compared with those of other varieties.

4.4. Varietal Type

Having considered the variation amongst varieties in their expression of various traits, it is then possible to combine expressions of traits to define types of varieties. The extent to which numbers of types proliferate depends on how expressions of the traits are categorised. If a trait varies and is categorised on a quantitative scale, then potentially, a very large number of types is possible. If such a scale is simplified and actual expressions are grouped into classes, which may still be quantitative, then a more limited number of types is created. For example, yield can vary limitlessly over a very wide range of values so, depending on the level of precision required, the number of classes into which yield can be divided can be large or small. Thus we may simplify the scale by, for example, expressing yield as a percentage relative to some control which effectively creates classes with intervals of 1%. On the 1997 UK Recommended List (Anon., 1995-6), a class interval of 1% on the winter wheat List was equivalent to 100 kg/ha and there were 15 classes for yield between 90 and 104% of the mean yield. Alternatively, we may choose to categorise varieties into low, intermediate and high-yielding. Some traits may only be expressed in a few ways and therefore only a few types are possible. For example, endosperm texture in wheat is either hard or soft so there are only two types of wheat possible based on this trait, hard- and soft-milling types.

The numbers of types therefore depends on: the number of traits and the number of classes into which each trait is categorised. The range of expressions of individual traits may limit the number of types of varieties which may be determined. It is more likely, however, that subjective categorisation of the expressions of traits will determine the range of types.

In this programme we have identified six traits which contribute to the influence of nitrogen availability on crop performance in terms of its grain yield, namely N uptake, GAI, CNR, shoot production, biomass production and harvest index. All these traits have been assessed quantitatively and therefore, potentially, each variety has a unique expression for each trait. Therefore with ten varieties there may be ten types for each trait. With six traits and, at the simplest two expressions of each trait, 2^6, i.e. 64, types are theoretically possible. With ten expressions of each trait, 10^6, i.e. one million variety types would be possible.

4.4.1. Combining expressions of traits to identify variety types

The expressions of all traits are considered together at each growth stage to determine if expressions of traits are combined in particular ways.

In the earlier part of the life cycle, green area is likely to be associated with the number of shoots produced, varieties with more shoots having higher GAI. Since a GAI of about 5 is needed to intercept most of the incoming radiation, magnitudes of GAI's less than 5 will have a critical effect on the capacity of the crop to intercept light and produce biomass. Therefore it might be expected that biomass would be associated with green area, varieties with higher GAIs having higher biomasses.

Expressions of the traits for all varieties in early spring and at GS 31 were examined to see if these combinations were found.

Early spring F0

Rialto was at one end of the range of types identified from the early spring results, having high expressions of all traits relative to other varieties (Table 4.34). It had taken up more nitrogen from the soil over the winter months and had produced one of the highest shoot populations amongst the varieties. Although its GAI was intermediate, it had the highest biomass at this stage. At the other end of the range of types, Longbow had low expressions of all traits relative to the other varieties. It had taken up less nitrogen from the soil over the winter months and had produced fewer shoots. Its GAI and biomass were low relative to most other varieties.

Table 4.34. Varietal traits in early spring

	N uptake	Shoot number	GAI	Biomass
Apollo	23.8	990	0.67	0.51
Avalon	28.4	920	0.61	0.65
Cadenza	27.0	798	0.52	0.66
Haven	28.9	1324	0.55	0.67
Hereward	27.3	848	0.39	0.64
Hunter	27.3	1236	0.63	0.64
Longbow	25.2	877	0.33	0.58
Mercia	28.1	929	0.62	0.65
Rialto	31.3	1117	0.57	0.72
Riband	27.5	1067	0.48	0.62

Other combinations of expressions of traits were also found. For example, Cadenza, Haven, Hunter and Riband had similar uptakes of nitrogen, but Haven and Hunter both produced very high shoot populations whereas shoot numbers in Riband were intermediate and those in Cadenza were very low. Hunter had a high GAI relative both to these and the other varieties, yet biomass in all four varieties was very similar. Apollo had an unexpected combination of expressions of traits, having a low nitrogen uptake, a high GAI and a low biomass.

This variation in the combinations of expressions of the traits from variety to variety accounts for the poor correlation between the traits at this growth stage (Table 4.35). Biomass and N uptake were significantly correlated ($p<0.001$), with biomass increasing by 26 kg/ha for each additional kg/ha nitrogen taken up. However this increase in biomass was not associated with increases in either GAI or shoot number at this stage.

Table 4.35. Relationships between traits in early spring

Comparison of:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
Shoot number	N uptake	32.3 ± 27.92	14.3	0.28
GAI	Shoot number	$2.4\text{x}10^{-4} \pm 2.07\text{x}10^{-4}$	14.3	0.28
Biomass	GAI	0.0048 ± 0.1816	0.009	0.98
Biomass	Shoot number	$8.0\text{x}10^{-5} \pm 11.2\text{x}10^{-5}$	6.1	0.49
Biomass	N uptake	0.026 ± 0.0032	89.5	<0.001
GAI	N uptake	0.0071 ± 0.0190	1.73	0.72

GS 31 F0

At GS 31, Longbow behaved in the same way as earlier in the spring in having low expressions of all traits relative to other varieties (Table 4.36). However Rialto, although it continued to have a very high nitrogen uptake, had lost more shoots than other varieties to have one of the lowest shoot populations at GS 31. Its GAI was intermediate but it continued to have the highest biomass of the varieties. At GS 31 Haven had a lower nitrogen uptake than Cadenza and Hunter, which it was similar to in early spring, but it still produced the highest shoot population of all the varieties. The GAI of Haven was one of the lowest amongst the varieties but its biomass was intermediate. Other unexpected combinations of traits were found. Mercia, which had intermediate N uptake and shoot numbers relative to other varieties, had high GAI and high biomass. Avalon, with high N uptake but low shoot numbers, had high GAI and biomass relative to other varieties.

Table 4.36. Varietal traits at GS 31

	N uptake	**Shoot number**	**GAI**	**Biomass**
Apollo	54.7	852	2.22	1.96
Avalon	59.0	867	2.36	2.22
Cadenza	56.1	840	2.01	2.00
Haven	53.3	1047	1.88	1.99
Hereward	56.2	883	1.90	2.02
Hunter	56.1	934	2.20	2.10
Longbow	52.1	849	1.83	1.85
Mercia	56.9	928	2.32	2.10
Rialto	60.3	843	2.13	2.26
Riband	54.2	1003	2.01	1.87

Varieties with greater N uptake produced more GAI, GAI increasing by 0.0486 units per kg/ha increase in N uptake (p=0.044) (Table 4.37). Varieties with more GAI tended to produce more biomass, biomass increasing by 0.77 t/ha per unit increase in GAI (p= 0.064). There was a tendency for biomass to increase as N uptake increased but, unlike in early spring, the increase of 35 kg/ha in biomass per kg/ha N taken up was not significant.

Table 4.37. Relationships between traits at GS 31

Comparison of:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
Shoot number	N uptake	4.84 ± 6.080	7.35	0.45
GAI	Shoot number	0.0013 ± 0.0014	9.09	0.40
Biomass	GAI	0.767 ± 0.356	36.7	0.064
Biomass	Shoot number	$8.49 \times 10^{-4} \pm 18.67 \times 10^{-4}$	2.52	0.66
Biomass	N uptake	0.035 ± 0.0314	13.8	0.29
GAI	N uptake	0.0486 ± 0.0204	41.5	0.044

GS 65

Later in the life cycle shoot survival may reflect GAI, in that greater capacity for intercepting light and producing dry matter will increase the growth of the shoots and therefore the likelihood of their survival.

F0

At GS 65 in the F0 treatment, Rialto continued to have a high N uptake and quite a low shoot number relative to other varieties (Table 4.38). Its GAI was relatively low yet its biomass was the highest relative to other varieties. Longbow still had quite a low N uptake and a low shoot number compared to other varieties. Despite having a relatively high GAI, biomass of Longbow was one of the lowest. Cadenza, Haven and Hunter had similar N uptakes and shoot numbers, yet Cadenza had the lowest GAI and Hunter one of the highest GAI's and their biomasses were similar. Mercia, with an intermediate N uptake, had the highest shoot population and GAI yet its biomass was intermediate. Avalon, with a high N uptake, had almost 100 less shoots per m^2 than Mercia but a similar GAI and biomass.

Table 4.38. Varietal traits at GS 65 at F0

	N uptake	Shoot number	GAI	Biomass
Apollo	103.7	429	3.46	9.65
Avalon	111.9	414	3.83	9.64
Cadenza	105.4	444	3.31	9.81
Haven	104.8	444	3.65	9.94
Hereward	109.0	474	3.68	9.64
Hunter	101.2	449	3.89	9.71
Longbow	104.8	412	3.61	9.07
Mercia	109.0	510	3.92	9.75
Rialto	113.2	438	3.37	10.54
Riband	107.4	409	3.63	9.00
Range	*12.0*	*101*	*0.61*	*1.54*

When regression analyses were conducted, the traits were not found to be associated with one another (Table 4.39).

GS 65 F2

In the F2 treatment at GS 65, Rialto behaved in a very similar way relative to other varieties to its behaviour in the F0 treatment, having a high N uptake, intermediate shoot population, low GAI and high biomass (Table 4.40). Longbow had an intermediate N uptake, a low shoot population and a low GAI relative to other varieties, yet produced an intermediate biomass. Haven and Hunter both had high N uptakes whilst Cadenza had a low N uptake, yet shoot populations were similar in all three varieties. GAI's were low in Cadenza, high in Haven and very high in Hunter relative to other varieties but biomasses were similar in Cadenza and Hunter and high in Haven. Avalon had one of the lowest N uptakes in contrast to its N uptake in the F0 treatment and its shoot population, GAI and biomass were also low relative to other varieties. Mercia, like Avalon, had a low N uptake and a low biomass but its shoot population and GAI were relatively high.

Table 4.39. Relationships between traits at GS 65 at F0

Comparison of:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
Shoot number	N uptake	0.670 ± 2.906	0.66	0.82
GAI	Shoot number	0.0024 ± 0.00223	12.7	0.31
Biomass	GAI	-0.570 ± 0.6994	7.66	0.44
Biomass	Shoot number	0.0050 ±0.0046	13.0	0.31
Biomass	N uptake	0.0425 ± 0.03757	13.8	0.29
GAI	N uptake	-0.0031 ± 0.01963	0.30	0.88

Table 4.40. Varietal traits at GS 65 at F2

	N uptake	**Shoot number**	**GAI**	**Biomass**
Apollo	231.7	595	5.54	13.07
Avalon	211.2	524	5.25	11.84
Cadenza	225.0	637	4.86	13.34
Haven	250.0	616	6.05	14.05
Hereward	235.7	617	5.87	12.78
Hunter	257.3	634	6.37	13.50
Longbow	238.0	509	5.29	12.30
Mercia	227.4	668	5.71	12.11
Rialto	250.8	577	5.51	14.17
Riband	224.3	557	5.70	12.73
Range	*46.1*	*159*	*1.51*	*2.33*

In contrast to the F0 treatment where there were no significant correlations between the traits, some traits were associated at F2 at GS 65 (Table 4.41). Much smaller ranges of variation in each trait at F0 than at F2 may have made identification of associations between traits more difficult statistically. At F2 biomass of the varieties was significantly correlated (p=0.11) with N uptake, increasing by 42 kg/ha for every additional kg/ha N taken up. GAI of the varieties also increased significantly (p=0.043) by 0.0195 units per kg/ha increase in N uptake.

Table 4.41. Relationships between traits at GS 65 at F2

Comparison of:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
Shoot number	N uptake	0.973 ± 1.2252	7.31	0.45
GAI	Shoot number	0.0030 ± 0.00276	13.1	0.30
Biomass	GAI	0.562 ± 0.6163	9.42	0.39
Biomass	Shoot number	0.0050 ± 0.00514	10.4	0.36
Biomass	N uptake	0.0419 ± 0.00127	57.6	0.011
GAI	N uptake	0.0195 ± 0.00813	41.9	0.043

Harvest

Biomass at harvest would be expected to be associated with N uptake because of associations between these two traits at earlier growth stages. Harvest index might be expected to decrease as ear number increases because of greater competition at higher ear populations and/or because the higher order tillers contributing to higher ear numbers (seed populations having been similar) would be less efficient at partitioning dry matter to their ears.

F0

Rialto with the highest N uptake at F0 at harvest had the highest biomass, but its ear numbers were low relative to other varieties (Table 4.42). Although its harvest index was only average, its yield was the highest of the varieties. Haven, Hereward and Hunter had similar N uptakes, similar ear numbers and similar biomasses. However their harvest indices differed more widely and consequently their yields varied across the range found amongst all the varieties. Longbow had a low N uptake, a low ear number and a low biomass but efficient partitioning of its dry matter resulted in an average yield. Mercia, whose N uptake was intermediate, had higher ear numbers than other varieties and a high biomass yet its yields were average, not dissimilar from those of Longbow, because of its lower harvest index.

Table 4.42. Varietal traits at harvest at F0

	N uptake	Ear number	Biomass	Harvest index	Yield
Apollo	110.1	363	11.19	47.6	5.47
Avalon	116.2	352	11.56	45.5	5.38
Cadenza	112.7	396	11.84	45.4	5.52
Haven	119.9	395	12.12	48.4	6.04
Hereward	119.5	415	11.94	45.7	5.57
Hunter	119.4	395	12.23	47.6	5.83
Longbow	109.5	345	11.40	49.2	5.64
Mercia	117.9	439	12.04	47.4	5.76
Rialto	125.0	369	12.50	47.0	6.12
Riband	114.0	358	11.78	50.2	5.99

Biomass of the varieties at F0 at harvest was strongly correlated ($p<0.001$) with N uptake, increasing by 74 kg/ha per kg/ha N taken up, in agreement with trends earlier in the life cycle (Table 4.43). Yield was also associated with N uptake, although not significantly so ($p=0.066$), increasing by 32 kg/ha per kg/ha N taken up. Increases in yield of the varieties without fertilizer nitrogen were strongly associated with increases in their biomass ($p=0.018$) but only weakly associated with increased harvest index ($p=0.096$).

Table 4.43. Relationships between traits at harvest at F0

Comparison of:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
Ear number	N uptake	2.558 ± 1.9998	17.0	0.24
Biomass	Ear number	0.00645 ± 0.004023	24.3	0.15
Yield	Biomass	0.471 ± 0.1581	52.6	0.018
Yield	Harvest index	0.0896 ± 0.0475	30.8	0.096
Biomass	N uptake	0.074 ± 0.0120	82.4	<0.001
Yield	N uptake	0.032 ± 0.0149	36.0	0.066
Yield	Ear number	0.00076 ± 0.002991	0.8	0.81
Harvest index	N uptake	-0.081 ± 0.1119	6.1	0.49
Harvest index	Ear number	-0.017 ± 0.0176	11.0	0.35
Harvest index	Biomass	-0.450 ± 1.4133	1.2	0.76

Harvest F2

Rialto had a high N uptake and low ear numbers at F2 at harvest (Table 4.44). Its biomass was higher than that of other varieties and although its harvest index was average it produced the highest grain yield. Hunter also had a high N uptake and low ear numbers but its biomass was lower than that of Rialto and although Hunter had a higher harvest index, its yield was also lower. Hereward with a lower N uptake than Hunter produced more ears but a similar biomass. A low harvest index resulted in its yields being at the bottom end of the range amongst the varieties. Haven had a much lower N uptake and lower ear numbers than either Hereward or Hunter, yet its biomass was similar. A high harvest index resulted in it having the second highest yield amongst the varieties. Longbow with a low N uptake had few ears and a low biomass. However efficient partitioning of its biomass resulted in average yields for Longbow. Mercia had a similar N uptake to Longbow but had more ears than any other variety. Its biomass was similar to that of Longbow but inefficient partitioning resulted in its yields being lower. Despite having a high N uptake, Avalon produced less biomass than other varieties and, with inefficient partitioning, produced the lowest yields.

Table 4.44. Varietal traits at harvest at F2

	N uptake	**Ear number**	**Biomass**	**Harvest index**	**Yield**
Apollo	214.9	505	16.23	47.9	8.41
Avalon	220.1	475	15.77	46.9	7.91
Cadenza	219.5	513	16.56	47.1	8.39
Haven	215.1	505	16.40	49.7	8.79
Hereward	221.9	552	16.30	46.9	8.22
Hunter	227.9	519	16.38	48.9	8.69
Longbow	210.7	457	16.20	49.2	8.42
Mercia	214.3	601	16.14	47.3	8.20
Rialto	226.7	499	16.83	48.2	8.87
Riband	210.3	451	15.93	50.6	8.64

Yield was strongly correlated with both biomass (p=0.043) and harvest index (p=0.025), increasing by 0.64 t/ha per 1t/ha increase in biomass and by 0.16 t/ha per unit increase in harvest index (Table 4.45). Neither yield nor biomass were significantly correlated with N uptake as they were at F0. Harvest index was weakly associated with ear number (p=0.094), decreasing by 0.16% per increment of 10 ears/m^2.

Table 4.45. Relationships between traits at harvest at F2

Comparison of:	with:	Regression coefficient	Coefficient of determination (R^2) (%)	Significance of relationship (%)
Ear number	N uptake	1.843 ± 2.4727	6.5	0.48
Biomass	Ear number	0.0015 ± 0.00234	4.7	0.55
Yield	Biomass	0.641 ± 0.2664	41.9	0.043
Yield	Harvest index	0.161 ± 0.0587	48.5	0.025
Biomass	N uptake	0.026 ± 0.0147	28.0	0.12
Yield	N uptake	0.008 ± 0.0169	2.7	0.65
Yield	Ear number	-0.0015 ± 0.0023	5.2	0.53
Harvest index	N uptake	-0.084 ± 0.0680	16.0	0.25
Harvest index	Ear number	-0.016 ± 0.0085	31.0	0.094
Harvest index	Biomass	-0.240 ± 1.5101	0.3	0.88

Where varieties had higher N uptake, GAI also increased on some occasions (GS 31 and GS 65 at F2) and biomass often increased (early spring, GS 31, GS 65 at F2 and at F0 at harvest. However increases in GAI amongst the varieties were only associated with increased biomass on one occasion (GS 31). At harvest yield of the varieties without fertilizer was greater in those varieties with higher N uptakes. Yield in both fertilizer N treatments was strongly associated with biomass of the varieties. Increases in harvest index contributed to increased yield of the varieties at F2 but not at F0.

Thus, in general, varieties with greater N uptake had higher biomass production which in turn led to their grain yields being higher, particularly where no fertilizer had been applied.

4.4.2. Bread v feed types

Expressions of traits in the bread-making varieties: Avalon, Cadenza, Hereward, Mercia and Rialto, were compared with those of the feed varieties: Apollo, Haven, Hunter, Longbow and Riband (Tables 4.46 - 4.51). Bread varieties are generally expected to have lower yields and higher grain N% than feed varieties.

Table 4.46. N uptake (kg/ha) in bread and feed varieties

	Bread	Feed	s.e.	Sig.
F0				
Early spring	28.4	26.5	0.84	0.15
GS 31	**57.7**	**54.1**	**0.76**	**0.010**
GS 65	**109.7**	**104.4**	**1.19**	**0.013**
Harvest	118.2	114.6	2.12	0.26
F2				
GS 65	230.0	240.3	6.26	0.28
Harvest	220.5	215.8	2.66	0.25

Table 4.47. Green area index in bread and feed varieties

	Bread	Feed	s.e.	Sig.
F0				
Early spring	0.54	0.53	0.052	0.90
GS 31	2.14	2.03	0.084	0.36
GS 65	3.62	3.65	0.099	0.86
F2				
GS 65	5.44	5.79	0.184	0.22

Table 4.48. Canopy nitrogen requirement (g/m^2) in bread and feed varieties

	Bread	Feed	s.e.	Sig.
F0				
Early spring	3.59	3.54	0.125	0.77
GS 31	2.87	2.87	0.068	0.72
GS 65	2.63	2.41	0.096	0.14
F2				
GS 65	3.83	3.73	0.141	0.64

Table 4.49. Shoot numbers per m^2 in bread and feed varieties

	Bread	Feed	s.e.	Sig.
F0				
Early spring	922.4	1098.8	69.0	0.11
GS 31	872.1	937.0	30.2	0.17
GS 65	455.7	428.6	13.02	0.18
Harvest	394.1	371.2	13.15	0.25
F2				
GS 65	604.6	582.2	23.7	0.52
Harvest	527.9	487.5	18.5	0.16
% survival				
F0	45.2	39.8	N/A	N/A
F2	60.5	52.4	N/A	N/A

Table 4.50. Biomass (t/ha) in bread and feed varieties

	Bread	Feed	s.e.	Sig.
F0				
Early spring	0.664	0.604	0.020	0.09
GS 31	**2.120**	**1.954**	**0.487**	**0.043**
GS 65	9.88	9.47	0.178	0.15
Harvest	11.98	11.75	0.179	0.39
F2				
GS 65	12.85	13.13	0.367	0.60
Harvest	16.32	16.23	0.141	0.66

Table 4.51. Harvest in bread and feed varieties

	Bread	Feed	s.e.	Sig.
F0				
Grain yield (t/ha at 85%DM)	5.67	5.79	0.118	0.48
Harvest index (%)	**46.2**	**48.6**	**0.46**	**0.006**
Nitrogen harvest index (%)	74.8	75.1	0.44	0.69
Grain N%	1.73	1.64	N/A	N/A
F2				
Grain yield (t/ha at 85%DM)	8.32	8.59	0.124	0.16
Harvest index (%)	**47.3**	**49.3**	**0.36**	**0.005**
Nitrogen harvest index (%)	74.0	74.8	0.34	0.12
Grain N%	2.23	2.14	N/A	N/A

Bread and feed varieties were similar for most traits on most occasions during the growing season. N uptakes at F0 at GS 31 and GS 65 were significantly higher in the bread than in the feed varieties. At GS 31 biomass of the bread varieties at F0 was also significantly higher than that of the feed varieties. Feed varieties were significantly better than bread varieties at partitioning their biomass into the grain at harvest both with and without fertilizer. These higher harvest indices would account for higher yields in feed than in bread varieties. Since N uptakes and nitrogen harvest indices were similar in the bread and feed varieties, lower N% in feed than in bread varieties can be attributed to dilution of the nitrogen in the grain by the increased amount of carbohydrate partitioned to the grain.

Implications for crop management

Bread varieties are currently managed to maximise protein, i.e. N content of the grain and yield. There is no evidence from these experiments to suggest that this needs to be altered.

Implications for breeding

Bread varieties are less efficient than feed varieties at partitioning biomass to the grain. Harvest index could be targeted more specifically in breeding programmes to improve the yield of bread varieties. To improve quality for bread-making, nitrogen harvest index could be targeted although it seems to be a very conservative trait of varieties.

4.4.3. 1B/1R v Non-1B/1R types

Following the introduction of the Rht genes into wheat varieties in the mid-1970's a second major innovation was the introduction of the 1B/1R translocated rye genes (mostly to feed wheats), the first UK-bred 1B/1R variety, Hornet, being introduced in 1984. These are thought to be associated with increased leaf "greenness" and greater persistence of green canopy, leading to increased grain filling and higher specific weights (Angus, Pers. Comm.).

Expressions of traits in varieties with the 1B/1R translocation: Apollo, Haven, Hunter, and Rialto, were compared with those of the varieties without the 1B/1R translocation: Avalon, Cadenza, Hereward, Longbow, Mercia and Riband (Tables 4.52 - 4.55).

Table 4.52. N uptake (kg/ha) in +1B1R and -1B1R varieties

	+1B/1R	-1B/1R	s.e.	Sig.
F0				
Early spring	27.8	27.3	1.06	0.69
GS 31	56.1	55.8	1.32	0.84
GS 65	105.7	107.9	1.90	0.40
Harvest	118.6	115.0	2.39	0.27
F2				
GS 65	**247.5**	**226.9**	**5.06**	**0.014**
Harvest	221.2	216.1	2.95	0.23

Table 4.53. Canopy nitrogen requirement (g/m²) in +1B1R and -1B1R varieties

	+1B/1R	-1B/1R	s.e.	Sig.
F0				
Early spring	3.42	3.66	0.126	0.19
GS 31	2.83	2.87	0.076	0.72
GS 65	2.44	2.58	0.118	0.39
F2				
GS 65	3.73	3.81	0.158	0.68

Table 4.54. Biomass (t/ha) in 1B/1R and non-1B/1R varieties

	+1B/1R	-1B/1R	s.e.	Sig.
F0				
Early spring	0.635	0.633	0.0298	0.97
GS 31	2.078	2.010	0.0691	0.47
GS 65	9.96	9.49	0.188	0.09
Harvest	12.01	11.76	0.198	0.36
F2				
GS 65	13.70	12.52	0.265	0.009
Harvest	16.46	16.15	0.135	0.11

Table 4.55. Harvest assessments in 1B/1R and non-1B/1R varieties

	+1B/1R	-1B/1R	s.e.	Sig.
F0				
Grain yield (t/ha at 85%DM)	5.87	5.64	0.122	0.20
Harvest index (%)	47.6	47.3	0.84	0.71
Nitrogen harvest index (%)	74.6	75.2	0.47	0.35
Grain N%	1.66	1.70	N/A	N/A
F2				
Grain yield (t/ha at 85%DM)	8.69	8.30	0.116	0.030
Harvest index (%)	48.7	48.0	0.66	0.45
Nitrogen harvest index (%)	75.1	73.9	0.29	0.011
Grain N%	2.18	2.18	N/A	N/A

+1B/1R and -1B/1R varieties were similar for most traits on most occasions during the growing season. N uptake and biomass at GS 65 in the F2 treatment were significantly greater in varieties with than in those without the 1B/1R translocation. At harvest grain yield was higher in varieties with the 1B/1R translocation when fertilizer was applied although without fertilizer there was a similar trend for grain yield to be higher in the 1B/1R varieties. When fertilizer was applied partitioning of nitrogen to the grain was greater in the 1B/1R varieties, although this did not have any effect on grain N% and overall the NHIs were similar to those when no fertilizer N was applied.

Greater N uptake and biomass at GS 65 may have contributed to the higher grain yields in the 1B/1R varieties, harvest indices being similar in the two types. There was a non-significant trend for green area at anthesis to be higher in varieties with than in those without the 1B1R translocation. However, since information on longevity of the green area during grain filling was not collected in these experiments, it is not known if there was greater persistence of green area in 1B/1R varieties or if it contributed to higher grain yields of these varieties.

Implications for crop management

Varieties with the 1B/1R translocation appear to take up more nitrogen than non-1B/1R varieties and use it to produce biomass. Such varieties could probably benefit more from being grown in situations where fertility is high as they will exploit it more efficiently and profitably.

Implications for breeding
The mechanisms and processes which contribute to greater N uptake could be investigated to identify traits which could be included in breeding programmes.

Conclusions

- Within the set of varieties in this programme, a few varieties stood out from the group in having unusual, i.e. higher or lower expressions of traits than the remainder of the group. For example, Rialto had high N uptake and high biomass at all growth stages and Longbow generally had low N uptake and low biomass. However most varieties fell into intermediate categories in their expressions of traits and were difficult to distinguish from one another. This may be a feature of this particular group of varieties and a different group of varieties may have shown a completely different pattern of variation. However this group does represent both the range of types of wheat varieties currently available and also an age succession. Therefore it is unlikely that greater variation would have been found amongst commercially successful varieties.

- Variation amongst the varieties in their grain yield was associated with variation in their total biomass at harvest. Variation in biomass was associated with variation in N uptake on a number of occasions during the growing season. However variation in production of green area, either in the quantity produced or in the efficiency with which nitrogen was used to produce it, or in shoot production, did not explain how this variation in biomass came about. Therefore the traits included in this programme may not have been appropriate for use in distinguishing between varieties in their behaviour in or response to different conditions.

- In this group of ten varieties, bread-making varieties and feed varieties were similar in most traits and varieties with the 1B/1R translocation were similar to those without the 1B/1R translocation. In both cases variation between varieties within each group was much greater than the differences between each of the two groups. Therefore characteristics of the varieties not linked with either of these features play a much greater role in determining the expressions of the traits.

4.5 Varietal suitabilities

In the Introduction, the following expressed traits were identified as advantageous in low soil N environments and disadvantageous in high soil N environments:

- high uptake of nitrogen
- high GAI, particularly early in the growing season.

In a high soil N environment, the following traits were identified as being advantageous:

- smaller GAI, particularly later in the growing season
- good resistance to diseases and lodging.

High uptake of nitrogen

Varieties good at acquiring nitrogen from the soil will have an advantage in low soil N environments over those less able to acquire soil nitrogen. This will be particularly important for early growth before fertilizer nitrogen is applied to the crop.

Results on grain N offtakes without fertilizer N from the Levington programme (see Section 4.1) suggested that older varieties were more able to acquire soil N than more modern varieties. However results on total crop N offtake without fertilizer N at harvest from this programme suggest that varieties were similar in their effectiveness at acquiring soil N (Table 4.18).

When the winter period is considered, Rialto had taken up 31 kg/ha compared with Apollo which had taken 24 kg/ha by early spring (Table 4.17). By GS 31 uptake of nitrogen from the soil had at least doubled in most varieties, Rialto having 60 kg/ha and Longbow 52 kg/ha, uptakes of all the varieties on the two occasions being highly correlated ($p = 0.041$) (Table 4.19). At harvest Rialto had the highest N uptake at F0 and second highest N uptake at F2 whilst Apollo and Longbow had the lowest N uptakes at F0, and at F2 were amongst the four varieties with the lowest N uptakes. Although the performance of Rialto in different soil N environments is not indicated by these results with and without fertilizer, its excellent yields at F2 suggest that there was no disadvantage to it having a high N uptake when nitrogen was readily available.

At ADAS Boxworth, where greatest differences between Soil N treatments were observed, the varieties did not differ in their yields in response to Soil N either with or without fertilizer N (Table 4.8). N uptakes of the varieties were similar at all soil N's at GS 31, GS 65 and at harvest in the three Soil N treatments at ADAS Boxworth.

Green area index

Varieties which produce a large canopy, either because they have taken up a lot of nitrogen and/or because they have used the nitrogen taken up more efficiently in producing green area, will be able to intercept more light and produce more biomass. The quantity of green area available is limiting to light interception early in the season before a GAI of 5, at which most, i.e. 95% of the incoming radiation is intercepted, is achieved and later, during grain filling as senescence progresses and GAI declines. High maximum GAI, i.e. GAI at GS 65, may be associated with high biomass at harvest because the duration of the green area, and therefore the duration of photosynthetic activity, is likely to be greater in varieties where the GAI is initially higher. The magnitude of the maximum GAI can also be considered to be an indicator of how soon

GAI reached 5 and therefore achieved full interception of incoming radiation and maximum rate of dry matter production.

However crops with higher GAIs may also use more water so that the canopy senesces more rapidly curtailing photosynthesis and biomass production. Also when the green area is greater than 5, the quantity which is needed to intercept most of the radiation, the additional canopy will be contributing little to biomass production and therefore will not be of benefit to the crop. Associations between maximum GAI and biomass production could therefore be either positive or negative.

Avalon, Hunter and Mercia had high GAIs relative to other varieties in early spring, at GS 31 and at GS 65 in the F0 treatment (Table 4.20). These high GAIs did not lead to greater biomass production in these varieties than in the other varieties in early spring (Table 4.35) or at GS 65 (Table 4.39) although at GS 31, there was a weak but non-significant correlation between biomass and GAI (Table 4.37).

Low biomass at harvest was produced by varieties with contrasting GAIs at GS 65, namely Avalon, which had a low maximum GAI, and Riband, which had a high maximum GAI (Tables 4.38, 4.40, 4.42 and 4.44). Conversely, Rialto and Cadenza, which had low maximum GAIs similar to Avalon, produced very high biomass at harvest. Regression analyses of biomass at harvest with GAI at GS 65 for each fertilizer treatment showed that there was no association between these traits in this set of varieties. Therefore maximum GAI was not associated with biomass production at harvest.

At Boxworth, differences between the varieties in their production of green area and biomass at GS 31 ($p < 0.001$ for both) were consistent in all three Soil N treatments (Table 4.9). At harvest varieties differed in their biomass ($p = 0.019$) but the varieties behaved similarly irrespective of Soil N treatment.

Conclusions

- High uptake of nitrogen and high GAI were neither advantageous in low soil N environments nor disadvantageous in high soil N environments. Smaller GAI was not found to be advantageous where soil N was abundant.

- The varieties included in this programme, representing a range of ages, some with and some without the 1B/1R translocation and drawn from both bread-making and feed types, gave similar yields in low and high Soil N environments. Likewise their traits were expressed similarly in all Soil N environments.

- Nevertheless in situations where disease is not controlled and/or lodging is not prevented it would be expected that varieties with good resistance to disease and to lodging would maintain their performances compared with those varieties with lower resistance to disease and to lodging.

4.6. New traits

In this programme biomass production and grain yield of the varieties were found to be clearly associated. There was some indication that variation in N uptake was associated with the variation in biomass production. Rialto, in particular, had high N uptake and high biomass production during the growing season and produced the highest grain yields. However variation in GAI, CNR and shoot production did not account for associations between and variation in N uptake, biomass production and grain yield. The association between N uptake and yield in newer varieties could be monitored routinely in the UK Variety Testing System by measuring N uptake on a limited scale with particular emphasis on uptake after the winter. The mechanisms and traits contributing to differences in N uptake need to be identified so that breeders can incorporate them into their breeding programmes.

4.7. Conclusions and scope for further work

Varieties were similar in their ability to perform in both low and high Soil N environments. Therefore no definitive need for variety evaluation procedures to take account of soil N environment was shown.

Fertilizer N management of winter wheat crops should continue to take into account crop requirement, the availability of soil N, the risk of lodging and the intended use of the grain, but could also be customised to individual varieties in relation to the above factors (i.e. capacity for N uptake and biomass production).

There was some indication that in some environments varieties did respond differently to fertilizer N. These differences in behaviour need to be investigated further and the implications for variety evaluation and crop management determined.

Increases in both biomass and harvest index can contribute to yield improvement in winter wheat varieties. There was some indication that increases in biomass may be attributed to improved N uptake. Further investigation of the mechanisms and processes contributing to these changes in varieties would be very beneficial to breeders.

Future work:

- Variation in recovery of fertilizer N during the growing season at different sites should be further investigated.
- Differences between varieties in their ability to recover fertilizer N in early spring at Crossnacreevy should be verified.
- The differences in response of varieties to fertilizer N from region to region need to be further investigated.
- The mechanisms contributing to variation in N uptake need to be further investigated.

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APPENDIX TABLES

Appendix table 1. *Environmental measurements: rainfall, temperature and irradiance*

1.1 Monthly rainfall (mm) at the three sites

	Boxworth			Crossnacreevy			Harper Adams		
	93-4	94-5	95-6	93-4	94-5	95-6	93-4	94-5	95-6
October	84	68	20	42	94	111	69	46	19
November	60	31	55	71	105	124	55	53	30
December	79	39	59	145	103	66	97	86	68
January	61	78	44	152	123	182	57	93	38
February	28	53	54	134	91	85	49	64	56
March	42	39	18	79	85	69	62	38	39
April	72	11	12	66	25	118	36	14	52
May	58	23	18	45	38	82	38	37	52
June	24	20	28	44	51	32	14	15	31
July	26	18	40	70	83	51	43	27	19
August	62	8	54	92	7	96	43	7	68
September	78	93	-	69	64	-	-	69	-

1.2 Mean monthly air temperature (^oC) at the three sites

	Boxworth			Crossnacreevy			Harper Adams		
	93-4	94-5	95-6	93-4	94-5	95-6	93-4	94-5	95-6
October	8.9	10.2	13.4	7.9	9.5	12.0	6.5	9.7	13.4
November	4.6	9.6	7.6	5.9	9.5	8.2	3.2	9.5	6.7
December	5.4	5.6	1.2	4.4	5.9	3.9	4.3	5.6	1.4
January	5.0	4.5	3.3	4.5	4.3	5.8	4.1	4.2	4.6
February	3.2	6.2	2.1	3.1	5.2	3.4	1.9	6.0	1.6
March	7.4	5.4	3.7	6.1	4.5	4.6	7.3	5.1	4.0
April	8.1	9.0	8.4	6.9	8.1	7.5	7.9	8.7	5.8
May	10.8	12.0	8.8	9.2	9.7	8.3	10.7	11.3	7.0
June	15.1	14.2	15.0	11.7	13.8	12.7	14.5	13.9	13.6
July	18.9	19.8	17.4	14.3	15.8	14.3	17.4	18.4	14.6
August	16.7	19.6	17.5	13.4	17.2	14.2	15.6	18.2	15.6
September	13.2	13.9	-	11.6	12.5	-	-	13.1	-

1.3 Mean monthly soil temperature (^oC), at 10 cm depth, at the three sites

	Boxworth			Crossnacreevy			Harper Adams		
	93-4	94-5	95-6	93-4	94-5	95-6	93-4	94-5	95-6
October	8.0	9.5	11.5	9.5	11.6	14.2	7.2	8.7	13.6
November	4.5	8.5	7.1	6.7	10.5	10.1	4.2	8.2	7.3
December	4.2	5.6	2.5	5.2	7.4	6.2	3.5	4.7	2.7
January	3.6	3.6	3.0	4.7	5.6	6.8	2.9	2.3	3.9
February	2.1	5.0	1.1	4.4	6.6	4.6	1.9	3.7	1.6
March	6.0	3.9	2.7	7.1	6.6	6.7	5.4	3.0	4.1
April	7.2	8.1	6.3	9.5	11.0	10.2	7.4	8.5	5.9
May	11.5	11.5	8.1	13.2	*	13.2	11.8	12.5	8.0
June	15.8	13.6	14.3	14.6	16.9	*	15.8	15.4	11.0
July	19.5	17.9	15.2	17.6	18.8	*	19.1	18.9	12.8
August	16.1	18.5	14.4	16.8	19.3	*	16.3	21.0	14.8
September	12.6	12.9	-	14.2	15.6	-	12.0	13.8	-

** The temperature probe was not working on these occasions.*

1.4 Irradiance ($MJ/m^2/day$) at the three sites

	Boxworth*			Crossnacreevy			Harper Adams		
	93-94	94-95	95-96	93-94	94-95	95-96	93-94	94-95	95-96
October	3.6	3.9	7.3	4.3	4.8	5.0	n/a	5.8	3.1
November	2.0	1.4	3.1	1.8	1.9	2.1	n/a	2.2	5.7
December	1.2	2.6	1.7	1.1	1.3	1.2	1.8	1.7	5.3
January	2.3	2.2	1.9	1.6	1.4	0.9	2.5	2.1	1.5
February	2.7	5.4	4.9	2.3	3.5	4.6	3.2	3.8	3.8
March	4.1	10.7	6.6	7.2	7.0	4.8	7.3	9.4	5.5
April	5.9	10.7	13.2	11.9	11.6	9.8	12.8	13.3	11.0
May	5.1	13.7	16.5	14.9	15.6	15.2	13.8	15.6	11.8
June	8.5	19.0	21.1	13.3	18.5	17.7	16.7	17.5	14.0
July	8.2	16.9	18.6	13.9	15.5	15.3	18.4	17.3	16.5
August	5.9	19.8	14.5	12.1	16.0	10.9	12.7	17.7	12.5
September	3.8	17.0	-	8.8	8.7	-	8.0	8.1	-

**At Boxworth irradiance was measured as sunshine hours/day from October 1993 to December 1994, and then as $MJ/m^2/day$ from January 1994-5 onwards.*

Appendix table 2. Site descriptions and trial husbandry details

2.1 Boxworth
Soil type: clay.
Soil series: Hanslope.
Soil organic matter (%): 3.7%.
Previous crops (before pre-treatment seasons): winter wheat (for all three years).
(a) 1993-4 husbandry.

Pre-treatment.
Pre-treatment crop: oil-seed rape.
Crop harvested: 29/07/93.
R1 & R2 ploughed in: 09/08/93.

Experimental season.
Wheat sown: 10/10/93.
F1 fertilizer (40 kgN/ha) applied: 20/03/94.
F2 fertilizer applied: 27/04/94.
F2 amounts: 205 kgN/ha on R0F2, 190 kgN/ha on R1F2, 100 kgN/ha on R2F2.
Harvest: 16&18/08/94.

(b) 1994-5 husbandry.
Pre-treatment.
Pre-treatment crop: oil-seed rape.
Crop harvested: 18/07/94.
R1 & R2 ploughed in: 28/07/94.

Experimental season.
Wheat sown: 11/10/94.
F1 fertilizer (40 kgN/ha) applied: 21/03/95.
F2 fertilizer applied: 02/05/95.
F2 amounts: 203 kgN/ha on R0F2, 191 kgN/ha on R1F2, 0 kgN/ha on R2F2.
Harvest: 28/07/95.

(c) 1995-6 husbandry.
Pre-treatment.
Pre-treatment crop: oil-seed rape.
Crop harvested: 19/07/95.
R1 & R2 ploughed in: 01/08/95.

Experimental season.
Wheat sown: 29/09/95.
F1 fertilizer (40 kgN/ha) applied: 18/03/96.
F2 fertilizer applied: 07/05/96.
F2 amounts: 165 kgN/ha on R0F2, 155 kgN/ha on R1F2, 0 kgN/ha on R2F2.
Harvest: 09/08/96.

2.2 Crossnacreevy

Soil type: clay loam
Soil organic matter (%): 10.6%.
Previous crops (before pre-treatment seasons): grass (for all three years).

(a) 1993-4 husbandry.
Pre-treatment.
Pre-treatment crop: grass.
Cut: not cut during growing season.
Burnt off: 12/08/93.
Chopped: burnt off grass was chopped on 14/09/93.
R1 & R2 ploughed in: 16/09/93.

Experimental season.
Wheat sown: 22/10/93.
F1 fertilizer (40 kgN/ha) applied: 31/03/94.
F2 fertilizer applied: 14/04/94.
F2 amounts: 235 kgN/ha on R0F2 and R1F2, 220 kgN/ha on R2F2.
Harvest: 26/09/94.

(b) 1994-5 husbandry.
Pre-treatment.
Pre-treatment crop: grass.
Cut: not cut during growing season.
Burnt off: 02/08/94.
Chopped: burnt off grass chopped on 25/08/94.
R1 & R2 ploughed in: 03/09/94.

Experimental season.
Wheat sown: 18/10/94.
F1 fertilizer (40 kgN/ha) applied: 23/3/95.
F2 fertilizer applied: 5/5/95.
F2 amounts: 250 kgN/ha on R0F2 and R1F2, 220 kgN/ha on R2F2.
Harvest: 19/8/95.

(c) 1995-6 husbandry.
Pre-treatment.
Pre-treatment crop: grass.
Cut: mown several times during growing season and either removed (R0 plots), or wilted on plots (R1 and R2 plots).
Burnt off: 07/08/95.
R1 & R2 ploughed in: 16/08/95.

Experimental season.
Wheat sown: 03/10/95.
F1 fertilizer (40 kgN/ha) applied: 05/03/96.
F2 fertilizer applied: 24/04/96.
F2 amounts: 245 kgN/ha on R0F2 and R1F2, 215 kgN/ha on R2F2.
Harvest: 14/09/96.

2.3 Harper Adams

Soil type: sandy loam.
Soil organic matter (%): 2.4%.
Previous crops (before pre-treatment seasons): sugar beet before 1992-1993 pre-treatment, linseed before next two pre-treatment years.

(a) 1993-4 husbandry.
Pre-treatment.
Pre-treatment crop: grass.
Crop cut: mown several times during growing season and either removed (R0 plots), or wilted on plots (R1 and R2 plots).
Crop burnt off: 1/9/93.
R1 & R2 ploughed in: 14/9/93.

Experimental season.
Wheat sown: 16/10/93.
F1 fertilizer (40 kgN/ha) applied: 26/3/94.
F2 fertilizer applied: 1/5/94.
F2 amounts: 220 kgN/ha on R0F2, 180 kgN/ha on R1F2, 140 kgN/ha on R2F2.
Harvest: 19/8/94.

(b) 1994-5 husbandry.
Pre-treatment.
Pre-treatment crop: grass.
Crop cut: mown several times during growing season and either removed (R0 plots), or wilted on plots (R1 and R2 plots).
Crop burnt off: 25/8/94.
R1 & R2 ploughed in: 31/8/94.

Experimental season.
Wheat sown: 06/10/94.
F1 fertilizer (40 kgN/ha) applied: 14/3/95.
F2 fertilizer applied: 19/5/95.
F2 amounts: 235 kgN/ha on all F2 plots.
Harvest: 9/8/95.

(c) 1995-6 husbandry.
Pre-treatment.
Pre-treatment crop: grass.
Crop cut: mown several times during growing season and either removed (R0 plots), or wilted on plots (R1 and R2 plots).
Crop burnt off: 22/8/95.
R1 & R2 ploughed in: 13/9/95.

Experimental season.
Wheat sown: 9/10/95.
F1 fertilizer (40 kgN/ha) applied: 22/3/96.
F2 fertilizer applied: 26/4/96.
F2 amounts: 220 kgN/ha on R0F2, 170 kgN/ha on R1F2, 150 kgN/ha on R2F2.
Harvest: 19/8/96.

*Appendix table 3. Crop establishment in autumn/winter (plants per m^2)**

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	7/2/94	-	-	25/1/94	9/1/95	-	10/2/94	-	9/1/96	
Apollo	216	-	-	225	221	-	241	-	185	217.6
Avalon	206	-	-	230	215	-	216	-	274	228.2
Cadenza	190	-	-	178	214	-	184	-	307	214.6
Haven	195	-	-	198	220	-	218	-	322	230.6
Hereward	207	-	-	216	210	-	221	-	329	236.6
Hunter	208	-	-	217	208	-	220	-	310	232.6
Longbow	201	-	-	173	208	-	167	-	309	211.6
Mercia	211	-	-	225	217	-	232	-	309	238.8
Rialto	198	-	-	212	221	-	209	-	337	235.4
Riband	200	-	-	203	222	-	226	-	303	230.8
M.Huntsman	-	-	-	-	218	-	-	-	-	
Soissons	-	-	-	-	229	-	-	-	-	
significance	*0.006*	-	-	*<.001*	*0.363*	-	*0.012*	-	*<.001*	
e.s.e.	*4.7*	-	-	*4.2*	*5.9*	-	*13.9*	-	*8.1*	
R0	202	-	-	217	220	-	216	-	300	
R1	208	-	-	204	218	-	213	-	299	
R2	199	-	-	202	213	-	211	-	296	
significance	*0.532*	-	-	*0.230*	*0.638*	-	*0.683*	-	*0.879*	
e.s.e.	*5.4*	-	-	*5.9*	*5.3*	-	*4.42*	-	*4.75*	
c.v.	9.8	-	-	8.5	11.5	-	22.6	-	6.7	
mean	203	-	-	208	217	-	213.3	-	298	

** Values in the table are means over F0, F1 and F2 plots as no fertilizer had been applied at the time of measurement.*

Appendix table 4. Ground cover

4.1. Estimated % ground cover at Boxworth and Crossnacreevy in 1993-4 season

Site	**Boxworth**	**Crossnacreevy**							
date	17/3/94	11/4/94		20/4/94		4/5/94[a]		12/5/94	
fertilizer	mean*	F0	F2	F0	F2	F0	F2	F0	F2
variety									
Apollo	18.1	18.2	18.8	18.7	23.8	35.5	52.2	51.3	70.8
Avalon	20.6	18.5	19.3	19.7	24.7	36.0	52.0	53.3	72.5
Cadenza	16.9	15.5	14.7	17.3	20.5	34.5	51.5	50.2	71.3
Haven	16.6	16.2	15.8	17.2	22.2	34.7	53.7	48.5	69.5
Hereward	16.3	18.2	17.5	18.8	23.2	34.3	53.0	49.5	69.7
Hunter	18.3	17.8	18.0	18.5	23.2	35.7	52.2	50.8	67.3
Longbow	15.3	15.8	15.7	17.5	21.3	35.2	53.2	49.7	68.0
Mercia	20.4	18.2	17.2	18.7	23.0	36.2	50.5	49.7	66.8
Rialto	18.2	18.7	19.3	19.0	26.7	36.5	56.3	51.2	71.8
Riband	20.1	16.3	16.3	18.0	23.2	34.5	52.5	49.8	71.5
significance	*<.001*	*0.763*		*0.177*		*0.518*		*0.501*	
e.s.e.	*0.47*	*0.51*		*0.75*		*1.07*		*1.38*	
R0	17.9	17.2	17.8	18.3	23.3	33.1	51.2	43.2	65.6
R1	17.6	16.8	17.6	17.8	23.4	35.0	53.2	51.0	71.2
R2	18.8	17.9	16.4	18.9	22.8	37.8	53.6	57.0	73.0
significance	*0.413*	*0.373*		*0.010*		*0.810*		*0.674*	
e.s.e.	*0.62*	*0.59*		*0.37*		*1.69*		*3.81*	
c.v.	11.0	7.2		8.5		5.7		5.3	
mean	18.1	17.3	17.3	18.3	23.2	35.3	52.7	50.4	69.9

* These results have been meaned across fertilizer treatment, as fertilizer had not been applied to the crop when the observations were made.

[a] At Crossnacreevy on 4/5/94 there was a fertilizer N x soil N x variety interaction (p=0.031).

4.2. Estimated % ground cover at Crossnacreevy in 1994-5 season

Site	**Crossnacreevy 1994-5**						
date	14/12/94	16/1/95	6/2/95	27/2/95	21/3/95	19/4/95	
fertilizer	mean*	mean*	mean*	mean*	mean*	F0	F2
variety							
Apollo	15.1	20.1	31.6	37.3	48.4	64.2	80.8
Avalon	14.8	19.3	31.8	36.8	47.9	62.5	80.8
Cadenza	15.9	21.8	33.9	39.2	48.9	62.5	79.2
Haven	15.0	19.6	30.9	35.5	46.4	62.5	78.3
Hereward	15.3	18.7	30.6	36.1	46.6	62.5	79.2
Hunter	14.8	19.6	31.1	35.9	46.6	60.8	76.7
Longbow	13.8	18.3	29.7	34.2	44.8	59.2	77.5
Mercia	14.9	19.4	30.8	37.4	48.3	64.2	80.8
Rialto	15.0	19.6	31.9	37.0	48.5	65.8	82.5
Riband	14.8	19.2	31.1	36.0	47.2	61.7	77.5
M.Huntsman	14.5	19.3	30.3	35.3	45.4	61.7	78.3
Soissons	15.4	20.4	31.8	37.5	48.0	61.7	78.3
significance	*<.001*	*<.001*	*<.001*	*<.001*	*<.001*	*0.998*	
e.s.e.	*0.21*	*0.24*	*0.29*	*0.38*	*0.40*	*1.66*	
R0	14.6	18.9	30.6	34.9	45.6	58.3	81.0
R1	14.8	18.9	30.1	35.3	46.4	63.3	80.0
R2	15.5	21.1	33.1	39.4	49.8	65.6	76.5
significance	*0.083*	*<.001*	*0.177*	*0.010*	*<.001*	*0.041*	
e.s.e.	*0.25*	*0.25*	*1.11*	*0.84*	*0.48*	*1.58*	
c.v.	6.0	5.1	4.0	4.5	3.6	5.5	
mean	15.0	19.6	31.3	36.5	47.2	62.4	79.2

* See above.

Appendix table 5. Crop height

5.1 Crop height at F0 after ear emergence (cm)

Site	**Boxworth**			**Crossnacreevy**			
season	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**[a]	**mean**
date	27/7/94	-	-	17/6/94	21/7/95	31/7/96	
variety							
Apollo	80.56	-	-	40.92	57.78	69.08	62.08
Avalon	81.56	-	-	58.52	66.11	75.08	70.32
Cadenza	87.78	-	-	44.08	62.03	73.63	66.88
Haven	70.22	-	-	44.08	50.81	62.21	56.83
Hereward	76.00	-	-	48.17	63.42	73.50	65.27
Hunter	75.56	-	-	47.67	58.28	70.21	62.93
Longbow	76.67	-	-	44.25	53.53	72.50	61.74
Mercia	75.83	-	-	46.17	58.94	70.92	62.97
Rialto	73.50	-	-	44.17	54.72	68.21	60.15
Riband	78.78	-	-	42.75	57.75	72.25	62.88
M.Huntsman	-	-	-	-	73.47	89.25	81.36
Soissons	-	-	-	-	64.67	71.54	68.10
significance	*0.311*	-	-	*0.003*	*0.038*	*<.001*	
e.s.e.	*1.689*	-	-	*1.338*	*1.189*	*0.828*	
R0	69.87	-	-	42.58	59.78	67.00	
R1	75.23	-	-	45.45	59.51	71.47	
R2	87.83	-	-	50.21	61.08	78.63	
significance	*<.001*	-	-	*0.077*	*0.942*	*0.078*	
e.s.e.	*0.806*	-	-	*1.366*	*1.760*	*1.192*	
c.v.	4.9	-	-	5.6	4.3	2.6	
mean	77.64	-	-	46.08	60.12	72.36	

[a] At Crossnacreevy in 1995-6 there was a fertilizer N x soil N x variety interaction (p=0.013).

5.2 *Crop height at F2 after ear emergence (cm)*

Site	Boxworth			Crossnacreevy			
season	93-4	94-5	95-6	93-4	94-5	95-6[a]	mean
date	27/7/94	-	-	17/6/94	21/7/95	31/7/96	
Apollo	93.11	-	-	72.42	70.72	86.01	80.57
Avalon	90.61	-	-	83.17	77.81	85.05	84.16
Cadenza	97.83	-	-	75.92	77.81	88.55	85.03
Haven	83.72	-	-	74.83	67.97	82.05	77.14
Hereward	83.50	-	-	72.92	73.42	83.59	78.36
Hunter	85.72	-	-	73.92	72.11	82.34	78.52
Longbow	91.06	-	-	73.33	71.81	84.43	80.16
Mercia	90.61	-	-	70.58	69.47	79.18	77.46
Rialto	90.33	-	-	74.67	68.56	82.34	78.97
Riband	89.78	-	-	74.83	73.28	86.14	81.01
M.Huntsman	-	-	-	-	85.92	98.01	91.96
Soissons	-	-	-	-	74.56	84.05	79.30
significance	*0.311*	-	-	*0.003*	*0.038*	*<.001*	
e.s.e.	*1.689*	-	-	*1.338*	*1.189*	*0.828*	
R0	88.98	-	-	74.78	73.24	83.24	
R1	89.67	-	-	75.65	72.75	84.92	
R2	90.23	-	-	73.55	74.87	87.28	
significance	*<.001*	-	-	*0.077*	*0.942*	*0.078*	
e.s.e.	*0.806*	-	-	*1.366*	*1.760*	*1.192*	
c.v.	4.9	-	-	5.6	4.3	2.6	
mean	89.63	-	-	74.66	73.62	85.15	

[a] See above.

Appendix table 6. Lodging

Virtually no lodging was observed at Crossnacreevy and Harper Adams in any of the experimental years or at Boxworth in 1994-5 and 1995-6. The lodging noted at Boxworth in 1993-4 is detailed in Table 5.1. below.

6.1 Lodging (%) at Boxworth: pre-harvest assessment

season	**93-4**	**93-4**
	F0	**F2**
date	18/8/94	18/8/94
variety		
Apollo	15.00	23.00
Avalon	0.17	1.17
Cadenza	0.00	1.00
Haven	7.50	18.83
Hereward	0.33	0.00
Hunter	0.67	2.00
Longbow	8.00	15.33
Mercia	0.83	3.33
Rialto	0.00	0.17
Riband	21.33	19.17
significance	*0.945*	
e.s.e.	*5.895*	
R0	1.30	4.50
R1	6.85	15.15
R2	8.00	5.55
significance	*0.176*	
e.s.e.	*3.593*	
c.v.	156.8	
mean^{+}	5.38	8.40

Appendix table 7. *Grain number per ear*

7.1 Grain number per ear at F0 at harvest

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	29/8/94	17/8/95	3/9/96	-	3/8/95	16/8/96	
Apollo	38.54	39.86	39.53	31.33	30.14	37.69	-	31.30	38.74	35.89
Avalon	36.92	34.81	42.40	30.25	23.89	28.13	-	33.15	32.67	32.78
Cadenza	41.22	31.65	29.90	31.93	31.97	29.36	-	27.27	30.77	31.76
Haven	41.99	38.09	40.42	30.72	24.61	29.53	-	36.05	32.58	34.25
Hereward	35.38	38.15	34.32	27.10	29.20	31.39	-	32.82	30.40	32.34
Hunter	40.99	41.70	39.85	30.40	31.87	31.99	-	35.47	38.16	36.30
Longbow	41.17	40.35	41.25	32.85	33.15	29.63	-	35.30	31.36	35.63
Mercia	37.63	34.09	31.99	33.68	33.36	29.38	-	32.78	32.12	33.13
Rialto	42.13	40.45	39.86	33.73	33.75	37.12	-	36.76	37.13	37.62
Riband	42.92	39.88	44.18	32.79	33.84	32.26	-	38.33	35.82	37.50
M.Huntsman	-	-	-	-	27.39	32.78	-	-	-	30.09
Soissons	-	-	-	-	23.02	24.73	-	-	-	23.88
significance	*0.760*	*0.056*	*0.217*	*<.001*	*0.025*	*<.001*	-	*0.036*	*0.105*	
e.s.e.	*1.490*	*1.435*	*0.970*	*1.426*	*1.658*	*1.208*	-	*1.925*	*1.709*	
R0	37.47	33.70	37.79	29.70	30.01	30.88	-	32.99	33.23	
R1	38.91	35.54	39.47	31.29	28.57	31.68	-	34.87	32.53	
R2	43.29	44.47	37.86	33.45	30.47	30.94	-	33.91	36.16	
significance	*0.228*	*0.003*	*0.049*	*0.139*	*0.926*	*0.264*	-	*0.724*	*0.132*	
e.s.e.	*2.314*	*1.248*	*0.764*	*1.272*	*2.466*	*1.209*	-	*1.942*	*1.123*	
c.v.	8.8	8.5	6.1	10.7	11.6	8.9	-	13.7	12.2	
mean	39.89	37.90	38.37	31.48	29.68	31.65	-	33.92	33.97	

[a] At Boxworth in 1995-6 there was a soil N x variety interaction (p=0.007), but no fertiliser N x soil N x variety interaction. For all varieties, except Hunter, grain number per ear did not vary significantly between R0 and R2 treatments. Some varieties, however, had higher numbers of grains per ear in R1 plots compared to R0 plots, and these values were significantly greater than those for the R2 plots; this was true of Apollo, Haven and Longbow.

Appendix table 7. *Grain number per ear*

7.1 Grain number per ear at F0 at harvest

Site	Boxworth			Crossnacreevy			Harper Adams			
season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	29/8/94	17/8/95	3/9/96	-	3/8/95	16/8/96	
Apollo	38.54	39.86	39.53	31.33	30.14	37.69	-	31.30	38.74	35.89
Avalon	36.92	34.81	42.40	30.25	23.89	28.13	-	33.15	32.67	32.78
Cadenza	41.22	31.65	29.90	31.93	31.97	29.36	-	27.27	30.77	31.76
Haven	41.99	38.09	40.42	30.72	24.61	29.53	-	36.05	32.58	34.25
Hereward	35.38	38.15	34.32	27.10	29.20	31.39	-	32.82	30.40	32.34
Hunter	40.99	41.70	39.85	30.40	31.87	31.99	-	35.47	38.16	36.30
Longbow	41.17	40.35	41.25	32.85	33.15	29.63	-	35.30	31.36	35.63
Mercia	37.63	34.09	31.99	33.68	33.36	29.38	-	32.78	32.12	33.13
Rialto	42.13	40.45	39.86	33.73	33.75	37.12	-	36.76	37.13	37.62
Riband	42.92	39.88	44.18	32.79	33.84	32.26	-	38.33	35.82	37.50
M.Huntsman	-	-	-	-	27.39	32.78	-	-	-	30.09
Soissons	-	-	-	-	23.02	24.73	-	-	-	23.88
significance	*0.760*	*0.056*	*0.217*	*<.001*	*0.025*	*<.001*	-	*0.036*	*0.105*	
e.s.e.	*1.490*	*1.435*	*0.970*	*1.426*	*1.658*	*1.208*	-	*1.925*	*1.709*	
R0	37.47	33.70	37.79	29.70	30.01	30.88	-	32.99	33.23	
R1	38.91	35.54	39.47	31.29	28.57	31.68	-	34.87	32.53	
R2	43.29	44.47	37.86	33.45	30.47	30.94	-	33.91	36.16	
significance	*0.228*	*0.003*	*0.049*	*0.139*	*0.926*	*0.264*	-	*0.724*	*0.132*	
e.s.e.	*2.314*	*1.248*	*0.764*	*1.272*	*2.466*	*1.209*	-	*1.942*	*1.123*	
c.v.	8.8	8.5	6.1	10.7	11.6	8.9	-	13.7	12.2	
mean	39.89	37.90	38.37	31.48	29.68	31.65	-	33.92	33.97	

[a] At Boxworth in 1995-6 there was a soil N x variety interaction (p=0.007), but no fertilizer N x soil N x variety interaction. For all varieties, except Hunter, grain number per ear did not vary significantly between R0 and R2 treatments. Some varieties, however, had higher numbers of grains per ear in R1 plots compared to R0 plots, and these values were significantly greater than those for the R2 plots; this was true of Apollo, Haven and Longbow.

7.2 Grain number per ear at F2 at harvest

Site	**Boxworth**			**Crossnacreevy**			**Harper Adams**			
Season	**93-4**	**94-5**	**95-6[a]**	**93-4**	**94-5**	**95-6**	**93-4**	**94-5**	**95-6**	**mean**
date	17/8/94	2/8/95	9/8/96	22/9/94	17/8/95	3/9/96	-	3/8/95	16/8/96	
Apollo	44.07	47.88	39.70	31.68	41.52	37.76	-	34.62	34.08	38.91
Avalon	41.80	44.66	41.13	29.45	41.83	36.56	-	26.99	33.76	37.02
Cadenza	47.14	39.84	31.29	37.14	41.33	33.41	-	35.04	32.89	37.26
Haven	43.53	46.02	40.26	34.03	45.02	34.90	-	36.36	34.67	39.35
Hereward	43.24	41.78	39.42	31.00	41.55	34.04	-	34.07	30.42	36.94
Hunter	44.30	48.46	40.01	35.94	43.25	34.87	-	37.37	37.52	40.21
Longbow	45.53	47.82	42.17	36.07	49.57	38.39	-	33.44	36.01	41.12
Mercia	38.03	36.48	32.50	32.93	38.80	31.79	-	30.09	31.49	34.01
Rialto	47.70	42.29	44.19	38.06	45.33	35.83	-	42.16	34.08	41.20
Riband	46.29	48.55	44.89	35.91	46.94	39.95	-	40.90	41.46	43.11
M.Huntsman	-	-	-	-	36.47	30.28	-	-	-	33.38
Soissons	-	-	-	-	36.84	33.10	-	-	-	34.97
significance	*0.760*	*0.056*	*0.217*	*<.001*	*0.025*	*<.001*	-	*0.036*	*0.105*	
e.s.e.	*1.490*	*1.435*	*0.970*	*1.426*	*1.658*	*1.208*	-	*1.925*	*1.709*	
R0	47.19	45.39	41.71	36.74	44.45	36.81	-	35.83	36.05	
R1	42.50	45.61	39.77	31.25	41.56	33.01	-	34.49	34.22	
R2	42.80	42.13	37.19	34.67	41.11	35.40	-	34.99	33.64	
significance	*0.228*	*0.003*	*0.049*	*0.139*	*0.926*	*0.264*	-	*0.724*	*0.132*	
e.s.e.	*2.314*	*1.248*	*0.764*	*1.272*	*2.466*	*1.209*	-	*1.942*	*1.123*	
c.v.	8.8	8.5	6.1	10.7	11.6	8.9	-	13.7	12.2	
mean	44.16	44.38	39.56	34.22	42.37	35.80	-	35.10	34.64	

[a] See above.