PROJECT REPORT No. 235

# REDUCING WINTER WHEAT PRODUCTION COSTS THROUGH CROP INTELLIGENCE INFORMATION ON VARIETY AND SOWING DATE, ROTATIONAL POSITION, AND CANOPY MANAGEMENT IN RELATION TO DROUGHT AND DISEASE CONTROL

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By

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## ABSTRACT

This project assessed the potential to reduce production costs for wheat, based on understanding how the crop grows and forms grain. The project assessed the value to the grower of choosing varieties according to their suitability to growing conditions, and then adjusting husbandry practices according to assessments of the crop's progress through the season. The total benefit from this approach was estimated to be £80-100 per ha. This estimate was derived from four sub-projects:

**Matching variety to sowing date:** Varieties with contrasting physiological characteristics differed in their responses to sowing date. The average yield loss due to delays in sowing from the end of September to mid-November in 1997 or mid-December in 1998 was 1.0 t/ha and 1.7 t/ha respectively. When planting early, the highest yields were obtained from slow developing varieties; when planting late, they were obtained from fast developing varieties. Varieties lost yield at different rates as drilling was delayed, so that variety rankings for yield altered significantly. Developmental rates were best assessed either by date of the first node stage (GS 31) or date of flowering (GS61). These rates explained a significant proportion of the variation in yield loss due to delayed drilling. Adoption of developmental rate as an indicator of varietal suitability to a drilling date would have been worth at least £30-40/ha, and more if quality characteristics were also taken into account.

**Matching varieties and management to potential 'finishing':** Fields with light soil or risk of take-all are subject to poor finishing. Experiments were conducted from which it was estimated that choice of varieties with high stem reserves (water soluble carbohydrate), rapid development and economical tillering would boost yields by between 0.4 and 0.8 t $ha^{-1}$ in a take-all situation. If half the varieties on non-first wheat land have detrimental traits at present, their replacement with better suited varieties would improve non-first wheat profits by £20/ha.

In experiments on light soil, reducing canopy size by Canopy Management (1) diminished water use pre-flowering by approximately 20 mm, (2) did not depress the depth of maximum extraction of water, and (3) showed little evidence of significantly reducing root density in the upper 1 m of the profile. These effects on the variety Mercia implied that Canopy Management should be equally applicable on droughty and water retentive soils. The benefit to the industry from applying Canopy Management has been estimated as £10/ha.

**Matching fungicide-dose to crop nutrient status:** Optimum nitrogen (N) for yield was 92 and 161 kg N/ha in two experiments in 1997 and 1998 respectively. Canopy sizes that coincided with optimum N use were about green area index (GAI) 6, confirming previous predictions. The progress of yellow rust on two susceptible varieties was related to the N status of the crop, and indications were that Septoria and mildew behaved similarly, such that canopies of optimal size were less at risk than larger canopies. Comparing fungicide doses, the optimum rate of triazole plus morphiline was less with nil N than with optimal N. The margin over fungicide costs was similar with optimal and large canopies, probably because the fungicides used were very active against the main disease, yellow rust. It is predicted that optimum canopies would require reduced fungicide doses for diseases which are less easy to control, such as Septoria. In any case, the financial return achieved with optimal canopies was as great as with large canopies, needed less fungicide and fertiliser, and incurred less lodging. It is concluded that N should be applied to achieve optimum canopy size, then fungicides should be adjusted accordingly. Combined optimisation of N and fungicides would save £38-70/ha compared to use of standard recommended rates.

**Assessment of crop progress:** Reference crop techniques were developed to provide 'live' intelligence of crop growth and development. It was shown that benchmarks for growth would need to be altered to account for a change of reference variety from Mercia to Consort; the main differences were due to a greater canopy survival of Consort. There was a similarity in growth rates between sites and seasons, so it appeared possible that differences in grain yield might be predicted in part according to date of onset of 'grand growth'. However, variation in canopy survival was also important, and is not yet predictable. Tests of electronic dissemination allowed weekly updating of intelligence and doubled the number of times that information was accessed by a user group over a two month period. On-farm techniques for canopy assessment were tested and developed with users. The method was based on a shoot count. A correction for area per leaf would only be needed for large varietal differences, or high accuracy.

## SUMMARY

As prices fall and costs increase, it becomes increasingly important to choose varieties and judge husbandry operations accurately. Good judgements depend in turn upon good information on crop growth and development. The four sub-projects described below, revealed new information on growth and development of wheat crops which enables more accurate variety choice and which suggests how the timing of husbandry operations and the amounts of growth regulators, fungicides and fertilisers, can be varied according to intelligence about differences in crop state between sites and seasons.

## 1. VARIETY SUITABILITY TO SOWING DATE

Wheat is now drilled over a wider range of dates than ever before. Increased unit size, reduced labour, a perception that ever earlier drilling increases yield, and delayed harvest of high value root crops have resulted in sowing dates spread over as much as 5 months. The choice of variety across this range of sowing dates is currently given little consideration. Information on variety suitability to sowing date in the NIAB Variety Handbook (1999) shows little difference in yield between early and late drilling and few changes in variety ranking. Fielder (1988) demonstrated some varietal sowing date suitability, these were due to standing power and disease resistance differences. Within the industry there has long been a perception that slow developing varieties are better suited to early drilling and fast ones to late. The rate of development is frequently demonstrated by the rate of apical development (date of double ridges). In practice a few varieties have gained popularity over the years for suitability to particular sowing dates, e.g. Fenman and Soissons for late sowings after root crops. Such examples are however rare, due to the perception that high yielding slow developing varieties still yield more when late drilled than fast developing varieties.

Previous HGCA-funded work (Kirby *et al*, 1998), highlighted some of the weaknesses in the way wheat development was seen in the past. It suggested a new approach to understanding variety/sowing date interactions, in which the timing of flowering or the start of grain filling was key. Understanding gained through other HGCA-funded projects (e.g. Sylvester-Bradley *et al*, 1998) of how wheat grows and produces its yield showed that we should optimise the main yield forming process. As the crop progresses through the year, incident radiation increases to a maximum in May - July and then declines. Temperature does not reach its peak until July. As temperature increases, crop development rate increases, so shortening the duration of any growth phase. Therefore, at any given level of radiation in warmer temperatures the growth during a developmental phase will be less. In order to achieve maximum yield we therefore want grain filling to begin in early May, when temperatures are low and radiation high. However, previous study showed that this objective must be tempered with an awareness that as the crop develops it becomes more sensitive to frost; variety and sowing date must be combined to delay the start of stem extension until after significant risk of air frosts has passed, and ear emergence until after significant risk of ground (radiation) frost has passed.

### Results and discussion

There were two main experiments per year. The first, looked at the response of 6 varieties chosen to exhibit specific physiological characteristics across a range of 6 sowing dates from normal (late Sept.) to late (Dec.). The second experiment (Typing trial) included a wider range of varieties including new and 'up and coming' varieties sown either early or late, to provide up to date information for the grower. Despite the use of plant growth regulators (PGR's) lodging occurred in both years in the early sowings in the first experiment, whilst there were significant variety by sowing date interactions in both. These largely reflected the standing powers of the varieties. In the typing trials however lodging was either absent or occurred at very low levels. It is these experiments on which the main conclusions are drawn, although they are supported by the greater range of sowings in the first experiment.

The average yield loss due to delayed sowing from the end of September to mid-November or mid-December in harvest years 1997 and 1998 respectively, were 1.0 t/ha and 1.7 t/ha. In both years there was a significant effect of variety on the yield loss incurred, the range being from 0.4 to 1.8 and 0.1 to

4.9 t/ha in 1997 and 1998 respectively. The varieties therefore, lost yield at different rates with delayed drilling, and this resulted in variety rankings for yield altering significantly (Table 1). Taking Consort and Charger as examples, drilling either, across both years and drilling dates would have produced average yields of 8.8 and 9.0 t/ha respectively. Drilling Consort early and Charger late would have increased this average yield to 9.4 t/ha, or increased output over the use of a single variety by £28-42/ha, for no additional input cost. The choice of variety for wheat crops which are likely to be drilled late is therefore of paramount importance to the profitability of those crops.

**Table 1.** Yield from two years of typing trial showing yield loss from late drilling at Rosemaund.

| | 1996/7 | | | 1997/8 | | |
|---|---|---|---|---|---|---|
| VARIETY | Sown 29/9/96 | Sown 14/11/96 | Yield loss from delayed sowing (t/ha) | Sown 26/9/97 | Sown 16/12/97 | Yield loss from delayed sowing (t/ha) |
| Abbot | 10.8 | 10.0 | 0.7 | 7.7 | 6.5 | 1.2 |
| Avalon | 9.8 | 9.2 | 0.6 | 6.9 | 5.1 | 1.7 |
| Brigadier | 11.6 | 9.7 | 1.8 | 9.2 | 7.3 | 1.8 |
| Buster | 10.6 | 9.9 | 0.7 | 8.1 | 7.0 | 1.1 |
| Cadenza | 11.3 | 10.5 | 0.9 | 8.2 | 7.5 | 0.7 |
| Caxton | 10.4 | 9.5 | 0.8 | 7.8 | 6.8 | 1.0 |
| Charger | 10.8 | 10.1 | 0.7 | 8.5 | 6.6 | 1.8 |
| Consort | 11.4 | 9.7 | 1.7 | 9.5 | 4.5 | 4.9 |
| Drake | 11.5 | 10.4 | 1.2 | 9.1 | 6.7 | 2.3 |
| Haven | 11.8 | 10.2 | 1.6 | 9.3 | 8.1 | 1.1 |
| Mercia | 9.4 | 8.7 | 0.7 | 7.1 | 5.6 | 1.5 |
| Rialto | 11.0 | 10.1 | 0.8 | 9.1 | 7.7 | 1.4 |
| Riband | 11.5 | 9.9 | 1.6 | 9.0 | 6.0 | 3.0 |
| Soissons | 9.4 | 9.0 | 0.4 | 6.8 | 6.6 | 0.1 |

Identifying varieties suitable for late drilling has previously been very time-consuming or been achieved through trial and error. Within this project assessing developmental rate by either the date of GS31 or GS61 from a normal drilling date has explained a significant proportion of the variation in yield loss due to delayed drilling (Figs 1 & 2). These methods, which rely on observation of external growth stage, are much easier and cheaper than dissection of apices, and could therefore prove to be of enduring value in exploiting the potential of the range of genetic material available to the grower.

In addition to these observations there must be an awareness of the process within each variety which controls development rate to avoid costly mistakes. For example cv. Spark has little or no vernalisation response and develops late from a normal sowing date due to a high photoperiod requirement; if drilled very early in long days, it may start stem extension before the winter and suffer severe frost damage and yield loss.

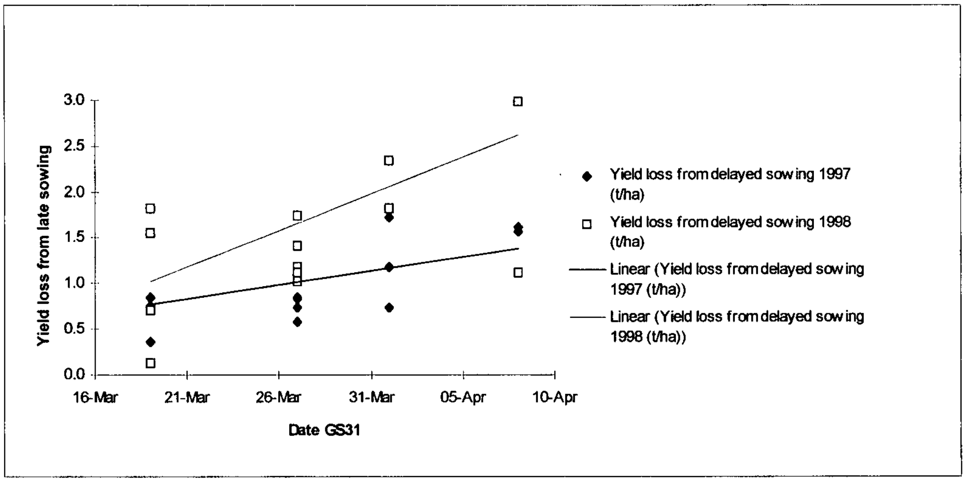



**Figure 1.** Date of GS31 vs. loss of yield from late sowing in 1997 and 1998

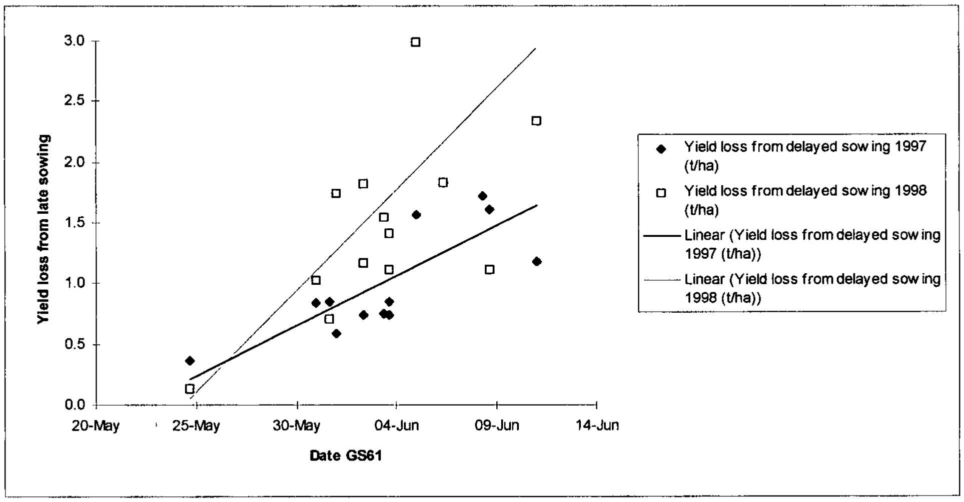



**Figure 2.** Date of GS61 vs. loss of yield from late sowing in 1997 and 1998.

## 2. MANAGEMENT WITH GOOD AND POOR FINISHING

'Finishing' is the crop's ability to continue assimilate production during the latter stages of grain fill. This will be affected by the water availability, as defined by soil type and rainfall, and the incidence and severity of take-all root loss which affects non-first wheats. About 20% of UK wheat is grown on light soil (Foulkes *et al.*, 1994) and Austin (1978) has estimated that each year drought reduces yield by about 17 %. Over the period 1989-96 non-first wheats accounted for between 36 and 59 % of the UK wheat crop. The percentage has been lower in the years 1995 and 1996 following the widespread introduction of set-aside. However, a large amount of set-aside is natural regeneration, which is not a complete take-all break (Jones *et al.*, 1996), so a larger proportion may be at risk from take-all infection. Vaiydanathan *et al.* (1987) reported that, overall in non-first wheat crops after discounting the effects of N, mean yield loss due to take-all was in the order of 1 t $ha^{-1}$. Objectives of the experimental programme were to test the benefit of altering husbandry in contrasting finishing environments, specifically variety choice in relation to first and second wheat environments, and nitrogen fertiliser management in relation to droughted and undroughted conditions.

## 2.1. Interaction between variety and rotational position

Although there is no evidence for consistent varietal differences in susceptibility to take-all (Scott *et al.*, 1998), the capacity of varieties to tolerate root loss may not be the same, e.g. in the ADAS Crop Centre trial series of 1992 some varieties lost only 0.3 t $ha^{-1}$ whilst others lost more than 1 t $ha^{-1}$ when grown as a second wheat. At the beginning of this project (1995), growers' choice of non-first wheat varieties did not take account of potential differences in tolerance to take-all because guidelines to make informed decisions were not available. The basis for detecting varietal suitability in the current work is therefore to identify physiological traits that may confer tolerance of take-all in second or successive wheats.

Project Report No. 184 'Exploitation of Varieties for UK Cereal Production' (HGCA, 1998) has provided evidence to support hypotheses that:

(i) Varieties which accumulate large stem reserves of water soluble carbohydrate are better adapted to compensate for the yield limiting effects of take-all.

(ii) Rapid developing varieties are better adapted to tolerate take-all, because i) the disease has less time to establish itself and reduce yield and ii) water usage tends to be less, thus leaving greater soil supplies which may be accessed more easily by roots restricted by take-all.

(iii) Varieties with efficient production of tillers are likely to tolerate take-all better by restricting the amount of water wasted in the production of tillers destined to die, whose dry matter is not effectively redistributed within the plant (Thorne and Wood, 1987).

It was intended that these preliminary findings should be further corroborated and, if necessary refined in two field experiments (1996-97 & 1997-98) testing nine varieties, with contrasting physiological traits, established in first and second wheat treatments. Soil residual N was balanced across first and second wheat treatments to allow tolerance of root loss due to take-all to be detected without any confounding effect of differential responses to N residues. Take-all index was assessed monthly on Spark from January onwards. Growth analysis was done at GS 31, 33, 39, 61 and harvest. Water soluble stem carbohydrate was measured at anthesis. Combine yield was assessed on 20 $m^2$ per plot.

### Results and discussion

*Take-all and yield*

Take-all indices were low during the spring and summers of 1997 and 1998 (less than 20 out of 100) and differences between the levels of infection for the 1st and 2nd wheats did not rise above five until after June in both seasons. Dry periods during late winter and spring may have restricted early progress of the disease in both seasons. Second wheats yielded on average 0.3 t $ha^{-1}$ less than the 1st wheats in both seasons, this difference was significant ($P<0.05$) in 1996-97 but not in 1997-98. The small yield difference between rotational positions is consistent with the low level of take-all (HGCA, 1998). Any effect of take-all on yield is likely to have been further reduced by the abundant water supply during grain filling caused by the greater than normal June rainfall in both seasons. As a result of the small 2nd wheat yield reductions, rotational position and variety did not interact in either season.

*Water soluble stem carbohydrates (WSCs)*

In general the varietal rankings were similar between years and agreed with previous work (HGCA, 1996; HGCA, 1998), with Drake and Rialto having about 1.1 t $ha^{-1}$ more WSCs than Mercia and Maris Huntsman. Rotational position did not have a significant effect on this trait. About 40% of WSCs contribute to grain fill (Austin *et al.*, 1977). This would mean that a well buffered variety would require 9 mm less water during grain fill to achieve its potential yield, assuming a water use efficiency of 5 g $m^{-2}$ $mm^{-1}$ (Green *et al.*, 1983).

*Developmental rate*

Soissons reached mid-anthesis 11 to 14 days before the slowest developing varieties (Spark and Drake). In both years, the rankings for the other varieties (in terms of mid-anthesis date) were consistent with information collected in HGCA (1998). Reaching anthesis 14 days early would be expected to confer a significant advantage in a take-all situation by enabling more grain filling before root function has been severely damaged by disease. The amount of water transpired by each variety between GS31 and mid-anthesis was calculated from potential evapotranspiration (PE) and leaf area index (LAI). This showed that, in agreement with Innes *et al.* (1985), the most rapidly developing variety transpired 11 mm less water than the slowest developing variety, mainly as a result of less transpiration in June when PE was high. However, extraction of this saved water may be impaired by smaller root systems which are often associated with rapidly developing crops (Barraclough and Leigh, 1984).

*Tiller economy*

In agreement with previous work (HGCA, 1998) Soissons had the most economic tillering pattern, losing about 270 shoots $m^{-2}$ between GS 31 and harvest, with Spark, Rialto, Brigadier and Drake all losing between 500 and 800 shoots $m^{-2}$. However, calculations of the amount of water transpired (and wasted) by the shoots destined to die resulted in different varietal rankings. Aborting shoots of Spark and Soissons transpired only 5 and 6 mm water, and those of Rialto and Brigadier transpired 16 and 20 mm. Spark, whose many small aborted tillers transpired little water, illustrated the importance of tiller size when death occurs. Choosing a variety with economical tillering (both in terms of number and time of death) may save up to 15 mm water in the soil.

In summary, choosing a variety with large reserves of WSCs above a variety with few WSCs may result in 9 mm less water required during grain fill for optimum yield to be realised. This would be expected to confer a yield improvement of 0.4 t $ha^{-1}$ in situations when the root system's ability to extract water is restricted by take-all. Choosing a variety with rapid development or economic tillering may reduce water use up to anthesis by 11 and 15 mm of water respectively, thus improving the availability of water during grain fill. The advantage that this will confer will depend on the severity with which take-all infection restricts water uptake. In a situation where all the saved water was extracted by an infected crop, the yield boost would be 0.6 and 0.8 t $ha^{-1}$ respectively. A variety with all three traits optimised could therefore confer a total yield benefit of 1.8 t/ha compared to one with a combination of all adverse traits. However, some of these traits may be confounded, e.g. rapid developing varieties may have less time to build up large reserves of WSCs, resulting in few varieties with combinations of all advantageous traits.

**Conclusions**

- Varietal rankings for the physiological traits likely to confer tolerance to take-all are consistent amongst sites and seasons.
- For each of the 3 traits, selecting a variety expressing the most favourable phenotype over the least favourable variety may boost yields by between 0.4 and 0.8 t $ha^{-1}$ in a take-all situation.
- Large stem reserves of water soluble carbohydrate, rapid development and economical tillering may be used by growers, variety testers and breeders to select for the most suitable varieties to be grown as non-first wheats.
- HGCA (1998) showed that by selecting varieties with advantageous combinations of traits, the yield reduction associated with non $1^{st}$ wheat could be cut by 0.3 t $ha^{-1}$. In practice this benefit will be greater because the previous HGCA research did not encounter seasons with severe take-all, for which differences in yield losses between varieties grown as non-first wheats can be 0.8 t $ha^{-1}$ (Spink *et al.*, 1996).
- It may be assumed that half of the non-first wheat area consists of varieties with detrimental traits (HGCA, 1999). Replacing these with better suited varieties would boost UK wheat production by 150,000t (£12 million) per year and improve non-first wheat profits by £20 $ha^{-1}$.

## 2.2 Canopy management on drought-prone soil types

The Canopy Management system for calculating N fertiliser inputs (based on N required for an optimal canopy size of *c.* GAI 5) increased the economic returns over conventional practice (HGCA, 1998a). At core experiments at ADAS Boxworth, Cambridgeshire and Sutton Bonington University Farm, Leicestershire, Canopy Management resulted in average savings in N of 35 and 10 kg $ha^{-1}$ in 1993 and 1994, respectively, compared to conventional practice. Overall the effect of Canopy Management was a yield increase of just over 0.1 t $ha^{-1}$ and an economic benefit of almost £10 $ha^{-1}$. In a series of satellite experiments, half of the site-seasons showed improved performance, but a number of comparisons in the dry seasons of 1994 and 1995 were unfavourable to Canopy Management. The objective in the present work is to investigate whether this is a consistent problem, and if so how best such a problem might be overcome.

Findings reported in Project no. 0070/1/91 suggested Canopy Management may predispose crops to greater yield loss in drought-affected sites. Previously it had been thought that, in dry conditions, smaller canopies with Canopy Management (GAI on average diminished from 7.1 to 6.0) would use less water before flowering, conserving more for grain filling. However, the associated reduction of 60 shoots $m^{-2}$ with Canopy Management may have reduced the amount of soluble stem carbohydrate accumulated, depressing tolerance of drought. Additionally, smaller vegetative growth with Canopy Management (crop biomass at GS61 on average smaller by *c.* 1 t $ha^{-1}$) may have diminished root growth, which occurs mainly from GS 31 to GS 61, again potentially increasing the vulnerability of Canopy Management crops to drought. The specific objectives of the current work were therefore to quantify effects of differences in canopy size, mediated through fertiliser N management, on (1) rooting depth and activity, (2) water uptake pre-flowering, (3) accumulation of soluble stem carbohydrate reserves, and (4) tolerance of late-season drought expressed at the level of grain yield.

There was one experiment of standard design in each of two seasons, 1996-7 and 1997-8. The variety used was Mercia. Two trickle-irrigation treatments (fully irrigated until complete canopy senescence and irrigated up to GS 59 only) were randomised as main plots and five fertiliser N treatments as sub-plots in a split-plot randomised block design. The five N treatments were : N1, nil N applied, and N2 - N5 each with four equal splits of N prills applied fortnightly starting in mid March, late March, early April and late April, respectively. The total amount of N applied to treatments N2 – N5 was the same; the total applied was 220 kg $ha^{-1}$ in 1997 and 180 kg $ha^{-1}$ in 1998.

### Results and discussion

*Effects of irrigation treatments on soil moisture deficit*

In 1997, due to June rainfall (114 mm) well above the long-term average, drought (defined as soil moisture deficit, SMD > 96 mm, i.e. that equating to 50% of available water, AW) only occurred for a short period in the treatment irrigated to GS 59, from 7-11 June and then from 20 July onwards (Appendix Figs 2.2.1 and 2.2.2). Differences between irrigation treatments in the duration and severity of drought imposed were effectively negligible. Similarly in 1998, SMD differences were always small due to high April (105 mm) and June (126 mm) rainfall, and late drought was absent. Present results therefore focus mainly on the effects of N treatments averaged across irrigation treatments.

*Effect of N treatments on shoot number, canopy size and stem reserves*

Amongst the four treatments where fertiliser N was applied, N3 was closest to conventional practice and N5 (late phasing of N) closest to Canopy Management. This was reflected in the larger maximum GAI for N3 compared to N5 : 6.4 vs 5.7 in 1997 and 7.8 vs 7.3 in 1998 (Appendix Fig. 2.2.4b). Of the four treatments where N fertiliser was applied, N3 amassed most stem reserves in both years (Appendix 2.2 Table 2.2.8). The decrease with later phasing of N at N5 was only marginal, in the order of 0.1 – 0.2 t $ha^{-1}$. It was noticeable that at nil N (N1) more stem reserves were amassed than in the other four N treatments in both years, the advantage being *c.* 0.4 t $ha^{-1}$ (Table 2). This is likely to be due to N deficiency depressing protein synthesis and thereby indirectly contributing to an increase in the pool of simple sugars available for storage in the stem. Later phasing of N at N5 diminished final ear number by 61 $m^{-2}$ and green area index by 0.7 in 1997 (Table 2), similar to the reported Canopy Management effects (HGCA, 1998a). Ear number was not depressed in 1998, but GAI was by about 0.5. Green areas were generally larger in 1998, associated with a higher background amount of soil residual N of 111 kg $ha^{-1}$ in February compared to 67 kg $ha^{-1}$ in 1997.

**Table 2.** Harvest ear number, maximum green area index and stem reserves shortly after flowering in 1997 and 1998.

| | Ears $m^{-2}$ | | Maximum GAI | | Stem reserves t $ha^{-1}$ | |
|---|---|---|---|---|---|---|
| | 97 | 98 | 97 | 98 | 97 | 98 |
| N1 (Nil ) | 480 | 594 | 3.5 | 6.4 | 2.6 | 1.6 |
| N2 (Early) | 664 | 621 | 6.2 | 8.6 | 2.0 | 1.1 |
| N3 (Early — intermediate) | 626 | 636 | 6.4 | 7.8 | 2.2 | 1.4 |
| N4 (Intermediate – late) | 603 | 595 | 5.9 | 8.0 | 1.6 | 1.3 |
| N5 (Late) | 565 | 637 | 5.7 | 7.3 | 2.0 | 1.2 |
| LSD N | 58.8 | 61.2 | 1.14 | 0.86 | 0.51 | 0.34 |
| Prob. | < 0.001 | NS | < 0.001 | < 0.001 | < 0.01 | < 0.001 |

*Water uptake*

Canopy differences were largest in 1997 and this year provided the best test of the effects of adjusting canopy size on pre-flowering water use. Diminishing maximum GAI from 6.4 to 5.7 (N3 vs N5) conserved 20 mm more water in the soil profile on 10 June (GS 61 occurring on 7 June) (Appendix 3.2 Fig. 2.2.6b). This saving equates to an additional 1.0 t $ha^{-1}$ of grain in a dry year, assuming a water use efficiency of 5 g $m^{-2}$ $mm^{-1}$. Decreasing the maximum GAI from 6.4 (N3) to 5.9 (N4) again resulted in a saving of water use to 10 June, in this case of 17 mm. The restricted water consumption to flowering with smaller maximum GAI in N5 would be advantageous on lighter, drought-prone soils in dry years where total water supply is limited.

The wet summer meant that total water uptake was largely independent of rooting depth and density, as the upper soil profile was continually replenished. During grain filling from 10 June to 30 July, N5 extracted a similar amount of water to N3 (Appendix 3.2 Fig. 2.2.6). This is consistent with green canopy area during grain fill being broadly similar for N3 and N5, despite the larger maximum GAI for N3. The maximum depth of extraction was unaffected by the depressed canopy size in N5 (Appendix Fig. 2.2.7). Furthermore, water uptake for N5 was generally similarly distributed with respect to soil depth to that in N3. There was thus no evidence for proportionately more water uptake deeper in the profile for N5, indicating root density in the upper profile was not reduced compared to N3 to the extent that it became necessary to draw more water from deeper to satisfy crop demand.

*Grain yield*

There were no significant differences between irrigation treatments in either year (Appendix table 2.2.9). In 1997, N2 to N5 treatment differences were not significantly different. In 1998, yields were greater with later phasing of N, due mainly to better canopy persistence associated with improved N uptake at N4 and N5 (Appendix Fig. 2.2.8b).

## Conclusions

- At core sites at Sutton Bonington and ADAS Boxworth, the yield benefit from Canopy Management was diminished in years with greater severity of drought : 0.14 t $ha^{-1}$ 1993; 0.08 t $ha^{-1}$ in 1994 and 0.04 t $ha^{-1}$ in 1995. In six satellite sites in 1995, Canopy Management was beneficial at two (average increase of 0.29 t $ha^{-1}$), but there was an average reduction of 0.53 t $ha^{-1}$ at the other 4 sites.
- Smaller stem reserves with a GAI decrease commensurate with that of Canopy Management in present experiments (average stem reserves decrease of 0.20 t $ha^{-1}$, N3 vs N5) appeared insufficient to explain yield reductions observed previously with Canopy Management.

- Canopy size decreases commensurate with Canopy Management diminished water use pre-flowering by in the region of 20 mm. These GAI decreases (1) did not depress the depth of maximum extraction of water, and (2) showed little evidence for large reductions in root density in the upper 1 m of the profile.
- The benefit to the industry from applying Canopy Management, on the basis of core sites at Sutton Bonington and ADAS Boxworth, was estimated as £10 $ha^{-1}$. Applied to the whole of the UK wheat area, the benefit would be *c.* £20 Million p.a.. The annual incidence of yield-limiting drought in wheat fields is *c.* 15% (Foulkes *et al.*, 1998). Present findings suggest that the figure £20 Million p.a. for the benefit of Canopy Management does not need to be revised downwards in order to account for any effects on drought-prone soils. Findings indicate that the figure for the annual benefit to the industry might actually be larger than £20 Million p.a., if the differential effects on drought-prone soil types were taken into account.

## 3. APPROPRIATE FUNGICIDE-DOSE ACCORDING TO HOST NUTRIENT STATUS

The husbandry experiments described in this section were designed to follow on from the results of two previous projects funded by MAFF and HGCA. The MAFF Open Contract CSA 2149 described how increasing the nutrient status of a wheat canopy by increasing fertiliser inputs increased the severity and epidemic development of yellow rust (*Puccinia striiformis*). The HGCA-funded Appropriate Fungicide Dose (AFD) series of experiments demonstrated that the fungicide dose required was dependent on disease severity and type (i.e. yellow rust versus *Septoria*). As a consequence, less severe epidemics generally required lower fungicide doses. By combining the ideas behind these two sets of experiments it was possible to test the hypothesis that using the canopy management 'rules', i.e. by manipulating nitrogen inputs (as compared to conventional N inputs), the severity of yellow rust would be decreased. A decrease in yellow rust severity would therefore lessen the required fungicide dose whilst still achieving an acceptable level of disease control, thereby maintaining profitability.

The objective of these experiments was to use variable nitrogen inputs to manipulate the crop canopy and then apply differential fungicide doses in order to control the resulting disease epidemics. Nitrogen was applied at five input levels:- 0, 80, 160, 240 and 320 kg N/ha with fungicide doses applied at 0 (untreated), 0.125, 0.5, 1.0 and 2.0 doses at three spray timings. The yellow rust susceptible varieties Slejpner and Brigadier were used in the experimental years 1996/97 and 1997/98 respectively. Measurements of disease severity, crop canopy size and harvest parameters were recorded throughout the season.

### Results and discussion

As in previous studies, the severity of yellow rust increased with increasing nitrogen input (Figure 3). Host nutrition also had an influence on mildew severity although disease levels were low. In subsidiary experiments on the susceptible variety, Riband, *Septoria* severity increased with increasing N input on leaf 3 but not leaf 1 or 2. It is likely that the mechanism by which nitrogen input affects the severity of *Septoria* differs from mildew and yellow rust which are both biotrophs. *Septoria* is a necrotrophic pathogen and is less dependent on host nutrient status. Disease development is therefore more likely to be influenced by canopy architecture and micro-climate.

Yellow rust control on nitrogen manipulated crops was achieved at low doses of fungicide at low N input levels. Control of symptoms on leaf 2 at doses>0.5 was achieved at all N levels. *Septoria* was also present at low levels, control at low doses was less effective than with yellow rust with some symptoms still present at 0.5 dose.

Optimum yield in 1997 (Figure 4) and 1998 occurred with nitrogen applications of 92 and 161 kg/ha N respectively. With optimum N, GAI at GS39 was 5.6 in 1997 and 6.5 in 1998, close to the theoretical optimum. Fungicides gave relatively good control of yellow rust in this study, the benefit from increasing dose being more pronounced in 1997 than 1998. When yield, nitrogen input and fungicide dose were taken into account, maximum profit in both years was achieved with a total fungicide dose of 1.0 (3 applications of 0.33).

The standard N amount on this site with this yield potential would be 240 to 250 kg N/ha. At this level of N input maximum output would have required two full doses of fungicide in 1997 and one full dose in 1998. The combined effects of less expense on fertiliser in both years, less expense on fungicide in 1997, and better yields by 0.1 t/ha in 1997 and 0.35 t/ha in 1998, were for the Canopy Management approach to increase margins over input costs by £70/ha in 1997 and £38/ha in 1998.

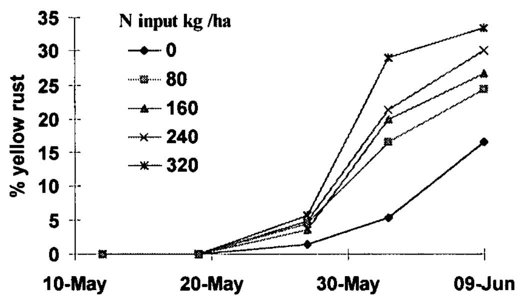



**Figure 3.** Yellow rust severity on leaf 2 in untreated plots at five N rates in 1997.

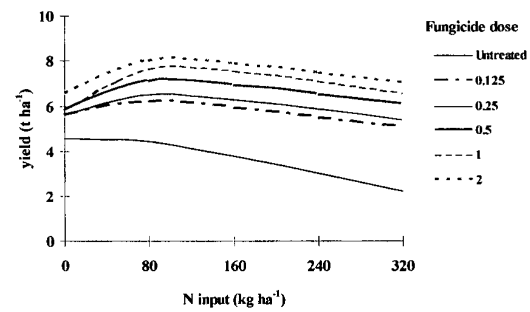



**Figure 4.** Yield (t/ha) at increasing fungicide dose at five N rates in 1997.

### Conclusions

- N opt. for yield was 92 kg/ha in 1997 and 161 kg N/ha in 1998 which related to canopy sizes of between GAI 5 and 6.
- Yellow rust was controlled at low doses of fungicide, however, pathogens such as *Septoria* are less likely to be controlled at these low fungicide doses.
- Canopies of optimal size were at less risk of disease than larger canopies (achieved with higher nitrogen inputs). Thus, it is necessary to apply nitrogen to achieve optimum canopy size, and then adjust fungicides accordingly.
- Improved margin over input costs due to joint optimisation of both N and fungicide inputs was £70/ha in 1997 and £38/ha in 1998.

## 4. ASSESSMENT OF CROP PROGRESS

The HGCA Wheat Growth Guide and the detailed research reports underlying it have increased the availability of information on usual crop states at each growth stage in wheat. The Guide established a system of benchmarks for wheat management. This supported strategic planning of the most likely time of husbandry operations. However, no two crops are the same. Differences in site, season, sowing date and variety will change the timings required for operations in a particular crop. Acquisition of this information is currently difficult (sometimes destructive, and often labour intensive). Although remote sensing techniques may eventually make this information more readily available, an intermediate step is to provide 'live' information from ground observations of growth and development in 'reference' crops. This project addressed the speed with which 'live' intelligence from reference crops could be made available, and tested how benchmarks would need to be altered to account for variety changes.

Crops of Mercia (all years) and Consort (harvest 1997 and 1998) were grown as 'reference crops' (i.e. with optimal fungicide and fertiliser programmes to maximise yield) at Boxworth, Rosemaund and Sutton Bonington. Measurements were as described in *How to Run a Reference Crop* (Gay *et al* 1998). Further details are given in Appendix 4, Table 4.1.

## Results and Discussion

Generally timing of growth stages followed the pattern established by the benchmark crops, although stages 30 and 31 were earlier than they had been in the crops contributing to the benchmark crop. A particular feature noted in the early part of the year was that the time between successive growth stages was very variable, due to the variable weather at this time of year. Leaf production was completed up to 10 days earlier than in the benchmark crops, with the obvious consequences for the timing of flag leaf protectant sprays. In general ear emergence (GS 59) was within a week of the benchmark date except at Rosemaund in 1997.

If we compare the dry weight and green area production of these crops with that of the benchmark crop then those crops that had particularly early development of large GAIs, Rosemaund 1997 and Boxworth 1998 had dry weights higher than the those of the benchmark crops. The dry weight accumulation with time of the crop with the lowest GAI (Boxworth 1997) was reasonably close to the benchmark values. This confirms that dry weight accumulation represented by the benchmark values is likely to be a robust guide for the majority of crops although it may need significant modification for crops which have a lot of early leaf.

*Mercia versus Consort*

One of the potential problems with benchmark values and reference crops is that the varieties grown will change as better varieties become available. As part of the current experiments the consequences of such a change for the benchmark system were studied by comparing Mercia and Consort in 1997 and 1998. Generally the two varieties had similar initial GAI development, except at Sutton Bonington where there was a delay in leaf production in Consort. This may be related to short term manganese deficiency which can occur on this site, and to which Consort is particularly sensitive. However the time course of leaf senescence differed between varieties and in most crops GAI and LAI began to decline earlier in Mercia than in Consort. A consequence of this was that the early course of total dry weight and ear growth were similar in the two varieties, but the latter stages of grain filling continued for longer in Consort resulting in significantly higher grain yields, ear weights and total dry weights at harvest. The higher yields in Consort were achieved through higher numbers of grains per ear and greater weight per grain, effects large enough to overcome the lower number of ears per unit area. A further consequence of the longer duration of grain growth was a lower harvest index in Mercia than Consort. Since total nitrogen uptake was similar for the two varieties, it is not surprising that grain protein concentration was lower in Consort. In general, it appears that the growth of Mercia and Consort was very similar until the end of grain filling and thus benchmarks developed for Mercia are likely to be useful in Consort, particularly as there are few further management inputs after this time.

*The use of live information on the growth and development of wheat in managing crops.*

The data here show that in managing crops it is not sufficient to rely on benchmarks alone, since differences between sites and seasons may often result in the need for changing the timing of inputs. It has also demonstrated the need for information covering a number of sites since in some years (1996 and 1997) there were significant differences between regions in factors such as the development of GAI; whilst in other years no differences were observed between sites. Thus there is a need to collect data similar to that gathered here and to make it rapidly available to the industry. In this project it was feasible to provide this information and update it weekly. A short trial was also conducted using rapid electronic dissemination, and it was found that over a two month period the number of times the information was accessed by a group of users doubled in spite of no promotional activity, suggesting that live information on growth is likely to be extremely popular. The information likely to be of most use to the industry is that directly affecting farming operations, such as timing of spray and fertiliser applications. Well distributed reference crops could be used to inform the industry in which areas the spray timings are likely to be early or late in a particular season. They could also be used to inform the industry when canopies are likely to be large or small in the early spring to allow the reduction (large canopies) or increase (small canopies) in amounts of early fertiliser applications. It was also noted that duration of grain filling across the two varieties used was much more variable than the rate of ear growth, and thus monitoring of ear growth may give advance information on likely yields, which may be useful in planning marketing of grain.

*Methods for in-field assessments of green area index*

A draft GAI method was evaluated by 40 undergraduates on 10 plots of Brigadier and 10 plots of Soissons wheat in April 1997. Difficulties in interpretation were encountered and several changes were made to the draft text to improve its use. This enabled a more user-friendly version to be published in HGCA literature. The GAI method relies on assessing shoot and green leaf numbers and multiplying by a standard value for area per leaf, depending on the growth stage. The method was re-used on Reaper by 36 undergraduates in April 1998, and area per leaf was measured. The GAI was checked using a Delta T leaf area meter. The standard value of 12 $cm^2$ for area per leaf compared to a measured value of 15 $cm^2$. Mean GAI, calculated using the Mercia area per leaf was 2.46 and 3.07 using the Reaper area per leaf. The Reaper area per leaf value gave a GAI very similar to that measured with the Delta T area meter (2.97; SEM = 0.247). This varietal difference was of the same order as differences in GAI between observers. It is therefore likely that corrections for variety differences would only be needed in situations requiring high accuracy.

## GENERAL CONCLUSIONS

Application of an improved understanding of wheat growth and yield formation has been shown to provide significant benefits in financial performance of crops compared to conventional methods. Choice of variety according to defined physiological criteria was shown to improve margins of non-first wheats by £20/ha, and according to sowing date by a further £28-42/ha. A Canopy Management approach to nitrogen nutrition has been shown to be worth on average £10/ha, and was shown to be robust even in droughty conditions. These benefits were enhanced when the potential savings in disease control costs were taken into account, ranging from £38 to £70/ha.

The total benefit from improved crop intelligence was estimated to be of the order of £80-100 per ha. This total is similar to the benefits estimated by different means in previous research (Sylvester-Bradley 2000). There is therefore good evidence for these findings to be promoted with confidence through separate technology transfer projects such as that funded under the Sector Challenge arrangements.

## Appendix 1

## VARIETY SUITABILITY TO SOWING DATE

### INTRODUCTION

Wheat is now drilled over a wider range of dates than ever before. Increased unit size, reduced labour, a perception that ever earlier drilling increases yield, and delayed harvest of high value root crops have resulted in sowing dates spread over as much as 5 months. The choice of variety across this range of sowing dates is currently given little consideration. Information on variety suitability to sowing date in the NIAB Variety Handbook (HGCA 1999) shows little difference in yield between early and late drilling and few changes in variety ranking. Fielder (1988) demonstrated some varietal sowing date suitability, these were generally by named variety and to a large extent due to standing power and disease resistance differences. Within the industry there has long been a perception that slow developing varieties are better suited to early drilling and fast ones to late. The rate of development is frequently demonstrated by the rate of apical development (date of double ridges) although the popularity of this has not been widespread possibly due to the time and expense required for the apical dissections. In practice a few varieties have gained popularity over the years for suitability to particular sowing dates, particularly late sowings after root crops (e.g. Fenman and Soissons). Such examples are however rare due to the perception that high yielding slow developing varieties although they loose yield faster with delayed sowing still yield more when late drilled than physiologically better suited varieties.

Previous HGCA funded work (Kirby *et al*, 1998), highlighted some of the weaknesses of the way we were looking at wheat development in the past, particularly the usefulness (or otherwise) of double ridges which is physiologically meaningless to the crops development. It also hypothesised a new approach to understanding variety sowing date interactions, in which the timing of flowering or the start of grain filling is key. Understanding gained through other HGCA funded projects (e.g. Sylvester-Bradley *et al*, 1998) of how wheat grows and produces its yield shows that we should not be pursuing increases in total crop growth but rather optimising the main yield forming processes. As you progress through the year in the UK incident radiation increases to a maximum in May - July and then declines, temperature meanwhile lags not reaching its peak until July. As temperature increases, crop development rate increases shortening the duration of any growth phase. Therefore, at any given level of radiation in warmer temperatures the growth during a certain developmental phase will be less. In order to achieve maximum yield we therefore want grain filling to begin in early May, when temperatures are low and radiation high. However, previous works showed that this objective must be tempered with an awareness that as the crop develops it becomes more sensitive to frost, and variety and sowing date combined to delay the start of stem extension until after significant risk of hard air frosts has passed, and ear emergence until after significant risk of ground (radiation) frost has passed.

## MATERIALS AND METHODS

The project consisted of 2 experiments carried out in each of 2 years at ADAS Rosemaund on a silty clay loam soil.

### Treatments

***Experiment 1. Variety typing***

Twenty varieties were included over harvest years 1997 and 1998, 15 of which were common to both years (Table 1.1). The varieties included well established ones on which information on responses and physiology already exists to put the work in context with previous work. The remaining varieties were new or 'up and coming' varieties to increase the relevance of the work to the levy payer. Each variety was sown at both an early (29/9/96 & 26/9/97) and late (14/11/96 & 16/12/97) sowing date in each year.

Table 1.1. Varieties included in typing trials for 1997 and 1998 harvest years.

| 1997 | 1998 |
|---|---|
| ABBOT | ABBOT |
| AVALON | AVALON |
| BRIGADIER | BRIGADIER |
| BUSTER | BUSTER |
| CADENZA | CADENZA |
| CAXTON | CAXTON |
| CHARGER | CHARGER |
| CONSORT | CONSORT |
| CROFTER | - |
| DRAKE | DRAKE |
| - | EQUINOX |
| - | HARRIER |
| HAVEN | HAVEN |
| MERCIA | MERCIA |
| RALEIGH | - |
| - | REAPER |
| RIALTO | RIALTO |
| RIBAND | RIBAND |
| SOISSONS | SOISSONS |
| SPARK | SPARK |

***Experiment 2. Sowing date response***

The experiment consisted of six varieties which were selected on evidence from previous studies as those which demonstrated different developmental characteristics (Table 1.2). They were targeted to be sown on six dates at 15 day intervals from late Sept - mid December in harvest years 1997 and 1998 (Table 1.3).

Table 1.2. Varieties and rational for use in the sowing date response experiments

| Variety | Rational for choice |
|---|---|
| Brigadier | Medium Phyllochron |
| Buster | Short Phyllochron |
| Cadenza | Low vernalisation, low photoperiod response |
| Consort | Long Phyllochron |
| Soissons | High vernalisation, low photoperiod response |
| Spark | Low vernalisation, high photoperiod response |

Table 1.3. Actual drilling dates achieved for harvest years 1997 and 1998

| Time of sowing | 1997 | 1998 |
|---|---|---|
| 1 | 30/09/96 | 26/09/97 |
| 2 | 14/10/96 | 10/10/97 |
| 3 | 29/10/96 | 24/10/97 |
| 4 | 13/11/96 | 13/11/97 |
| 5 | 28/11/96 | 5/12/97 |
| 6 | 17/12/96 | 16/12/97 |

**Assessments**

***Experiment 1. Variety typing***

Development rate was observed by the date at which each variety in the early drilled plots reached first node detectable (GS 31) or start of flowering (GS 61). Crop growth, canopy size and biomass distribution was assessed at GS 32 and GS 59 on the first sowing date and pre-harvest on both sowing dates. Photosynthetically active radiation (PAR) interception was measured at GS 32 and GS 59 and soluble carbohydrate reserves in the stems was measured at GS 61 + 75°C days on the early sowing date.

***Experiment 2. Sowing date response***

Date of emergence and plant population was recorded for each treatment. Between March and harvest 5 or 6 samples of cvs Consort, Soissons and Spark were taken on a calendar date across sowing dates to record; crop growth, canopy size, shoot numbers and nitrogen uptake. Lodging was recorded sequentially from its first occurrence, and at each subsequent lodging event. Combine grain yield, thousand grain weight, moisture and specific weight were measured.

## RESULTS AND DISCUSSION

### *Experiment 1. Variety typing*

There was a wide range in the dates of developmental stages both between varieties in a year and between years, despite the drilling dates in the 2 years being only 3 days apart (Table 1.3). The range for the date of GS 31 was 31st March to the 14th April in 1997 but earlier and more protracted in 1998 ranging from 19th March to the 8th April. The date of GS 61 was more similar in the two years ranging from 26th May to the 10th June in 1997 and 24th May to 11th June in 1998 (Table 1.4).

Table 1.4. Dates of reaching First node stage (GS 31) and start of flowering (GS61)

| | Date of GS 31 | | Date of GS 61 | |
|---|---|---|---|---|
| VARIETY | 1997 | 1998 | 1997 | 1998 |
| ABBOT | 08-Apr | 27-Mar | 02-Jun | 02-Jun |
| AVALON | 02-Apr | 27-Mar | 01-Jun | 01-Jun |
| BRIGADIER | 08-Apr | 19-Mar | 04-Jun | 06-Jun |
| BUSTER | 05-Apr | 27-Mar | 04-Jun | 03-Jun |
| CADENZA | 02-Apr | 19-Mar | 01-Jun | 31-May |
| CAXTON | 14-Apr | 27-Mar | 02-Jun | 31-May |
| CHARGER | 08-Apr | 01-Apr | 01-Jun | 02-Jun |
| CONSORT | 14-Apr | 01-Apr | 06-Jun | 08-Jun |
| CROFTER | 08-Apr | - | 06-Jun | - |
| DRAKE | 08-Apr | 01-Apr | 08-Jun | 11-Jun |
| EQUINOX | - | 27-Mar | - | 06-Jun |
| HARRIER | - | 08-Apr | - | 08-Jun |
| HAVEN | 14-Apr | 08-Apr | 10-Jun | 08-Jun |
| MERCIA | 08-Apr | 19-Mar | 04-Jun | 03-Jun |
| RALEIGH | 14-Apr | - | 09-Jun | - |
| REAPER | - | 01-Apr | - | 06-Jun |
| RIALTO | 02-Apr | 27-Mar | 02-Jun | 03-Jun |
| RIBAND | 08-Apr | 08-Apr | 02-Jun | 05-Jun |
| SOISSONS | 31-Mar | 19-Mar | 26-May | 24-May |
| SPARK | 08-Apr | 08-Apr | 08-Jun | 11-Jun |

Plant number established was similar in both years of the experiment with 191 and 200 plants per $m^2$ in 1997 and 1998 respectively, although this represented only about 62% of sown seeds. 'Maximum' shoot number per $m^2$ as measured at GS 32 were slightly higher in 1997 at 800 shoots/$m^2$ compared to 711 in 1998 (Tables 1.5 & 1.6). Inspection of the shoot counts in the reference crops indicates, however, that in 1997 shoot number had been declining for a few weeks before the GS 32 sample but in 1998 shoot number was close to maximum. Total GAI, biomass and nitrogen uptake at GS 32 were lower in 1997 than 1998 (Tables 1.5 & 1.6), this is contrary to the reference crop information. In 1997 very dry spring weather (see annex 1) limited nitrogen uptake, any crop on a low soil mineral nitrogen soil would have experienced a restriction to growth, which may explain the difference between the two crops which were located in different fields. Canopy nitrogen requirement (N:GA ratio) was very similar across the varieties in the 2 years averaging 24 kg/ha N per unit GAI (Tables 1.5 & 1.6).

There was significant varietal variation in 'maximum' shoot number per $m^2$ in 1997, and although varietal rankings were similar in 1998, it did not reach statistical significance in this year. There was also significant varietal variation in total crop biomass and N:GA ratio at GS 32 in both years, and in total GAI and Nitrogen off-take in 1998 only (Tables 1.5 & 1.6).

At GS 59 maximum GAI of the crops in each year correlated well with the observations in the reference crops, being 0.6 GAI smaller in 1998 than in the previous year. Final shoot number also correlated well with the reference crop information for the 2 years, there being an additional 40 shoots per $m^2$ in 1997 than 1998. Total biomass was however greater in 1998 at GS 59 possibly due to the greater early season growth resulting from earlier canopy development (Tables 1.7 & 1.8).

As with the GS 32 growth analysis there was significant varietal variation in most crop parameters measured. Shoot number and total crop biomass varied significantly in both years. There was a range of about 200 shoots per $m^2$ between varieties in both years. Soissons and Brigadier represented the extremes of total crop biomass in both years Brigadier being 3.4 and 5 t/ha larger than Soissons in 1997 and 1998 respectively. Water soluble carbohydrate reserves varied significantly between varieties in both years (Tables 1.7 & 1.8). In 1997 they ranged from 1.42 to 4.21 t/ha in 1998 the range was slightly smaller, from 1.85 to 3.79 t/ha, both of these ranges are in line with those found in previous work (Scott *et. al.* 1998). There was also a significant correlation between the values found in varieties common to the 2 years ($r^2 = 0.79$), indicating a significant element of genetic control over this character.

Pre-harvest growth analysis in both 1997 and 1998 indicated a significant increase in harvest index following delayed drilling (Tables 1.9 & 1.10). This contradicts the commonly held hypothesis that; early drilling increase total biomass production and as harvest index is stable there is a direct increase in yield. There was a significant decrease in pre-anthesis growth in both years as indicated by the straw biomass. This was reflected in a tendency (though not significant) for the later sown crops to have lower ear populations. This reduction in early season growth was however compensated for by a significant increase in grain number per ear and grain weight per ear (1998 only) in the late sown plots (Tables 1.9 & 1.10).

There was a significant reduction in crop yield due to delayed sowing in both years (Tables 1.11 & 1.12). The 46 day reduction in drilling in the 1996/7 season resulting in a yield loss of 1.02 t/ha and the 80 day delay in the second year resulting in a 1.74 t/ha yield loss. Both of these results indicate yield loss at a rate of 22 kg/ha/day delay in sowing, this is similar to the rate found in previous work (Kirby *et al.* 1998). There was, however, a significant interaction between variety and sowing date in 1998 and a close to significant interaction (P = 0.059) in 1997. Choice of Soissons as a variety for late drilling would have reduced the rate of yield loss to 9 and 1 kg/ha/day in 1996/7 and 1997/8 respectively. Growing Brigadier as a late sown variety in 1996/7 or Consort in 1997/8 would have increased the rate of yield loss to 40 or 60 kg/ha/day respectively. The differences in the rate of yield loss due to delayed drilling resulted in significant changes in the ranking of varieties drilled early and late. An example of this is the 3 feed varieties Consort, Haven and Riband in 1998 which yielded 9.5, 9.3 and 9.0 t/ha respectively when early sown, however when sown late the rankings had changed and their yields were 4.5, 8.1 and 6.0 t/ha.

Effects on specific weight and thousand grain weight were generally small and inconsistent, although there was a significant improvement in thousand grain weight due to late sowing in 1997/8. Late sown crops were shorter than early sown in both years although in 1997/8 the average 6 cm reduction main effect was masked by a significant effect of variety on the degree of shortening which ranged from an increase of 0.6cm in Haven to -22cm in Spark.

Table 1.5. 1997 growth stage 32 crop sampling results, time of sowing 1 only.

| | | Shoot no.'s /m2 | | G.A.I. | | | Crop dry matters t/ha | | | Nit offtake Kg/ha Total | N:GA ratio Kg/ha Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variety | Plant No's/m2 | Pot Fertile | Dead & Dying | Leaf | Stem | Total | Green Material | Dd+dy Shts | Total | | |
| ABBOT | 168 | 800 | 120 | 3.3 | 0.4 | 3.64 | 2.93 | 0.06 | 3.24 | 71.5 | 19.9 |
| AVALON | 173 | 812 | 31 | 2.5 | 0.3 | 2.86 | 2.20 | 0.02 | 2.51 | 73.6 | 26.0 |
| BRIGADIER | 188 | 806 | 51 | 2.6 | 0.2 | 2.85 | 2.54 | 0.03 | 2.90 | 67.2 | 22.0 |
| BUSTER | 203 | 671 | 66 | 2.7 | 0.3 | 2.99 | 2.46 | 0.04 | 2.75 | 70.7 | 23.3 |
| CADENZA | 163 | 612 | 32 | 1.7 | 0.2 | 1.90 | 1.78 | 0.02 | 2.04 | 63.9 | 33.9 |
| CAXTON | 174 | 652 | 136 | 2.7 | 0.3 | 3.06 | 2.56 | 0.07 | 2.90 | 58.1 | 19.1 |
| CHARGER | 213 | 829 | 35 | 2.4 | 0.3 | 2.70 | 2.34 | 0.01 | 2.52 | 62.8 | 23.6 |
| CONSORT | 242 | 748 | 39 | 2.3 | 0.3 | 2.57 | 2.43 | 0.03 | 2.80 | 66.0 | 25.3 |
| CROFTER | 182 | 923 | 54 | 2.3 | 0.2 | 2.57 | 2.24 | 0.01 | 2.50 | 60.2 | 23.4 |
| DRAKE | 226 | 1035 | 144 | 2.7 | 0.4 | 3.06 | 3.06 | 0.07 | 3.59 | 73.8 | 24.2 |
| HAVEN | 188 | 833 | 44 | 2.6 | 0.3 | 2.82 | 2.69 | 0.03 | 3.00 | 63.4 | 22.7 |
| MERCIA | 172 | 942 | 25 | 3.1 | 0.4 | 3.47 | 2.58 | 0.01 | 2.89 | 60.3 | 17.4 |
| RALEIGH | 207 | 816 | 100 | 2.5 | 0.3 | 2.84 | 2.74 | 0.06 | 3.26 | 78.4 | 27.7 |
| RIALTO | 172 | 660 | 25 | 2.9 | 0.3 | 3.13 | 2.60 | 0.01 | 2.80 | 76.0 | 24.3 |
| RIBAND | 181 | 805 | 106 | 3.1 | 0.3 | 3.39 | 2.77 | 0.09 | 3.20 | 67.8 | 20.0 |
| SOISSONS | 182 | 712 | 31 | 2.5 | 0.3 | 2.81 | 2.36 | 0.05 | 2.62 | 72.9 | 26.1 |
| SPARK | 221 | 944 | 38 | 2.7 | 0.4 | 3.09 | 2.91 | 0.03 | 3.34 | 78.6 | 26.0 |
| MEAN | 192 | 800 | 63 | 2.6 | 0.3 | 2.93 | 2.54 | 0.04 | 2.87 | 68.6 | 23.8 |
| Variety s.e.d | 32 | 84 | 41 | 0.4 | 0.1 | 0.42 | 0.30 | 0.03 | 0.35 | 10.8 | 3.2 |
| P value | NS | <0.001 | 0.042 | 0.108 | 0.038 | 0.105 | 0.035 | 0.143 | 0.024 | NS | 0.007 |
| df | 32 | 30 | 30 | 29 | 29 | 29 | 30 | 30 | 30 | 30 | 29 |

Table 1.6. 1998 growth stage 32 crop sampling results, time of sowing 1 only.

| | **Plant no.** | **Shoot no.** | | **G.A.I.** | | | **Biomass t/ha** | | | **Nit offtake Kg/ha** | **N:GA ratio Kg/ha** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | potentially fertile | dead and dying | Leaf | Stem | total | green material | dead & dying | total | Total | Total |
| **ABBOT** | 213 | 690 | 43 | 3.07 | 0.04 | 3.42 | 4.91 | 0.47 | 5.38 | 123 | 23.1 |
| **AVALON** | 183 | 627 | 41 | 2.31 | 0.03 | 2.59 | 3.90 | 0.38 | 4.28 | 95 | 22.2 |
| **BRIGADIER** | 228 | 775 | 31 | 2.89 | 0.02 | 3.19 | 5.37 | 0.51 | 5.87 | 124 | 20.9 |
| **BUSTER** | 188 | 591 | 51 | 2.59 | 0.04 | 2.85 | 4.32 | 0.44 | 4.75 | 99 | 20.9 |
| **CADENZA** | 202 | 632 | 80 | 2.63 | 0.09 | 3.08 | 4.21 | 0.49 | 4.7 | 123 | 26.4 |
| **CAXTON** | 220 | 491 | 36 | 3.18 | 0.02 | 3.60 | 3.63 | 0.43 | 4.06 | 102 | 25.5 |
| **CHARGER** | 195 | 807 | 39 | 4.18 | 0.05 | 4.52 | 4.08 | 0.54 | 4.62 | 105 | 23.1 |
| **CONSORT** | 193 | 657 | 4 | 2.72 | 0.00 | 2.96 | 3.50 | 0.37 | 3.87 | 87 | 22.4 |
| **DRAKE** | 194 | 888 | 46 | 3.48 | 0.08 | 3.90 | 3.98 | 0.49 | 4.47 | 103 | 22.9 |
| **EQUINOX** | 241 | 668 | 39 | 3.44 | 0.00 | 3.91 | 3.69 | 0.46 | 4.15 | 117 | 28.0 |
| **HARRIER** | 157 | 814 | 53 | 3.64 | 0.02 | 4.02 | 3.92 | 0.44 | 4.36 | 106 | 24.7 |
| **HAVEN** | 241 | 837 | 18 | 2.93 | 0.03 | 3.22 | 3.81 | 0.42 | 4.23 | 81 | 19.4 |
| **MERCIA** | 178 | 684 | 34 | 2.5 | 0.02 | 2.75 | 4.52 | 0.43 | 4.95 | 112 | 22.5 |
| **REAPER** | 155 | 622 | 23 | 2.77 | 0.03 | 3.13 | 3.28 | 0.37 | 3.66 | 89 | 24.6 |
| **RIALTO** | 204 | 766 | 147 | 2.4 | 0.09 | 2.70 | 3.42 | 0.44 | 3.86 | 112 | 29.1 |
| **RIBAND** | 193 | 608 | 64 | 2.65 | 0.03 | 2.91 | 3.22 | 0.38 | 3.59 | 86 | 23.9 |
| **SOISSONS** | 209 | 682 | 107 | 2.12 | 0.06 | 2.39 | 3.11 | 0.38 | 3.49 | 95 | 27.0 |
| **SPARK** | 201 | 912 | 67 | 3.64 | 0.02 | 3.86 | 4.00 | 0.53 | 4.52 | 118 | 26.1 |
| Mean | 200 | 708 | 51 | 2.95 | 0.04 | 3.28 | 3.94 | 0.44 | 4.38 | 104 | 24.0 |
| Variety s.e.d | 32.9 | 72.7 | 36.8 | 0.47 | 0.07 | 0.52 | 0.29 | 0.03 | 0.33 | 13.4 | 1.96 |
| P value | NS | <0.001 | 0.1 | 0.002 | NS | 0.005 | <0.001 | 0.036 | <0.001 | 0.035 | <0.001 |
| df | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |

Table 1.7. 1997 growth stage 59 crop sampling results and GS 61 + 75°C days soluble stem reserves (WSC), time of sowing 1 only.

| | Shoot no.'s /m2 | | G.A.I | | | | Crop dry matters t/ha | | | WSC |
|---|---|---|---|---|---|---|---|---|---|---|
| VARIETY | Pot Fertile | Dead & Dying | Leaf | Stem | Ear | Total | Green Material | Dd+dy Shts | Total | t/ha |
| ABBOT | 571 | 67 | 5.17 | 1.56 | 0.37 | 7.10 | 10.1 | 0.05 | 10.4 | 1.42 |
| AVALON | 517 | 28 | 4.66 | 1.46 | 0.34 | 6.46 | 9.1 | 0.02 | 9.4 | 2.07 |
| BRIGADIER | 703 | 156 | 6.37 | 1.85 | 0.44 | 8.66 | 12.0 | 0.12 | 12.4 | 3.35 |
| BUSTER | 573 | 14 | 4.85 | 1.54 | 0.35 | 6.75 | 10.8 | 0.00 | 10.9 | 3.07 |
| CADENZA | 512 | 14 | 4.09 | 1.29 | 0.34 | 5.72 | 9.8 | 0.00 | 9.9 | 2.83 |
| CAXTON | 530 | 37 | 5.21 | 1.61 | 0.32 | 7.14 | 8.0 | 0.02 | 10.6 | 2.84 |
| CHARGER | 655 | 62 | 4.64 | 1.51 | 0.46 | 6.61 | 9.8 | 0.04 | 10.0 | 2.86 |
| CONSORT | 650 | 83 | 5.88 | 1.62 | 0.32 | 7.82 | 10.6 | 0.07 | 10.9 | 2.71 |
| CROFTER | 516 | 45 | 5.11 | 1.65 | 0.38 | 7.15 | 11.2 | 0.05 | 11.4 | 2.79 |
| DRAKE | 606 | 67 | 5.97 | 1.78 | 0.41 | 8.16 | 10.9 | 0.04 | 11.2 | 3.37 |
| HAVEN | 599 | 61 | 6.29 | 1.68 | 0.33 | 8.30 | 11.4 | 0.04 | 11.7 | 4.07 |
| MERCIA | 626 | 0 | 4.74 | 1.45 | 0.41 | 6.60 | 10.8 | 0.00 | 11.0 | 2.09 |
| RALEIGH | 614 | 69 | 7.14 | 1.75 | 0.31 | 9.20 | 11.2 | 0.05 | 11.5 | 3.89 |
| RIALTO | 504 | 8 | 5.30 | 1.44 | 0.35 | 7.08 | 11.6 | 0.00 | 11.8 | 4.21 |
| RIBAND | 508 | 84 | 5.22 | 1.07 | 0.29 | 6.58 | 9.4 | 0.05 | 9.6 | 1.46 |
| SOISSONS | 571 | 95 | 4.77 | 1.42 | 0.34 | 6.53 | 8.4 | 0.09 | 8.7 | * |
| SPARK | 636 | 40 | 4.75 | 1.53 | 0.35 | 6.64 | 10.1 | 0.02 | 10.2 | 2.24 |
| MEAN | 582 | 55 | 5.30 | 1.54 | 0.36 | 7.21 | 10.3 | 0.04 | 10.7 | 2.80 |
| Variety s.e.d | 45.4 | 29.5 | 0.41 | 0.22 | 0.05 | 0.57 | 1.07 | 0.03 | 0.7 | 0.06 |
| P value | <0.001 | 0.001 | <0.001 | NS | 0.055 | <0.001 | 0.029 | 0.005 | <0.001 | <0.001 |
| df | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 32 | 26 |

Table 1.8. 1998 growth stage 59 crop sampling results and GS 61 + 75°C days soluble stem reserves (WSC), time of sowing 1 only.

| | shoot no. | | G.A.I | | | | Biomass | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Potentially fertile | Dead and dying | Leaf | Stem | Ear | Total | Green material | Dead and dying shoots | Total | WSC |
| **ABBOT** | 632 | 71 | 4.79 | 1.44 | 0.55 | 6.78 | 13.1 | 0.21 | 14.3 | 2.02 |
| **AVALON** | 436 | 92 | 4.44 | 1.18 | 0.34 | 5.96 | 10.5 | 0.16 | 11.5 | 1.85 |
| **BRIGADIER** | 572 | 98 | 5.13 | 1.26 | 0.48 | 6.88 | 14.4 | 0.30 | 15.5 | 2.73 |
| **BUSTER** | 565 | 112 | 4.50 | 1.20 | 0.43 | 6.12 | 13.6 | 0.37 | 14.9 | 2.75 |
| **CADENZA** | 565 | 4 | 5.10 | 1.51 | 0.34 | 6.95 | 11.5 | 0.01 | 12.6 | 2.44 |
| **CAXTON** | 460 | 45 | 4.34 | 1.00 | 0.33 | 5.67 | 10.7 | 0.35 | 11.8 | 2.57 |
| **CHARGER** | 601 | 164 | 5.01 | 1.24 | 0.41 | 6.66 | 11.4 | 0.29 | 12.2 | 2.64 |
| **CONSORT** | 460 | 101 | 4.85 | 1.11 | 0.36 | 6.32 | 11.2 | 0.19 | 12.0 | 2.58 |
| **DRAKE** | 652 | 153 | 5.46 | 1.47 | 0.44 | 7.37 | 13.3 | 0.34 | 14.3 | 3.23 |
| **EQUINOX** | 448 | 122 | 4.66 | 0.99 | 0.42 | 6.07 | 14.0 | 0.44 | 15.0 | 2.65 |
| **HARRIER** | 582 | 155 | 5.23 | 1.36 | 0.46 | 7.04 | 14.0 | 0.27 | 15.1 | 2.70 |
| **HAVEN** | 565 | 192 | 5.48 | 1.38 | 0.44 | 7.31 | 13.8 | 0.44 | 14.9 | 3.79 |
| **MERCIA** | 683 | 56 | 6.07 | 1.46 | 0.45 | 7.97 | 13.1 | 0.13 | 14.1 | 2.11 |
| **REAPER** | 519 | 121 | 5.61 | 1.33 | 0.40 | 7.34 | 12.4 | 0.31 | 13.5 | 2.79 |
| **RIALTO** | 524 | 132 | 5.66 | 1.37 | 0.39 | 7.41 | 13.3 | 0.43 | 14.7 | 3.47 |
| **RIBAND** | 446 | 143 | 4.24 | 1.32 | 0.37 | 5.93 | 12.0 | 0.35 | 13.1 | 2.21 |
| **SOISSONS** | 586 | 46 | 5.10 | 1.26 | 0.28 | 6.64 | 9.6 | 0.47 | 10.6 | 2.13 |
| **SPARK** | 624 | 108 | 4.83 | 1.41 | 0.43 | 6.67 | 12.8 | 0.19 | 13.6 | 2.16 |
| Mean | 551 | 106 | 5.03 | 1.29 | 0.41 | 6.73 | 12.5 | 0.29 | 13.5 | 2.60 |
| Variety s.e.d | 50 | 38 | 0.56 | 0.16 | 0.05 | 0.72 | 0.8 | 0.18 | 0.8 | 0.25 |
| P value | <0.001 | 0.002 | 0.0134 | 0.083 | 0.002 | NS | <0.001 | NS | <0.001 | <0.001 |
| df | 34 | 34 | 33 | 33 | 33 | 33 | 34 | 34 | 34 | 34 |

Table 1.9. Pre-harvest growth analysis Rosemaund 1997

| | Harvest Index | Biomass t/ha Straw & Chaff | Grain | Total | grain wt/ear | grain no/ear | ear no /m |
|---|---|---|---|---|---|---|---|
| **Early Sown** | | | | | | | |
| **ABBOT** | 52.8 | 8.2 | 9.2 | 17.3 | 1.76 | 43.5 | 519 |
| **AVALON** | 49.2 | 8.7 | 8.4 | 17.1 | 1.77 | 39.3 | 508 |
| **BRIGADIER** | 53.9 | 9.6 | 11.2 | 20.9 | 1.95 | 47.2 | 576 |
| **BUSTER** | 52.2 | 9.3 | 10.0 | 19.3 | 1.59 | 39.2 | 641 |
| **CADENZA** | 50.2 | 9.1 | 9.2 | 18.2 | 1.64 | 35.1 | 572 |
| **CAXTON** | 54.9 | 7.2 | 8.8 | 16.0 | 1.93 | 47.1 | 467 |
| **CHARGER** | 54.8 | 7.1 | 8.6 | 15.6 | 1.61 | 42.2 | 541 |
| **CONSORT** | 57.5 | 8.3 | 11.2 | 19.5 | 2.08 | 51.4 | 543 |
| **CROFTER** | 53.3 | 8.0 | 9.1 | 17.1 | 2.15 | 50.0 | 424 |
| **DRAKE** | 51.3 | 9.1 | 9.6 | 18.6 | 1.47 | 37.3 | 650 |
| **HAVEN** | 54.4 | 8.3 | 9.9 | 18.2 | 1.97 | 45.9 | 507 |
| **MERCIA** | 47.1 | 8.8 | 7.7 | 16.6 | 1.24 | 32.4 | 652 |
| **RALEIGH** | 53.5 | 9.1 | 10.5 | 19.6 | 1.77 | 45.4 | 593 |
| **RIALTO** | 50.9 | 7.8 | 8.2 | 16.0 | 1.80 | 48.5 | 456 |
| **RIBAND** | 56.8 | 7.8 | 10.2 | 18.0 | 2.20 | 50.9 | 465 |
| **SOISSONS** | 51.8 | 7.9 | 8.5 | 16.5 | 1.45 | 38.6 | 587 |
| **SPARK** | 51.5 | 9.3 | 9.9 | 19.1 | 1.52 | 43.4 | 648 |
| Mean | 52.7 | 8.4 | 9.4 | 17.9 | 1.76 | 43.27 | 550 |
| **Late Sown** | | | | | | | |
| **ABBOT** | 57.1 | 7.3 | 9.8 | 17.1 | 2 | 50.2 | 530 |
| **AVALON** | 54.8 | 7.8 | 9.5 | 17.3 | 1.99 | 49.4 | 477 |
| **BRIGADIER** | 57.3 | 7.9 | 10.6 | 18.5 | 2.04 | 50.5 | 523 |
| **BUSTER** | 56.0 | 7.7 | 9.7 | 17.3 | 1.94 | 48.4 | 517 |
| **CADENZA** | 58.0 | 7.7 | 10.7 | 18.4 | 2.35 | 53.4 | 467 |
| **CAXTON** | 56.4 | 7.3 | 9.5 | 16.8 | 1.91 | 47.1 | 520 |
| **CHARGER** | 61.5 | 6.7 | 10.7 | 17.3 | 2.24 | 61.4 | 475 |
| **CONSORT** | 56.0 | 7.7 | 9.8 | 17.5 | 2.01 | 51.5 | 488 |
| **CROFTER** | 53.3 | 8.4 | 9.6 | 18.0 | 2.12 | 49.9 | 453 |
| **DRAKE** | 57.1 | 7.6 | 10.1 | 17.8 | 1.74 | 45.9 | 588 |
| **HAVEN** | 56.8 | 7.3 | 9.7 | 17.0 | 2.23 | 53.2 | 434 |
| **MERCIA** | 53.2 | 7.2 | 8.2 | 15.3 | 1.57 | 40.0 | 525 |
| **RALEIGH** | 57.3 | 7.9 | 10.5 | 18.4 | 1.84 | 50.2 | 617 |
| **RIALTO** | 56.0 | 7.9 | 10.1 | 18.1 | 2.15 | 51.9 | 472 |
| **RIBAND** | 57.9 | 7.1 | 9.8 | 16.9 | 2.08 | 50.1 | 480 |
| **SOISSONS** | 58.6 | 6.3 | 8.9 | 15.2 | 1.93 | 52.3 | 462 |
| **SPARK** | 53.3 | 8.6 | 9.7 | 18.3 | 1.41 | 42.3 | 701 |
| Mean | 56.5 | 7.6 | 9.8 | 17.4 | 1.97 | 49.9 | 513 |
| Overall Mean | 54.6 | 8.0 | 9.6 | 17.6 | 1.86 | 46.6 | 532 |
| Sowing Date s.e.d | 0.53 | 0.20 | 0.40 | 0.59 | 0.12 | 3.16 | 37.40 |
| P value | 0.019 | 0.049 | NS | NS | NS | NS | NS |
| df | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Variety s.e.d | 1.50 | 0.49 | 0.45 | 0.79 | 0.14 | 3.67 | 44.91 |
| P value | <0.001 | 0.002 | <0.001 | <0.001 | <0.001 | 0.005 | <0.001 |
| Sowing Date x Variety s.e.d | 2.13 | 0.71 | 0.74 | 1.24 | 0.23 | 5.94 | 72.08 |
| P value | 0.126 | NS | 0.021 | NS | 0.090 | 0.134 | NS |
| df | 64 | 64 | 64 | 64 | 64 | 63 | 64 |

Table 1.10. Pre-harvest growth analysis Rosemaund 1998

| | | Biomass t/ha | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Early Sown** | Harvest Index | Straw | Grain | Chaff | Total | grain wt/ear | grain no/ear | ear no /m |
| **ABBOT** | 47.67 | 8.67 | 9.03 | 1.23 | 18.93 | 1.51 | 41.46 | 597.01 |
| **AVALON** | 37.81 | 8.49 | 5.81 | 0.80 | 15.10 | 1.26 | 31.17 | 462.64 |
| **BRIGADIER** | 47.90 | 8.71 | 9.13 | 1.25 | 19.09 | 1.75 | 42.36 | 525.33 |
| **BUSTER** | 47.00 | 8.39 | 8.36 | 1.06 | 17.81 | 1.68 | 43.66 | 500.70 |
| **CADENZA** | 44.85 | 9.08 | 8.14 | 0.91 | 18.12 | 1.68 | 40.36 | 487.32 |
| **CAXTON** | 51.22 | 7.02 | 8.50 | 1.05 | 16.57 | 1.94 | 49.48 | 438.19 |
| **CHARGER** | 50.40 | 7.53 | 8.65 | 1.04 | 17.23 | 1.53 | 42.58 | 573.76 |
| **CONSORT** | 50.89 | 7.61 | 9.05 | 1.06 | 17.73 | 1.92 | 43.99 | 470.44 |
| **DRAKE** | 44.88 | 8.97 | 8.01 | 0.87 | 17.85 | 1.72 | 40.19 | 468.06 |
| **EQUINOX** | 47.47 | 7.44 | 7.79 | 1.21 | 16.43 | 2.03 | 45.19 | 383.73 |
| **HARRIER** | 46.54 | 8.55 | 8.29 | 0.99 | 17.84 | 1.50 | 34.38 | 556.16 |
| **HAVEN** | 47.64 | 8.71 | 8.87 | 1.05 | 18.63 | 1.85 | 40.57 | 485.31 |
| **MERCIA** | 41.68 | 8.85 | 6.89 | 0.81 | 16.55 | 1.31 | 36.10 | 539.51 |
| **REAPER** | 48.10 | 7.98 | 8.36 | 1.04 | 17.38 | 1.80 | 41.90 | 480.38 |
| **RIALTO** | 46.23 | 9.11 | 8.77 | 1.05 | 18.92 | 1.89 | 44.65 | 463.22 |
| **RIBAND** | 51.40 | 7.98 | 9.81 | 1.28 | 19.07 | 2.26 | 49.98 | 434.67 |
| **SOISSONS** | 44.36 | 7.86 | 6.93 | 0.69 | 15.48 | 1.47 | 40.55 | 476.45 |
| **SPARK** | 43.64 | 9.58 | 8.14 | 0.93 | 18.66 | 1.28 | 37.90 | 642.28 |
| Mean | 46.68 | 8.35 | 8.26 | 1.02 | 17.63 | 1.69 | 41.49 | 499.76 |
| **Late Sown** | | | | | | | | |
| **ABBOT** | 52.65 | 5.89 | 7.89 | 1.15 | 14.93 | 2.12 | 47.70 | 372.04 |
| **AVALON** | 50.43 | 5.57 | 6.66 | 0.95 | 13.18 | 2.46 | 54.08 | 270.79 |
| **BRIGADIER** | 55.20 | 5.76 | 8.39 | 1.07 | 15.23 | 2.23 | 51.52 | 379.25 |
| **BUSTER** | 49.41 | 6.92 | 7.84 | 0.93 | 15.69 | 2.02 | 47.99 | 387.17 |
| **CADENZA** | 52.17 | 5.48 | 7.08 | 0.97 | 13.53 | 2.24 | 45.83 | 321.18 |
| **CAXTON** | 54.00 | 4.50 | 6.57 | 0.83 | 11.90 | 1.93 | 43.43 | 327.50 |
| **CHARGER** | 57.29 | 4.93 | 8.07 | 1.09 | 14.09 | 2.04 | 48.08 | 397.93 |
| **CONSORT** | 51.10 | 3.40 | 4.87 | 0.71 | 8.97 | 2.09 | 53.40 | 208.81 |
| **DRAKE** | 49.70 | 7.22 | 8.20 | 1.07 | 16.49 | 1.91 | 45.80 | 433.41 |
| **EQUINOX** | 56.38 | 5.94 | 9.28 | 1.25 | 16.47 | 2.60 | 51.54 | 361.40 |
| **HARRIER** | 54.79 | 5.79 | 8.29 | 1.11 | 15.19 | 2.10 | 53.29 | 411.78 |
| **HAVEN** | 51.64 | 7.42 | 9.16 | 1.14 | 17.71 | 2.15 | 43.61 | 431.62 |
| **MERCIA** | 51.19 | 6.01 | 7.25 | 0.93 | 14.19 | 1.94 | 43.67 | 377.58 |
| **REAPER** | 53.88 | 5.56 | 7.74 | 1.04 | 14.34 | 2.50 | 54.54 | 314.90 |
| **RIALTO** | 49.18 | 7.58 | 8.28 | 0.99 | 16.85 | 2.17 | 47.06 | 384.05 |
| **RIBAND** | 56.35 | 5.62 | 8.61 | 1.04 | 15.26 | 2.63 | 56.93 | 332.54 |
| **SOISSONS** | 54.10 | 5.81 | 7.92 | 0.93 | 14.66 | 1.89 | 43.99 | 419.82 |
| **SPARK** | 48.74 | 4.53 | 4.99 | 0.78 | 10.30 | 1.63 | 45.52 | 307.90 |
| Mean | 52.82 | 5.78 | 7.66 | 1.00 | 14.44 | 2.16 | 48.92 | 358.15 |
| Overall Mean | 49.72 | 7.08 | 7.96 | 1.01 | 16.05 | 1.92 | 45.14 | 429.63 |
| Sowing Date s.e.d | 0.71 | 0.47 | 0.61 | 0.06 | 1.13 | 0.04 | 0.85 | 44.12 |
| P value | 0.013 | 0.032 | NS | NS | NS | 0.007 | 0.013 | 0.086 |
| df | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| Variety s.e.d | 2.00 | 0.52 | 0.73 | 0.08 | 1.19 | 0.17 | 3.94 | 38.95 |
| P value | <0.001 | <0.001 | 0.002 | <0.001 | 0.002 | <0.001 | NS | 0.002 |
| Sowing Date x Variety s.e.d | 2.84 | 0.86 | 1.17 | 0.13 | 1.98 | 0.24 | 5.48 | 69.37 |
| P value | NS | 0.026 | 0.026 | 0.016 | 0.016 | NS | NS | 0.006 |
| df | 65 | 65 | 65 | 65 | 65 | 65 | 65 | 65 |

Table 1.11. 1996/7 Combine harvested yield (t/ha @ 85% dm), Specific weight (kg/hl), Thousand grain weight (g) and final crop height (cm)

| | | Yield (t/ha) | Specific weight | Thousand grain weight | Crop Height |
|---|---|---|---|---|---|
| **Early Sown** | ABBOT | 10.75 | 79.40 | 45.92 | 78.47 |
| | AVALON | 9.78 | 79.30 | 50.79 | 84.33 |
| | BRIGADIER | 11.57 | 77.10 | 46.36 | 79.07 |
| | BUSTER | 10.65 | 77.17 | 45.95 | 76.13 |
| | CADENZA | 11.31 | 79.40 | 52.21 | 87.67 |
| | CAXTON | 10.37 | 77.67 | 45.83 | 80.20 |
| | CHARGER | 10.80 | 77.47 | 43.37 | 72.80 |
| | CONSORT | 11.43 | 78.30 | 46.02 | 77.07 |
| | CROFTER | 11.25 | 78.67 | 50.01 | 86.73 |
| | DRAKE | 11.54 | 74.97 | 44.50 | 75.53 |
| | HAVEN | 11.81 | 74.83 | 48.64 | 76.60 |
| | MERCIA | 9.44 | 79.33 | 42.28 | 79.20 |
| | RALEIGH | 11.45 | 75.87 | 44.65 | 73.53 |
| | RIALTO | 10.96 | 78.90 | 45.06 | 83.87 |
| | RIBAND | 11.47 | 76.57 | 49.22 | 84.20 |
| | SOISSONS | 9.38 | 80.90 | 43.76 | 78.60 |
| | SPARK | 10.89 | 79.70 | 39.60 | 83.13 |
| | Mean | 10.87 | 77.95 | 46.15 | 79.83 |
| **Late Sown** | ABBOT | 10.01 | 77.43 | 41.21 | 69.33 |
| | AVALON | 9.19 | 76.93 | 45.77 | 76.60 |
| | BRIGADIER | 9.74 | 74.73 | 44.81 | 70.60 |
| | BUSTER | 9.91 | 75.90 | 45.19 | 69.33 |
| | CADENZA | 10.45 | 77.33 | 50.40 | 77.60 |
| | CAXTON | 9.54 | 74.40 | 45.18 | 69.93 |
| | CHARGER | 10.06 | 75.40 | 41.44 | 64.20 |
| | CONSORT | 9.71 | 76.60 | 44.56 | 70.33 |
| | CROFTER | 10.18 | 78.40 | 47.98 | 80.67 |
| | DRAKE | 10.36 | 73.83 | 43.25 | 71.53 |
| | HAVEN | 10.20 | 72.73 | 47.31 | 70.20 |
| | MERCIA | 8.69 | 79.30 | 44.59 | 73.27 |
| | RALEIGH | 10.10 | 71.87 | 41.98 | 67.73 |
| | RIALTO | 10.11 | 77.37 | 46.33 | 73.67 |
| | RIBAND | 9.91 | 74.33 | 46.14 | 73.07 |
| | SOISSONS | 9.02 | 80.50 | 41.75 | 68.07 |
| | SPARK | 10.21 | 79.67 | 38.03 | 79.93 |
| | Mean | 9.85 | 76.28 | 44.46 | 72.12 |
| | Overall Mean | 10.36 | 77.11 | 45.30 | 75.98 |
| | Sowing Date s.e.d | 0.13 | 0.35 | 0.59 | 1.36 |
| | P value | 0.017 | 0.04 | 0.112 | 0.030 |
| | df | 2 | 2 | 2 | 2 |
| | Variety s.e.d | 0.23 | 0.50 | 1.38 | 1.21 |
| | P value | <0.001 | <0.001 | <0.001 | <0.001 |
| | Sowing Date x Variety s.e.d | 0.35 | 0.77 | 1.98 | 2.15 |
| | P value | 0.059 | 0.007 | NS | 0.040 |
| | df | 64 | 63 | 63 | 64 |

Table 1.12. 1997/8 Combine harvested yield (t/ha @ 85% dm), Specific weight (kg/hl), Thousand grain weight (g) and final crop height (cm).

| | | Yield (t/ha) | Specific weight | Thousand grain weight | Crop Height |
|---|---|---|---|---|---|
| **Early Sown** | **ABBOT** | 7.69 | 75.20 | 43.00 | 72.00 |
| | **AVALON** | 6.88 | 74.87 | 47.66 | 76.13 |
| | **BRIGADIER** | 9.15 | 74.70 | 48.82 | 74.13 |
| | **BUSTER** | 8.11 | 73.47 | 45.27 | 75.87 |
| | **CADENZA** | 8.25 | 77.00 | 48.99 | 90.20 |
| | **CAXTON** | 7.83 | 74.53 | 46.16 | 75.53 |
| | **CHARGER** | 8.46 | 74.10 | 42.39 | 71.93 |
| | **CONSORT** | 9.45 | 75.90 | 51.22 | 74.93 |
| | **DRAKE** | 9.08 | 74.83 | 50.43 | 76.07 |
| | **EQUINOX** | 8.54 | 73.67 | 52.90 | 66.33 |
| | **HARRIER** | 9.17 | 74.20 | 49.43 | 73.20 |
| | **HAVEN** | 9.26 | 72.80 | 53.47 | 76.27 |
| | **MERCIA** | 7.13 | 77.37 | 42.85 | 80.40 |
| | **REAPER** | 8.36 | 74.53 | 50.57 | 78.00 |
| | **RIALTO** | 9.10 | 77.07 | 49.95 | 82.80 |
| | **RIBAND** | 9.00 | 73.83 | 53.17 | 78.80 |
| | **SOISSONS** | 6.76 | 78.20 | 42.70 | 74.87 |
| | **SPARK** | 7.67 | 78.23 | 39.64 | 84.80 |
| | Mean | 8.31 | 75.27 | 47.67 | 76.79 |
| **Late Sown** | | | | | |
| | **ABBOT** | 6.52 | 77.07 | 52.40 | 65.87 |
| | **AVALON** | 5.14 | 74.67 | 53.69 | 70.67 |
| | **BRIGADIER** | 7.32 | 75.93 | 50.89 | 70.80 |
| | **BUSTER** | 7.00 | 76.87 | 50.38 | 71.53 |
| | **CADENZA** | 7.55 | 77.43 | 57.61 | 81:80 |
| | **CAXTON** | 6.80 | 76.47 | 52.15 | 67.20 |
| | **CHARGER** | 6.64 | 77.37 | 50.06 | 64.80 |
| | **CONSORT** | 4.55 | 64.53 | 45.05 | 57.93 |
| | **DRAKE** | 6.73 | 71.43 | 49.29 | 71.07 |
| | **EQUINOX** | 8.36 | 75.30 | 59.45 | 65.93 |
| | **HARRIER** | 6.64 | 71.37 | 46.13 | 66.93 |
| | **HAVEN** | 8.15 | 74.83 | 57.79 | 76.87 |
| | **MERCIA** | 5.58 | 78.10 | 52.53 | 74.13 |
| | **REAPER** | 6.83 | 76.20 | 54.16 | 70.60 |
| | **RIALTO** | 7.69 | 78.40 | 54.13 | 80.47 |
| | **RIBAND** | 6.02 | 73.13 | 54.25 | 69.33 |
| | **SOISSONS** | 6.63 | 79.33 | 50.73 | 73.53 |
| | **SPARK** | 2.74 | 68.00 | 37.64 | 62.00 |
| | Mean | 6.57 | 74.93 | 51.84 | 70.08 |
| | Overall Mean | 7.44 | 75.10 | 49.75 | 73.44 |
| | Sowing Date s.e.d | 0.21 | 1.05 | 0.12 | 2.20 |
| | P value | 0.013 | NS | <0.001 | 0.093 |
| | df | 2 | 2 | 2 | 2 |
| | Variety s.e.d | 0.40 | 1.29 | 1.37 | 2.49 |
| | P value | <0.001 | <0.001 | <0.001 | <0.001 |
| | Sowing Date x Variety s.e.d | 0.59 | 2.06 | 1.89 | 4.07 |
| | P value | <0.001 | <0.001 | <0.001 | 0.003 |
| | df | 66 | 66 | 66 | 68 |

***Experiment 2. Sowing date response***

The duration in days between sowing and emergence was shortest in the first and second sowing dates in both years, the interval increasing thereafter as sowing was delayed (Table 1.13). For the last three sowing dates the interval between sowing and emergence was approximately one month longer in 1997 than in 1998, this is a reflection of the November to January temperatures being markedly below and above the long term average respectively (see annex 1). There were indications that there may be varietal differences in the sowing to emergence interval with Cadenza being consistently amongst the quickest to emerge and Brigadier and Consort the slowest. As these were visual assessments the observed differences may be due to morphological differences between varieties, making them appear either more advanced or backward than their neighbours rather than any actual difference in the rate of emergence.

Table 1.13. Date of 50% emergence for 1996/7 and 1997/8

| | Time of Sowing | | | | | |
|---|---|---|---|---|---|---|
| **VARIETY** | **1** | **2** | **3** | **4** | **5** | **6** |
| | | | **1997** | | | |
| **BRIGADIER** | 15-Oct | 27-Oct | 23-Nov | 15-Jan | 06-Feb | 13-Feb |
| **BUSTER** | 12-Oct | 25-Oct | 21-Nov | 14-Jan | 04-Feb | 13-Feb |
| **CADENZA** | 11-Oct | 24-Oct | 19-Nov | 13-Jan | 01-Feb | 12-Feb |
| **CONSORT** | 14-Oct | 26-Oct | 24-Nov | 16-Jan | 08-Feb | 16-Feb |
| **SOISSONS** | 14-Oct | 26-Oct | 21-Nov | 15-Jan | 06-Feb | 16-Feb |
| **SPARK** | 12-Oct | 25-Oct | 21-Nov | 15-Jan | 04-Feb | 15-Feb |
| | | | **1998** | | | |
| **BRIGADIER** | 06-Oct | 28-Oct | 12-Nov | 06-Dec | 12-Jan | 15-Jan |
| **BUSTER** | 04-Oct | 25-Oct | 08-Nov | 03-Dec | 10-Jan | 14-Jan |
| **CADENZA** | 04-Oct | 25-Oct | 08-Nov | 03-Dec | 10-Jan | 13-Jan |
| **CONSORT** | 06-Oct | 28-Oct | 12-Nov | 07-Dec | 13-Jan | 17-Jan |
| **SOISSONS** | 05-Oct | 27-Oct | 09-Nov | 04-Dec | 11-Jan | 14-Jan |
| **SPARK** | 06-Oct | 29-Oct | 13-Nov | 08-Dec | 15-Jan | 19-Jan |

Plant establishment declined with later drilling due to unfavourable ground conditions, this was particularly so with the fifth drilling date in 1997/8 (Table 1.14). There was generally no consistent difference between the varieties with the exception of Spark in the second year, which tended to have poorer emergence, this was related to the batch of seed which had poor germination/vigour rather than an inherent variety characteristic. This effect became more noticeable in poorer drilling conditions, and failed to establish a viable crop at the fifth drilling date.

Table 1.14. Plant establishment in March 1997 and 1998

| Time of Sowing | Brigadier | Buster | Cadenza | Consort | Soissons | Spark |
|---|---|---|---|---|---|---|
| | | | **1996/7 Plants/m² March** | | | |
| **TOS 1** | 251.0 | 238.2 | 245.9 | 255.1 | 257.6 | 256.1 |
| **TOS 2** | 276.0 | 285.2 | 236.7 | 272.0 | 246.9 | 261.2 |
| **TOS 3** | 247.9 | 231.1 | 208.1 | 218.3 | 213.2 | 220.3 |
| **TOS 4** | 208.6 | 200.9 | 202.9 | 202.9 | 207.5 | 233.1 |
| **TOS 5** | 175.3 | 208.1 | 141.1 | 150.8 | 148.2 | 186.1 |
| **TOS 6** | 136.5 | 148.8 | 130.9 | 144.2 | 113.0 | 153.9 |
| | | | **1997/8 Plants/m² March** | | | |
| **TOS 1** | 258.8 | 296.3 | 230.1 | 228.1 | 235.6 | 214.8 |
| **TOS 2** | 239.5 | 276.5 | 225.7 | 166.9 | 219.8 | 148.6 |
| **TOS 3** | 292.3 | 323.0 | 278.5 | 241.0 | 286.9 | 200.5 |
| **TOS 4** | 237.5 | 292.8 | 228.6 | 161.0 | 247.4 | 117.5 |
| **TOS 5** | 118.5 | 80.0 | 84.4 | 84.4 | 120.0 | 27.7 |
| **TOS 6** | 182.2 | 191.6 | 197.5 | 91.4 | 206.9 | 56.8 |

Three of the varieties were selected for more detailed analysis of crop growth which was collected throughout the season. Summaries of the data are presented through the text in graphical form and full data tables are presented in annex 2. Consort was chosen as it is the approved reference crop and representative of the majority of British wheats. Spark and Soissons were also chosen as they show high photoperiod and vernalisation requirements respectively.

At the earliest sampling dates the early drilled crops had significantly higher fertile shoot numbers than later drilled crops. These differences declined however as the crops proceeded through the season, there being no consistent reduction in fertile shoot number with delayed drilling at the later sampling dates (Figures 1.1 & 1.2). Early drilled crops showed a decline in shoot number from the earliest sampling in March or April in both years, later drilled crops, however, continued to produce additional shoots until May or June, from when they remained relatively static.

There was generally a significant effect of variety on fertile shoot number throughout the growing season. In 1997 Spark consistently produced the highest number of shoots per $m^2$ followed by Soissons and then Consort, in 1998, however, Soissons produced on average the largest number of shoots followed by Spark and then Consort. The lower shoot numbers produced by Spark in the second year may relate directly to its poorer establishment but may also indicate poorer vigour of the seed lot. These figures also hide a significant variety sowing date interaction in both years particularly in the earliest two samplings, although the form of the interaction was different in the 2 years. In 1996/7 Soissons produced a similar or higher number of shoots than either of the other 2 varieties in the earliest drillings but significantly fewer in the later drillings. Whilst in 1997/8 the reverse was true, Soissons producing sparser shoot populations in the earliest drillings but higher populations in the later drilling dates. For the later drilling dates in particular the differences between the years may be explained to a large extent by differences in plant establishment.

Crop canopy size measured as green area index (GAI), was significantly larger in 1996/7 peaking at just below 10 in the earliest drilling in May, compared to a maximum of less than 6 achieved in the third sowing measured in early July in 1997/8 (Figures 1.3 & 1.4).

The earliest drilling dates consistently produced the largest canopies in March and April. This effect was not directly related to greater shoot numbers as in 1998 at the March sampling it was the 3rd sowing date which had the largest shoot populations. As the seasons progressed differences between sowing dates diminished, and at the later samplings the latest sowing dates had the largest canopies due to senescence in the earlier sowings.

At the earliest samplings in both years Soissons consistently produced the largest canopy size from the early drillings. This effect was not caused by any significantly greater number of shoots per m$^2$, indeed Soissons often had the lowest shoot populations. Additionally, leaf tagging data from a related HGCA funded project indicates that Soissons does not produce any more leaves than either Spark or Consort at this time of the year, therefore the increased GAI must be due to larger leaves. In the later stages of the season Soissons had a significantly small canopy size than the other varieties, even from the later drillings, this is likely to be due to its faster developmental rate and earlier senescence.

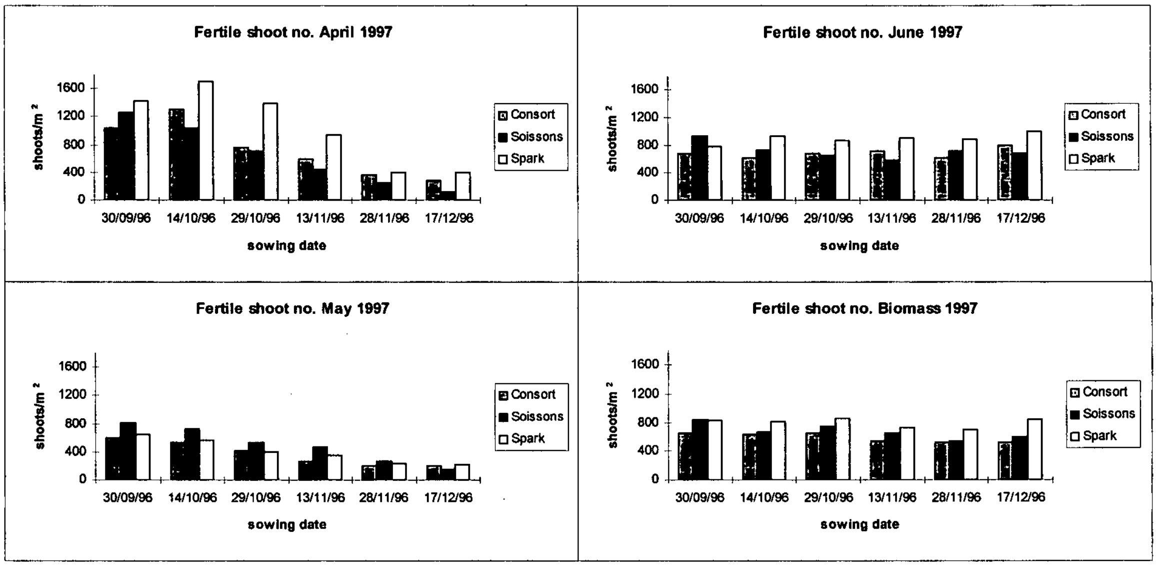



**Figure. 1.1 Fertile shoot number/m$^2$ of Consort, Soissons and Spark 1996/7.**

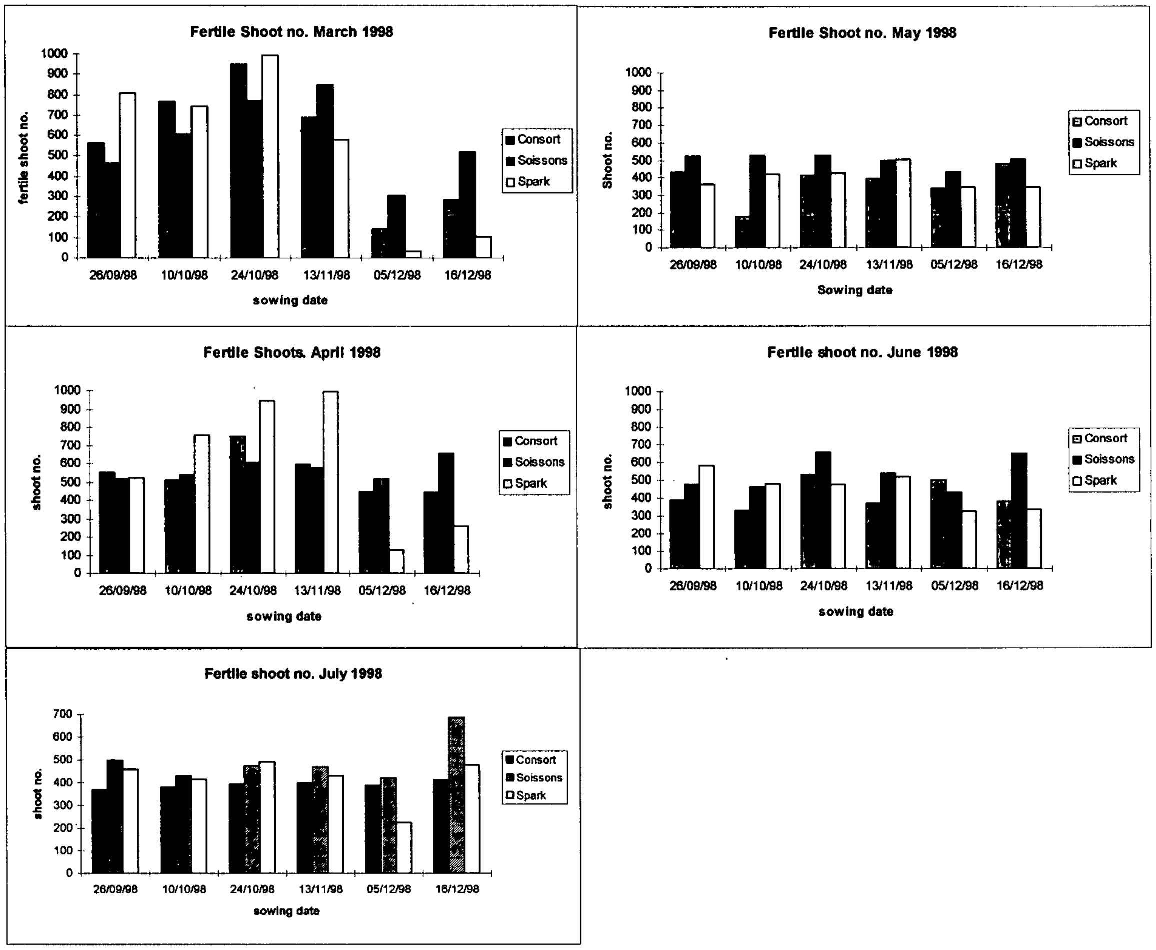



**Figure 1.2** **Fertile shoot number/m$^2$ of Consort, Soissons and Spark 1997/8.**

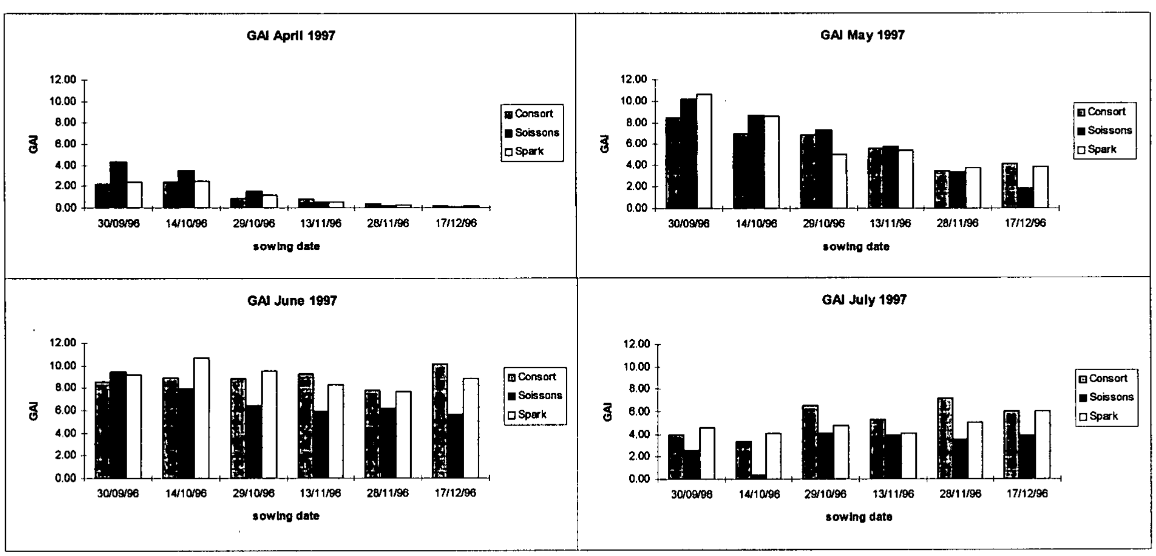



**Figure 1.3. Green area index measurements of Consort, Soissons and Spark in 1996/7.** Each bar is the average of 3 measurements.

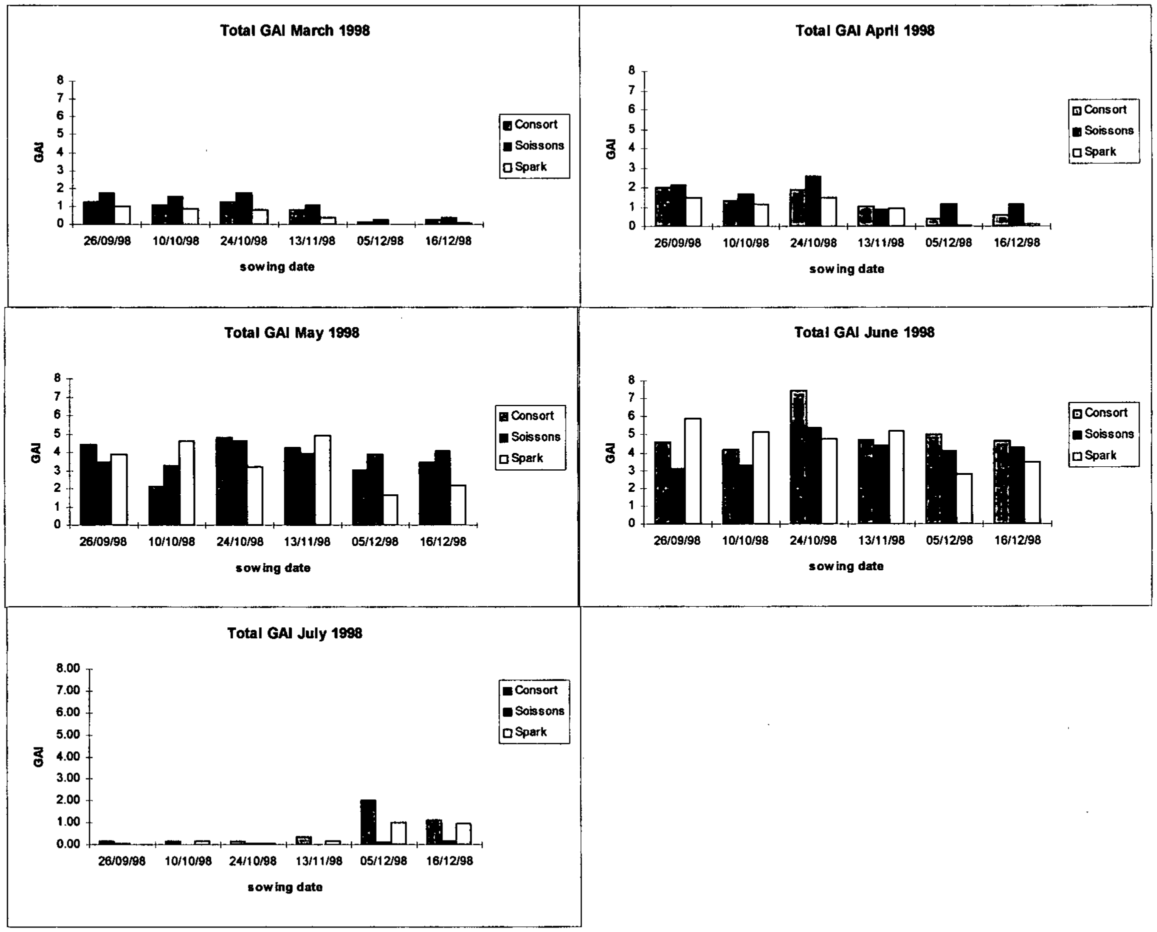



**Figure 1.4. Green area index measurements of Consort, Soissons and Spark in 1997/8.** Each bar is the average of 3 measurements.

The increased canopy size and light interception from early sowing in 1996/97 resulted in significantly greater total crop biomass early in the season. This increased biomass due to early sowing was then maintained through until July. In the second year a different picture emerged with there being little difference between the first 3 sowing dates, at any stage in the season. No particular explanation for this effect could be found, as establishment was not delayed and plant populations were comparable. The later 3 sowing dates tended to display a gradual decline in crop biomass as sowing was delayed but even this effect diminished as the season progressed. By the latest samplings any significant differences between sowings were largely due to the poor establishment of the 5th sowing date.

There were significant effects of variety on biomass accumulation and interactions between variety and sowing date. These were largely due to Soissons showing initial rapid accumulation of biomass, but later in the season the other varieties frequently caught up and eventually accumulated greater biomass overall.

Lodging occurred in both years despite the application of plant growth regulators, the severity and pattern of lodging was however quite different in the two years. In 1996/7 lodging started early (before the end of June) in the earliest drilled crops, but by the end of August was occurring in all sowing dates in the weakest varieties (Table 1.15). Despite this widespread lodging, it was always most severe in the earliest drilled crops.

In the second year the relationship between lodging and sowing date was not so clear, lodging occurring with almost as much severity in the 5th and 6th sowings as in the first, but generally less so in the 2nd 3rd and 4th (Table 1.16).

In both years there was a significant interaction between variety and sowing date. In the first year the optimum sowing date for each variety was dependant on the occurrence of early lodging (Table 1.17). When only the earliest sowing date lodged early, the second sowing date (14th October) produced the highest yield, however if both the first and second sowing date lodged early the third (29th October) produced the highest yield. There tended to be a decline in yield as sowing was delayed from the optimum the rate of decline did however vary depending on variety. The decline in yield was also not always systematic, for example Brigadier produced a higher yield from the last sowing date than from the 4th or fifth.

In the second year all varieties with the exception of Cadenza produced their highest yield from the 3rd sowing date (24th October) (Table 1.18). There was again a decline in yield as drilling was delayed after the optimum, the rate of which was variety dependant. The decline in yield from drillings before the optimum was not however fully explained by lodging as Buster which produced its maximum yield from a 24th October sowing, suffered no lodging in previous sowings.

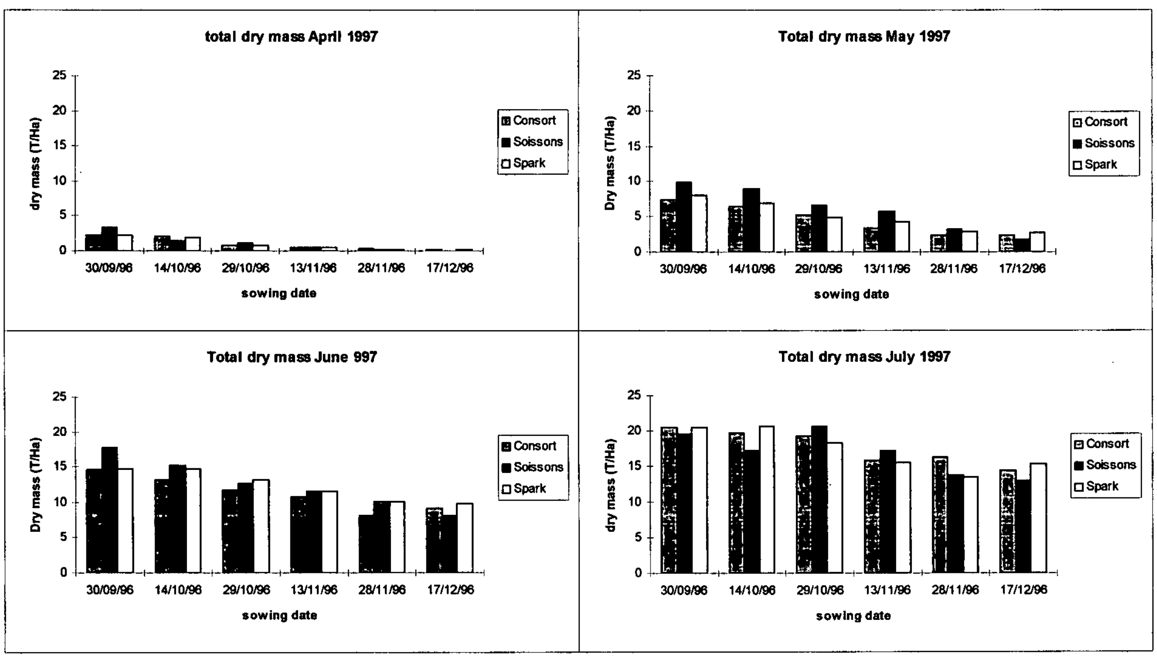



**Figure 1.5. Dry matter accumulation in 1996/7.**

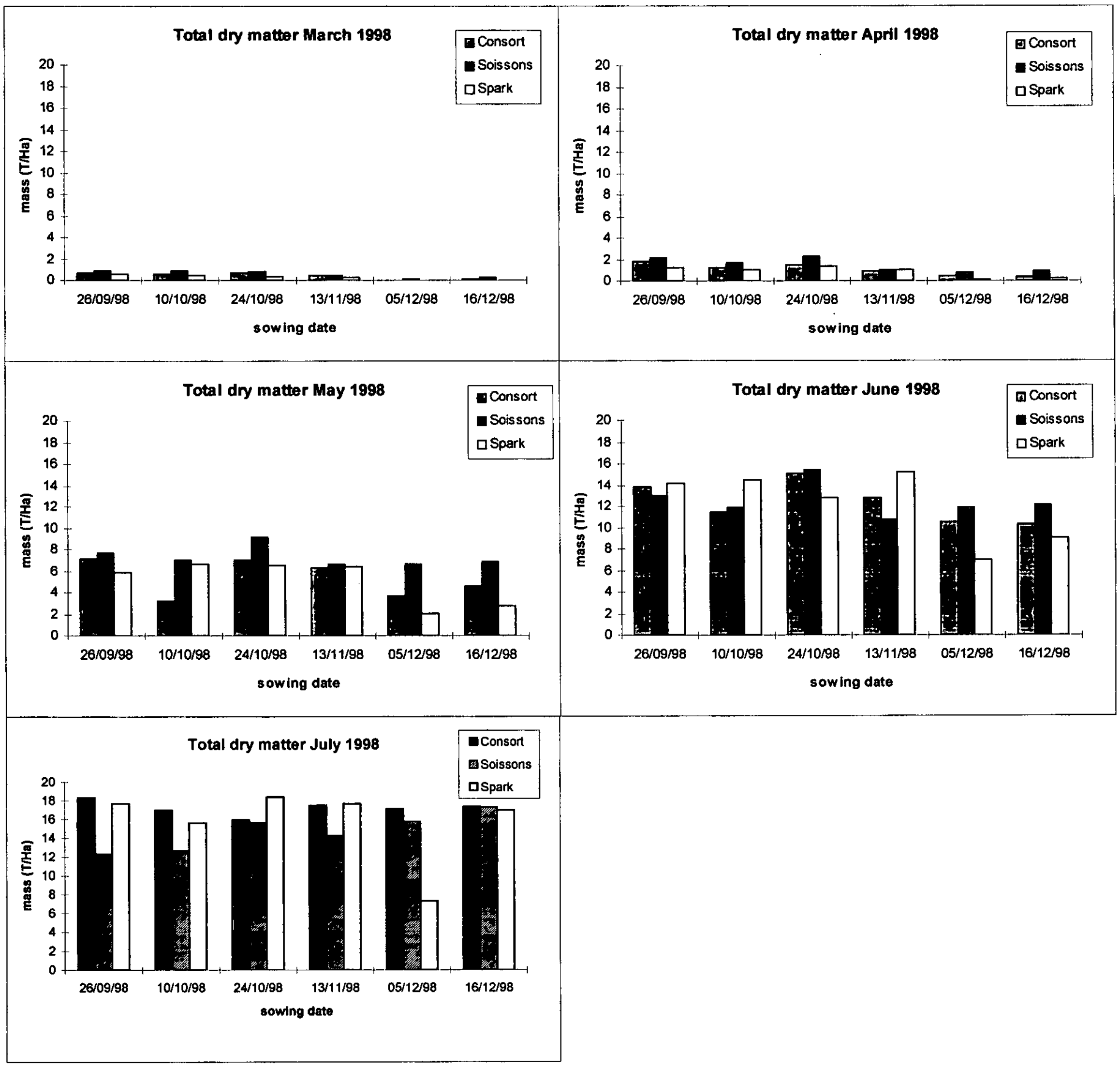



**Figure 1.6. Dry matter accumulation 1997/8.**

Table 1.15. 1996/7 lodging as % of plot area assessed on 30 June and 29 August.

| TOS | Brigadier | Buster | Cadenza | Consort | Soissons | Spark | **Mean** |
|---|---|---|---|---|---|---|---|
| | | | **30/06/97** | | | | |
| **1** | 60.0 | 18.3 | 84.3 | 23.3 | 93.3 | 33.3 | **52.1** |
| **2** | 5.0 | 0.0 | 45.0 | 0.0 | 73.3 | 10.0 | **22.2** |
| **3** | 0.0 | 0.0 | 0.0 | 0.0 | 1.7 | 0.0 | **0.3** |
| **4** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| **5** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| **6** | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | **0.0** |
| **Mean** | **10.8** | **3.1** | **21.6** | **3.9** | **28.1** | **7.2** | **12.4** |
| | | | **29/08/97** | | | | |
| **1** | 70.0 | 30.0 | 100.0 | 93.3 | 100.0 | 70.0 | **77.2** |
| **2** | 46.7 | 0.0 | 71.7 | 43.3 | 86.7 | 46.7 | **49.2** |
| **3** | 30.0 | 0.0 | 36.7 | 23.3 | 5.0 | 43.3 | **23.1** |
| **4** | 30.0 | 0.0 | 56.7 | 30.0 | 0.0 | 20.0 | **22.8** |
| **5** | 20.0 | 0.0 | 31.7 | 6.7 | 0.0 | 0.0 | **9.7** |
| **6** | 0.0 | 0.0 | 6.7 | 3.3 | 0.0 | 0.0 | **1.7** |
| **Mean** | **32.8** | **5.0** | **50.6** | **33.3** | **31.9** | **30.0** | **30.6** |

Table 1.16. 1997/8 lodging assessed as % plot area lodged on 27 August

| 27/8/98 | Variety | | | | | | |
|---|---|---|---|---|---|---|---|
| Sowing Date | Brigadier | Buster | Cadenza | Consort | Soissons | Spark | **Mean** |
| 1 | 13.3 | 0.0 | 50.0 | 0.0 | 38.3 | 0.0 | **16.9** |
| 2 | 0.0 | 0.0 | 21.7 | 1.7 | 10.0 | 0.0 | **5.6** |
| 3 | 5.0 | 0.0 | 11.7 | 10.0 | 8.3 | 3.3 | **6.4** |
| 4 | 0.0 | 3.3 | 6.7 | 5.0 | 5.0 | 5.0 | **4.2** |
| 5 | 6.7 | 0.0 | 38.3 | 35.0 | 0.0 | 0.0 | **13.3** |
| 6 | 0.0 | 0.0 | 36.7 | 30.0 | 0.0 | 0.0 | **11.1** |
| Mean | 4.2 | 0.6 | 27.5 | 13.6 | 10.3 | 1.4 | 9.6 |

Table 1.17. Yield (t/ha) of six varieties sown on six dates in 1996/7.

| | VARIETY | | | | | | |
|---|---|---|---|---|---|---|---|
| Sowing date | Brigadier | Buster | Cadenza | Consort | Soissons | Spark | **Mean** |
| TOS 1 | 7.69 | 9.99 | 6.07 | 8.44 | 5.28 | 7.88 | **7.56** |
| TOS 2 | 10.44 | 10.94 | 7.75 | 10.34 | 7.13 | 8.48 | **9.18** |
| TOS 3 | 10.34 | 10.50 | 10.05 | 9.15 | 10.14 | 8.64 | **9.80** |
| TOS 4 | 9.27 | 9.74 | 9.17 | 8.74 | 9.77 | 8.18 | **9.14** |
| TOS 5 | 8.80 | 9.84 | 9.45 | 8.63 | 9.39 | 8.27 | **9.06** |
| TOS 6 | 9.42 | 9.42 | 9.48 | 8.58 | 8.53 | 8.41 | **8.95** |
| **Mean** | **9.32** | **10.07** | **8.66** | **8.98** | **8.38** | **8.31** | **8.95** |

| | |
|---|---|
| Sowing Date s.e.d | 0.43 |
| P value | 0.008 |
| df | 10 |
| Variety s.e.d | 0.22 |
| P value | <0.001 |
| Sowing Date x Variety s.e.d | 0.65 |
| P value | <0.001 |
| df | 59 |

Table 1.18. Yield (t/ha) of six varieties sown on six dates in 1997/8.

| | VARIETY | | | | | | |
|---|---|---|---|---|---|---|---|
| Sowing date | Brigadier | Buster | Cadenza | Consort | Soissons | Spark | **Mean** |
| TOS 1 | 10.03 | 9.04 | 5.59 | 10.91 | 6.41 | 8.17 | **8.36** |
| TOS 2 | 10.27 | 8.98 | 8.99 | 10.87 | 7.77 | 9.68 | **9.43** |
| TOS 3 | 10.72 | 9.80 | 8.73 | 11.13 | 8.40 | 9.90 | **9.78** |
| TOS 4 | 10.64 | 8.48 | 8.92 | 9.86 | 8.08 | 9.39 | **9.23** |
| TOS 5 | 9.80 | 8.72 | 6.64 | 6.98 | 8.22 | 4.45 | **7.47** |
| TOS 6 | 9.59 | 9.53 | 7.56 | 6.62 | 8.12 | 5.48 | **7.82** |
| **Mean** | **10.18** | **9.09** | **7.74** | **9.40** | **7.84** | **7.85** | **8.68** |

| | |
|---|---|
| Sowing Date s.e.d | 0.85 |
| P value | 0.111 |
| df | 10 |
| Variety s.e.d | 0.41 |
| P value | <0.001 |
| Sowing Date x Variety s.e.d | 1.25 |
| P value | <0.001 |
| df | 60 |

Each figure in the table is the mean of 3 replicates. There was highly significant differences between the varieties studied in both years, and a highly significant variety: sowing date interaction.

## CONCLUSIONS

These experiments cast into doubt some commonly held beliefs about sowing date and sowing date variety interactions particularly in relation to sowings prior to mid to late October, namely:

*Early sowing results in greater crop growth.* Whilst this effect could be demonstrated in the first year of the experiment it did not hold true in the second, the lack of any hazard effect to explain this indicates that the sowing date growth correlation may not be as strong as previously thought.

*Increased crop growth and a stable harvest index from early sowing results in higher yield.* The typing experiments demonstrated that harvest index was not maintained at earlier sowings any increase in total crop growth would not therefore necessarily result in higher yield. In addition in the variety sowing date experiments even in the absence of lodging or other hazards yield was not highest from earlier sown crops.

*Varieties may differ in their response to sowing date but a high yield potential variety will always yield the most.* The occurrence of significant 'cross overs' of varieties in the typing trials, that is a change in the ranking of varieties for yield according to sowing date, demonstrates that choosing a variety well suited to the sowing date will produce the highest gross margin even in the absence of any quality premium for late drilled crops.

The typing experiments also indicate that the suitability of varieties to early or late sowing may be readily assessed in variety testing systems by observation of the occurrence of external developmental stages such as GS 31 or GS 61. This would provide a relatively low cost method of improving variety choice and gross margins across the range of sowing date for winter wheat currently employed.

**Annex 1 ADAS Rosemaund Weather data 1996-97 season**

| | Rainfall (mm) | | Sunshine (hours) | | Mean 10cm soil temp at 0900hrs GMT | | Days 0.1mm rain or more | Ground frosts | Air frosts |
|---|---|---|---|---|---|---|---|---|---|
| | LTM | 1996-97 | LTM | 1996-97 | LTM | 1996-97 | 1996-97 | 1996-97 | 1996-97 |
| **1996** | | | | | | | | | |
| January | 69.7 | 56.7 | 48.5 | 17.9 | 3.2 | 3.5 | 18 | 14 | 11 |
| February | 47.9 | 61.5 | 64.2 | 81.4 | 2.9 | 1.3 | 15 | 23 | 21 |
| March | 49.8 | 69.1 | 122.8 | 52.1 | 4.4 | 3.7 | 16 | 21 | 9 |
| April | 43.6 | 52.6 | 134.1 | 117.2 | 6.9 | 7.7 | 13 | 9 | 4 |
| May | 55.9 | 42.6 | 174.2 | 175.2 | 11.2 | 9.7 | 13 | 14 | 4 |
| June | 56.2 | 22.3 | 172.8 | 227.5 | 14.7 | 16.5 | 11 | 6 | 0 |
| July | 55.7 | 52.4 | 182.2 | 175.6 | 16.8 | 17.9 | 12 | 2 | 0 |
| August | 65.6 | 15.4 | 149.1 | 125.0 | 15.6 | 16.2 | 15 | 1 | 0 |
| September | 64.3 | 15.4 | 122.0 | 125.0 | 12.7 | 12.8 | 6 | 5 | 0 |
| October | 63.2 | 71.8 | 89.3 | 92.7 | 9.5 | 9.9 | 20 | 8 | 0 |
| November | 59.1 | 59.0 | 61.3 | 79.6 | 6.0 | 4.6 | 22 | 17 | 14 |
| December | 64.1 | 30.9 | 42.9 | 41.5 | 4.1 | 2.3 | 10 | 17 | 13 |
| **1997** | | | | | | | | | |
| January | 68.6 | 9.7 | 48.0 | 26.0 | 3.2 | 1.4 | 11 | 24 | 17 |
| February | 48.6 | 72.1 | 63.4 | 57.0 | 2.9 | 4.8 | 22 | 8 | 4 |
| March | 47.0 | 23.0 | 125.9 | 112.9 | 4.5 | 6.4 | 14 | 15 | 4 |
| April | 41.2 | 34.4 | 139.3 | 173.6 | 7.0 | 8.5 | 5 | 17 | 6 |
| May | 52.1 | 59.9 | 177.1 | 217.4 | 11.3 | 12.2 | 17 | 9 | 1 |
| June | 51.4 | 98.4 | 175.4 | 102.4 | 14.7 | 14.7 | 21 | 2 | 0 |
| July | 45.0 | 15.35 | 188.6 | 226.7 | 16.8 | 17.6 | 9 | 0 | 0 |
| August | 58.4 | 105.65 | 152.9 | 165.4 | 15.7 | 18.1 | 15 | 0 | 0 |
| September | 55.8 | 29.7 | 123.0 | 130.1 | 12.7 | 13.4 | 10 | 3 | 0 |
| October | 57.6 | 62.85 | 89.2 | 128.7 | 9.5 | 8.9 | 12 | 11 | 8 |
| November | 60.3 | 86.75 | 61.6 | 43 | 6.0 | 7.2 | 26 | 9 | 4 |
| December | 64.6 | 40.1 | 42.1 | 42.19 | 4.1 | 4.7 | 12 | 12 | 5 |

**Annex 1 (cont.)** **ADAS Rosemaund Weather data 1997-98 season**

| | Rainfall (mm) | | Sunshine (hours) | | Mean 10cm soil temp at 0900hrs GMT | | Days 0.1mm rain or more | Ground frosts | Air frosts |
|---|---|---|---|---|---|---|---|---|---|
| | LTM | 1997-89 | LTM | 1997-8 | LTM | 1997-8 | 1997-8 | 1997-8 | 1997-8 |
| **1997** | | | | | | | | | |
| January | 68.6 | 9.7 | 48.0 | 26.0 | 3.2 | 1.4 | 11 | 24 | 17 |
| March | 48.6 | 72.1 | 63.4 | 57.0 | 2.9 | 4.8 | 22 | 8 | 4 |
| March | 47.0 | 23.0 | 125.9 | 112.9 | 4.5 | 6.4 | 14 | 15 | 4 |
| April | 41.2 | 34.4 | 139.3 | 173.6 | 7.0 | 8.5 | 5 | 17 | 6 |
| May | 52.1 | 59.9 | 177.1 | 217.4 | 11.3 | 12.2 | 17 | 9 | 1 |
| June | 51.4 | 98.4 | 175.4 | 102.4 | 14.7 | 14.7 | 21 | 2 | 0 |
| July | 45.0 | 15.35 | 188.6 | 226.7 | 16.8 | 17.6 | 9 | 0 | 0 |
| August | 58.4 | 105.65 | 152.9 | 165.4 | 15.7 | 18.1 | 15 | 0 | 0 |
| September | 55.8 | 29.7 | 123.0 | 130.1 | 12.7 | 13.4 | 10 | 3 | 0 |
| October | 57.6 | 62.85 | 89.2 | 128.7 | 9.5 | 8.9 | 12 | 11 | 8 |
| November | 60.3 | 86.75 | 61.6 | 43 | 6.0 | 7.2 | 26 | 9 | 4 |
| December | 64.6 | 40.1 | 42.1 | 42.19 | 4.1 | 4.7 | 12 | 12 | 5 |
| **1998** | | | | | | | | | |
| January | 69.4 | 89.2 | 47.7 | 40.2 | 3.2 | 3.7 | 19 | 16 | 8 |
| February | 48.3 | 16.0 | 63.9 | 78.2 | 3.0 | 4.7 | 11 | 14 | 5 |
| March | 47.6 | 61.9 | 123.3 | 69.0 | 4.6 | 6.7 | 13 | 10 | 3 |
| April | 44.0 | 142.7 | 137.8 | 118.3 | 7.0 | 6.7 | 23 | 16 | 4 |
| May | 52.1 | 15.0 | 177.1 | 206.3 | 11.3 | 13.0 | 8 | 2 | 0 |
| June | 51.4 | 93 | 175.4 | 99.7 | 14.6 | 14.1 | 24 | 2 | 0 |
| July | 45.0 | 20.75 | 188.6 | 131.8 | 16.8 | 16.1 | 14 | 1 | 0 |
| August | 56.3 | 19.6 | 156.3 | 191.6 | 15.7 | 15.4 | 6 | 5 | 0 |
| September | 55.7 | 80.2 | 123.3 | 100.2 | 12.7 | 13.6 | 20 | 2 | 0 |
| October | 58.5 | 93.15 | 90.4 | 91.8 | 9.4 | 9.3 | 23 | 8 | 2 |
| November | 60.0 | 56.6 | 62.1 | 66.7 | 6.0 | 4.9 | 16 | 19 | 10 |
| December | 64.6 | 70.1 | 41.9 | 31 | 4.1 | 3.9 | 26 | 23 | 14 |

## Annex 2 Detailed crop growth results for experiment 2 Sowing Date Response

### 1997/8 March Biomass Results

| Sowing Date | Variety | Shoot no.'s /m2: Plant No's/m2 | Shoot no.'s /m2: Pot Fertile | Shoot no.'s /m2: Dead & Dying | Green Area Index: Lamina | Green Area Index: Stem | Green Area Index: Total | Crop dry matters t/ha: Green Leaf | Crop dry matters t/ha: Green Stem | Crop dry matters t/ha: Dd+dy Shts | Crop dry matters t/ha: Total | Nitrogen offtake kg/ha | N:green Area Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FIRST** | **CONSORT** | 191.36 | 564.89 | 106.10 | 1.17 | 0.08 | 1.26 | 0.37 | 0.14 | 0.06 | 0.70 | 26.58 | 21.68 |
| | **SOISSONS** | 220.37 | 461.83 | 102.30 | 1.62 | 0.12 | 1.74 | 0.49 | 0.28 | 0.06 | 0.91 | 26.83 | 16.04 |
| | **SPARK** | 199.38 | 810.64 | 76.93 | 0.93 | 0.06 | 0.99 | 0.34 | 0.10 | 0.06 | 0.52 | 23.29 | 23.79 |
| | **MEAN** | **203.70** | **612.45** | **95.11** | **1.24** | **0.09** | **1.33** | **0.40** | **0.17** | **0.06** | **0.71** | **25.57** | **20.50** |
| **SECOND** | **CONSORT** | 180.86 | 764.47 | 73.93 | 0.94 | 0.08 | 1.03 | 0.33 | 0.13 | 0.00 | 0.58 | 22.00 | 21.89 |
| | **SOISSONS** | 238.89 | 607.30 | 129.43 | 1.41 | 0.12 | 1.53 | 0.46 | 0.24 | 0.07 | 0.88 | 25.42 | 16.85 |
| | **SPARK** | 133.33 | 744.65 | 18.10 | 0.83 | 0.06 | 0.89 | 0.32 | 0.11 | 0.01 | 0.49 | 22.05 | 24.97 |
| | **MEAN** | **184.36** | **705.47** | **73.82** | **1.06** | **0.09** | **1.15** | **0.37** | **0.16** | **0.03** | **0.65** | **23.16** | **21.24** |
| **THIRD** | **CONSORT** | 231.48 | 951.42 | 39.78 | 1.16 | 0.09 | 1.25 | 0.41 | 0.14 | 0.02 | 0.66 | 27.40 | 21.90 |
| | **SOISSONS** | 317.90 | 770.70 | 38.16 | 1.61 | 0.12 | 1.73 | 0.50 | 0.19 | 0.01 | 0.77 | 30.73 | 17.72 |
| | **SPARK** | 159.88 | 991.97 | 0.00 | 0.73 | 0.07 | 0.80 | 0.26 | 0.11 | 0.00 | 0.38 | 18.40 | 22.82 |
| | **MEAN** | **236.42** | **904.70** | **25.98** | **1.17** | **0.10** | **1.26** | **0.39** | **0.15** | **0.01** | **0.60** | **25.51** | **20.81** |
| **FOURTH** | **CONSORT** | 183.95 | 687.67 | 0.00 | 0.78 | 0.05 | 0.82 | 0.28 | 0.06 | 0.01 | 0.41 | 18.64 | 22.68 |
| | **SOISSONS** | 293.21 | 849.66 | 42.32 | 0.95 | 0.09 | 1.04 | 0.30 | 0.12 | 0.01 | 0.49 | 19.87 | 19.14 |
| | **SPARK** | 100.00 | 581.67 | 0.00 | 0.33 | 0.03 | 0.36 | 0.13 | 0.04 | 0.00 | 0.19 | 10.61 | 30.63 |
| | **MEAN** | **192.39** | **706.33** | **14.11** | **0.69** | **0.05** | **0.74** | **0.24** | **0.08** | **0.01** | **0.36** | **16.37** | **24.15** |
| **FIFTH** | **CONSORT** | 37.04 | 114.77 | 0.00 | 0.10 | 0.01 | 0.11 | 0.03 | 0.01 | 0.00 | 0.05 | 2.73 | 27.23 |
| | **SOISSONS** | 69.14 | 308.08 | 0.00 | 0.24 | 0.02 | 0.26 | 0.09 | 0.03 | 0.00 | 0.13 | 6.35 | 20.95 |
| | **SPARK** | 12.96 | 34.10 | 3.01 | 0.01 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.01 | 0.80 | 52.24 |
| | **MEAN** | **39.71** | **152.32** | **1.00** | **0.12** | **0.01** | **0.13** | **0.04** | **0.01** | **0.00** | **0.06** | **3.29** | **33.47** |
| **SIXTH** | **CONSORT** | 90.74 | 286.69 | 5.24 | 0.21 | 0.01 | 0.23 | 0.09 | 0.02 | 0.00 | 0.12 | 6.30 | 27.82 |
| | **SOISSONS** | 162.35 | 518.28 | 0.00 | 0.34 | 0.05 | 0.39 | 0.15 | 0.05 | 0.00 | 0.21 | 10.73 | 28.25 |
| | **SPARK** | 52.47 | 105.21 | 0.00 | 0.05 | 0.01 | 0.05 | 0.02 | 0.01 | 0.00 | 0.03 | 1.98 | 74.54 |
| | **MEAN** | **101.85** | **303.39** | **1.75** | **0.20** | **0.02** | **0.22** | **0.09** | **0.03** | **0.00** | **0.12** | **6.34** | **43.54** |
| **GRAND MEAN** | | 159.74 | 564.11 | 35.29 | 0.74 | 0.06 | 0.81 | 0.25 | 0.10 | 0.02 | 0.42 | 16.71 | 27.29 |
| **Sowing Date s.e.d** | | 25.72 | 59 | 13.37 | 0.1849 | 0.01425 | 0.1961 | 0.0583 | 0.03312 | 0.01171 | 0.106 | 2.533 | 9.78 |
| | **P value** | 0.004 | <0.001 | 0.003 | 0.006 | 0.006 | 0.005 | 0.005 | 0.017 | 0.028 | 0.0583 | 0.001 | NS |
| | **df** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Variety s.e.d** | | 11.87 | 69.1 | 16.82 | 0.0882 | 0.0083 | 0.0957 | 0.0275 | 0.01546 | 0.01045 | 0.0426 | 1.528 | 6.57 |
| | **P value** | <0.001 | NS | 0.145 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | NS | <0.001 | 0.004 | 0.039 |
| **Sowing Date x Variety s.e.d** | | 35 | 150.3 | 36.19 | 0.2556 | 0.02193 | 0.2741 | 0.0801 | 0.04531 | 0.02396 | 0.1362 | 3.969 | 16.38 |
| | **P value** | 0.077 | 0.158 | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| | **df** | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 11 | 11 |

## 1996/7 April Biomass Results

| Sowing Date | Variety | Plant No's/m2 | Shoot no.'s /m2 Pot Fertile | Dead & Dying | Green area index Lamina | Stem | Total | Crop Dry Matters t/ha Green Material | Dd+dy Shts | Total | Nitrogen offtake Kg/Ha |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **FIRST** | **CONSORT** | 204.94 | 1037.78 | 32.46 | 1.97 | 0.26 | 2.23 | 1.59 | 0.02 | 2.23 | 75.10 |
| | **SOISSONS** | 230.86 | 1254.47 | 125.12 | 3.84 | 0.47 | 4.32 | 2.93 | 0.03 | 3.28 | 109.95 |
| | **SPARK** | 222.22 | 1412.47 | 45.49 | 2.16 | 0.28 | 2.44 | 1.76 | 0.02 | 2.20 | 76.70 |
| | **MEAN** | **219.34** | **1234.90** | **67.69** | **2.66** | **0.34** | **3.00** | **2.09** | **0.02** | **2.57** | **87.25** |
| **SECOND** | **CONSORT** | 208.02 | 1296.58 | 0.00 | 2.14 | 0.29 | 2.43 | 1.63 | 0.00 | 2.08 | 67.04 |
| | **SOISSONS** | 225.93 | 1034.61 | 0.00 | 3.15 | 0.37 | 3.52 | 1.35 | 0.00 | 1.49 | 49.36 |
| | **SPARK** | 213.58 | 1700.54 | 6.93 | 2.20 | 0.28 | 2.48 | 1.61 | 0.13 | 1.87 | 68.55 |
| | **MEAN** | **215.84** | **1343.91** | **2.31** | **2.50** | **0.32** | **2.81** | **1.53** | **0.04** | **1.81** | **61.65** |
| **THIRD** | **CONSORT** | 140.74 | 755.96 | 21.41 | 0.86 | 0.10 | 0.96 | 0.67 | 0.01 | 0.75 | 35.63 |
| | **SOISSONS** | 185.19 | 716.94 | 12.83 | 1.43 | 0.17 | 1.60 | 1.01 | 0.01 | 1.06 | 44.55 |
| | **SPARK** | 224.07 | 1394.02 | 13.10 | 1.10 | 0.14 | 1.23 | 0.77 | 0.01 | 0.82 | 38.45 |
| | **MEAN** | **183.33** | **955.64** | **15.78** | **1.13** | **0.13** | **1.26** | **0.82** | **0.01** | **0.88** | **39.54** |
| **FOURTH** | **CONSORT** | 184.57 | 601.23 | 21.33 | 0.74 | 0.06 | 0.81 | 0.49 | 0.01 | 0.53 | 26.11 |
| | **SOISSONS** | 121.60 | 440.44 | 7.09 | 0.52 | 0.07 | 0.59 | 0.40 | 0.00 | 0.41 | 21.50 |
| | **SPARK** | 174.69 | 947.73 | 12.84 | 0.48 | 0.07 | 0.55 | 0.42 | 0.01 | 0.48 | 23.57 |
| | **MEAN** | **160.29** | **663.13** | **13.75** | **0.58** | **0.07** | **0.65** | **0.43** | **0.01** | **0.47** | **23.73** |
| **FIFTH** | **CONSORT** | 98.77 | 356.89 | 0.00 | 0.31 | 0.04 | 0.35 | 0.24 | 0.00 | 0.25 | 13.40 |
| | **SOISSONS** | 69.75 | 249.36 | 5.85 | 0.17 | 0.02 | 0.19 | 0.15 | 0.00 | 0.16 | 8.17 |
| | **SPARK** | 92.59 | 404.19 | 0.00 | 0.23 | 0.03 | 0.26 | 0.18 | 0.00 | 0.18 | 10.63 |
| | **MEAN** | **87.04** | **336.81** | **1.95** | **0.24** | **0.03** | **0.27** | **0.19** | **0.00** | **0.20** | **10.73** |
| **SIXTH** | **CONSORT** | 112.96 | 283.08 | 0.00 | 0.20 | 0.02 | 0.22 | 0.16 | 0.00 | 0.17 | 8.95 |
| | **SOISSONS** | 74.07 | 109.87 | 0.00 | 0.09 | 0.01 | 0.10 | 0.08 | 0.00 | 0.08 | 4.27 |
| | **SPARK** | 116.67 | 391.84 | 13.00 | 0.18 | 0.03 | 0.20 | 0.16 | 0.00 | 0.18 | 10.22 |
| | **MEAN** | **101.23** | **261.60** | **4.33** | **0.16** | **0.02** | **0.18** | **0.14** | **0.00** | **0.14** | **7.81** |
| **GRAND MEAN** | | 161.18 | 799.33 | 17.64 | 1.21 | 0.15 | 1.36 | 0.87 | 0.01 | 1.01 | 38.45 |
| **Sowing Date s.e.d** | | 16.21 | 84.40 | 9.41 | 0.24 | 0.04 | 0.28 | 0.26 | 0.02 | 0.28 | 10.35 |
| | **P value** | 0.002 | <0.001 | 0.005 | <0.001 | <0.001 | <0.001 | 0.003 | ns | 0.001 | 0.003 |
| | **df** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Variety s.e.d** | | 9.35 | 51.10 | 13.08 | 0.13 | 0.01 | 0.14 | 0.14 | 0.02 | 0.15 | 5.08 |
| | **P value** | 0.820 | <0.001 | ns | 0.003 | <0.001 | 0.002 | ns | ns | ns | ns |
| **Sowing Date x Variety s.e.d** | | 24.75 | 132.50 | 27.81 | 0.35 | 0.04 | 0.39 | 0.38 | 0.04 | 0.41 | 14.50 |
| | **P value** | 0.078 | 0.047 | ns | 0.011 | 0.003 | 0.009 | 0.150 | ns | ns | ns |
| | **df** | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

## 1997/8 April Biomass Results

| Sowing Date | Variety | Shoot No.'s /m2 Pot Fertile | Shoot No.'s /m2 Dead & Dying | Green Area Index Leaf | Green Area Index Stem | Green Area Index Total | Crop dry matters t/ha Green Leaf | Crop dry matters t/ha Green Stem | Crop dry matters t/ha Dd+dy Shts | Crop dry matters t/ha Total | Nitrogen Offtake kg/ha | N:green Area Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FIRST** | **CONSORT** | 550.49 | 97.92 | 1.80 | 0.20 | 1.99 | 0.80 | 0.81 | 0.09 | 1.87 | 36.36 | 18.33 |
| | **SOISSONS** | 514.50 | 99.92 | 1.86 | 0.26 | 2.12 | 0.84 | 1.20 | 0.05 | 2.19 | 50.75 | 24.97 |
| | **SPARK** | 518.38 | 66.94 | 1.32 | 0.15 | 1.47 | 0.60 | 0.54 | 0.05 | 1.28 | 32.79 | 22.62 |
| | **MEAN** | **527.79** | **88.26** | **1.66** | **0.20** | **1.86** | **0.75** | **0.85** | **0.06** | **1.78** | **39.96** | **21.97** |
| **SECOND** | **CONSORT** | 510.26 | 127.56 | 1.18 | 0.13 | 1.31 | 0.60 | 0.50 | 0.08 | 1.30 | 52.51 | 39.05 |
| | **SOISSONS** | 537.49 | 98.83 | 1.46 | 0.21 | 1.66 | 0.68 | 0.92 | 0.06 | 1.77 | 48.41 | 28.58 |
| | **SPARK** | 760.34 | 76.76 | 1.01 | 0.11 | 1.12 | 0.53 | 0.41 | 0.03 | 1.04 | 17.65 | 15.78 |
| | **MEAN** | **602.69** | **101.05** | **1.22** | **0.15** | **1.36** | **0.60** | **0.61** | **0.05** | **1.37** | **39.52** | **27.81** |
| **THIRD** | **CONSORT** | 751.94 | 20.64 | 1.71 | 0.16 | 1.88 | 0.62 | 0.65 | 0.01 | 1.49 | 49.34 | 26.86 |
| | **SOISSONS** | 606.85 | 53.06 | 2.24 | 0.31 | 2.55 | 0.90 | 1.20 | 0.04 | 2.25 | 70.21 | 27.12 |
| | **SPARK** | 943.41 | 32.05 | 1.36 | 0.15 | 1.51 | 0.68 | 0.51 | 0.01 | 1.33 | 30.66 | 19.78 |
| | **MEAN** | **767.40** | **35.25** | **1.77** | **0.21** | **1.98** | **0.74** | **0.79** | **0.02** | **1.69** | **50.07** | **24.58** |
| **FOURTH** | **CONSORT** | 591.30 | 0.00 | 0.93 | 0.10 | 1.03 | 0.47 | 0.26 | 0.00 | 0.87 | 18.94 | 18.00 |
| | **SOISSONS** | 575.46 | 37.67 | 0.70 | 0.14 | 0.84 | 0.46 | 0.41 | 0.01 | 0.97 | 23.87 | 44.00 |
| | **SPARK** | 996.05 | 28.35 | 0.82 | 0.11 | 0.93 | 0.45 | 0.31 | 0.01 | 1.02 | 22.95 | 24.23 |
| | **MEAN** | **720.94** | **22.01** | **0.82** | **0.12** | **0.93** | **0.46** | **0.33** | **0.01** | **0.95** | **21.92** | **28.75** |
| **FIFTH** | **CONSORT** | 447.96 | 0.00 | 0.35 | 0.04 | 0.39 | 0.18 | 0.10 | 0.00 | 0.45 | 10.86 | 27.62 |
| | **SOISSONS** | 517.27 | 12.87 | 1.07 | 0.09 | 1.16 | 0.47 | 0.20 | 0.00 | 0.77 | 37.61 | 31.00 |
| | **SPARK** | 126.54 | 0.62 | 0.05 | 0.01 | 0.06 | 0.03 | 0.03 | 0.00 | 0.08 | 1.92 | 43.93 |
| | **MEAN** | **363.93** | **4.50** | **0.49** | **0.05** | **0.54** | **0.23** | **0.11** | **0.00** | **0.43** | **16.80** | **34.18** |
| **SIXTH** | **CONSORT** | 439.95 | 0.00 | 0.54 | 0.03 | 0.57 | 0.26 | 0.05 | 0.00 | 0.37 | 16.49 | 29.04 |
| | **SOISSONS** | 657.25 | 0.00 | 1.03 | 0.12 | 1.16 | 0.49 | 0.27 | 0.00 | 0.91 | 23.51 | 20.33 |
| | **SPARK** | 263.41 | 7.86 | 0.12 | 0.01 | 0.14 | 0.07 | 0.11 | 0.00 | 0.23 | 5.04 | 32.00 |
| | **MEAN** | **453.54** | **2.62** | **0.57** | **0.05** | **0.62** | **0.28** | **0.14** | **0.00** | **0.50** | **15.01** | **27.12** |
| **GRAND MEAN** | | 572.71 | 42.28 | 1.09 | 0.13 | 1.22 | 0.51 | 0.47 | 0.02 | 1.12 | 30.55 | 27.40 |
| **Sowing Date s.e.d** | | 59.1 | 7.06 | 0.2184 | 0.03025 | 0.2222 | 0.1043 | 0.1099 | 0.01168 | 0.2069 | 10.23 | 7.18 |
| | **P value** | 0.006 | <0.001 | 0.007 | 0.011 | 0.005 | 0.014 | 0.004 | 0.01 | 0.004 | 0.076 | NS |
| | **df** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Variety s.e.d** | | 66.7 | 11.05 | 0.1492 | 0.02168 | 0.1599 | 0.0541 | 0.0611 | 0.00752 | 0.1201 | 4.22 | 3.74 |
| | **P value** | NS | NS | 0.005 | 0.002 | 0.003 | 0.002 | <0.001 | NS | <0.001 | <0.001 | NS |
| **Sowing Date x Variety s.e.d** | | 145.8 | 24.06 | 0.3698 | 0.05268 | 0.3895 | 0.1503 | 0.1643 | 0.01904 | 0.317 | 13.26 | 10.37 |
| | **P value** | 0.051 | NS | NS | NS | NS | NS | NS | NS | NS | NS | 0.11 |
| | **df** | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Annex 2 (cont.)** **Detailed crop growth results for experiment 2 Sowing Date Response**

**1996/7 May Biomass Results**

| | | Shoot no.'s /m2 | | Green Area Index | | | Crop dry matters t/ha | | | Nitrogen | N:green |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sowing Date | Variety | Pot Fertile | Dead & Dying | Lamina | Stem | Total | Green Material | Dd+dy Shoots | Total | offtake kg/ha | area ratio |
| **FIRST** | **CONSORT** | 601.75 | 61.14 | 7.33 | 1.10 | 8.43 | 7.02 | 0.18 | 7.43 | 159.85 | 19.39 |
| | **SOISSONS** | 801.78 | 81.21 | 8.22 | 1.91 | 10.13 | 9.39 | 0.18 | 9.90 | 214.32 | 21.17 |
| | **SPARK** | 645.22 | 64.63 | 9.06 | 1.53 | 10.59 | 7.65 | 0.12 | 7.97 | 180.58 | 17.11 |
| | **MEAN** | **682.92** | **68.99** | **8.20** | **1.51** | **9.72** | **8.02** | **0.16** | **8.43** | **184.92** | **19.22** |
| **SECOND** | **CONSORT** | 526.83 | 52.36 | 6.02 | 0.93 | 6.95 | 6.13 | 0.15 | 6.50 | 166.24 | 24.72 |
| | **SOISSONS** | 720.94 | 72.84 | 7.08 | 1.66 | 8.74 | 8.49 | 0.15 | 8.90 | 183.32 | 21.75 |
| | **SPARK** | 558.10 | 56.03 | 7.22 | 1.36 | 8.58 | 6.54 | 0.17 | 6.89 | 182.98 | 21.23 |
| | **MEAN** | **601.96** | **60.41** | **6.77** | **1.32** | **8.09** | **7.05** | **0.16** | **7.43** | **177.51** | **22.57** |
| **THIRD** | **CONSORT** | 414.52 | 41.98 | 6.21 | 0.62 | 6.84 | 4.94 | 0.07 | 5.12 | 174.43 | 26.12 |
| | **SOISSONS** | 536.51 | 49.96 | 6.24 | 1.09 | 7.33 | 6.50 | 0.03 | 6.62 | 72.04 | 10.53 |
| | **SPARK** | 398.39 | 43.23 | 4.22 | 0.85 | 5.08 | 4.86 | 0.03 | 4.92 | 71.92 | 13.64 |
| | **MEAN** | **449.81** | **45.05** | **5.56** | **0.86** | **6.41** | **5.43** | **0.04** | **5.55** | **106.13** | **16.76** |
| **FOURTH** | **CONSORT** | 270.92 | 31.37 | 5.01 | 0.58 | 5.58 | 3.32 | 0.00 | 3.34 | 102.82 | 18.67 |
| | **SOISSONS** | 454.79 | 43.84 | 4.82 | 0.97 | 5.79 | 5.53 | 0.01 | 5.61 | 132.74 | 23.93 |
| | **SPARK** | 345.92 | 33.47 | 4.69 | 0.74 | 5.43 | 4.24 | 0.01 | 4.27 | 139.28 | 25.50 |
| | **MEAN** | **357.21** | **36.23** | **4.84** | **0.76** | **5.60** | **4.36** | **0.01** | **4.41** | **124.95** | **22.70** |
| **FIFTH** | **CONSORT** | 194.74 | 19.12 | 3.09 | 0.37 | 3.45 | 2.39 | 0.01 | 2.40 | 99.59 | 29.58 |
| | **SOISSONS** | 260.00 | 25.73 | 2.89 | 0.48 | 3.37 | 3.19 | 0.01 | 3.21 | 107.65 | 32.11 |
| | **SPARK** | 224.44 | 19.91 | 3.29 | 0.42 | 3.72 | 2.76 | 0.00 | 2.77 | 111.31 | 30.23 |
| | **MEAN** | **226.39** | **21.58** | **3.09** | **0.42** | **3.51** | **2.78** | **0.01** | **2.79** | **106.19** | **30.64** |
| **SIXTH** | **CONSORT** | 191.54 | 17.88 | 3.70 | 0.40 | 4.10 | 2.34 | 0.00 | 2.36 | 107.09 | 26.68 |
| | **SOISSONS** | 140.44 | 14.41 | 1.54 | 0.29 | 1.83 | 1.73 | 0.00 | 1.73 | 61.99 | 32.92 |
| | **SPARK** | 221.64 | 21.22 | 3.36 | 0.44 | 3.81 | 2.72 | 0.00 | 2.74 | 116.72 | 30.66 |
| | **MEAN** | **184.54** | **17.84** | **2.87** | **0.38** | **3.24** | **2.27** | **0.00** | **2.28** | **95.27** | **30.09** |
| **GRAND MEAN** | | 417.14 | 41.68 | 5.22 | 0.88 | 6.10 | 4.98 | 0.06 | 5.15 | 132.49 | 23.66 |
| **Sowing Date s.e.d** | | 100.80 | 70.62 | 0.62 | 0.12 | 0.73 | 0.35 | 0.04 | 0.36 | 17.65 | 3.56 |
| | **P value** | ns | 0.043 | 0.020 | 0.001 | 0.002 | <0.001 | 0.016 | <0.001 | 0.016 | 0.108 |
| | **df** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Variety s.e.d** | | 44.90 | 23.67 | 0.31 | 0.05 | 0.33 | 0.22 | 0.02 | 0.23 | 17.72 | 2.77 |
| | **P value** | <0.001 | 0.075 | ns | <0.001 | ns | <0.001 | ns | <0.001 | ns | ns |
| **Sowing Date x Variety s.e.d** | | 135.00 | 85.02 | 0.88 | 0.16 | 0.98 | 0.56 | 0.05 | 0.58 | 39.60 | 6.59 |
| | **P value** | 0.010 | ns | 0.058 | 0.014 | 0.034 | 0.031 | ns | 0.032 | ns | ns |
| | **df** | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 10 | 10 |

## Sowing date response May biomass summary

| Sowing Date | Variety | Shoot No.'s /m2 Pot Fertile | Dead & Dying | Green Area Index Leaf | Stem | Ear | Total | Green Leaf | Crop dry matters t/ha Straw | Ear | Total | N off Total | Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRST | CONSORT | 432.38 | 58.07 | 3.70 | 0.71 | 0.01 | 4.43 | 1.75 | 7.10 | 0.00 | 7.10 | 127.80 | 28.34 |
| | SOISSONS | 525.18 | 69.91 | 2.51 | 0.72 | 0.21 | 3.44 | 1.14 | 6.58 | 1.08 | 7.66 | 93.25 | 27.07 |
| | SPARK | 360.40 | 36.96 | 3.09 | 0.77 | 0.01 | 3.86 | 1.20 | 5.68 | 0.09 | 5.77 | 95.38 | 24.61 |
| | **MEAN** | **439.32** | **54.98** | **3.10** | **0.73** | **0.08** | **3.91** | **1.36** | **6.45** | **0.39** | **6.84** | **105.47** | **26.67** |
| SECOND | CONSORT | 409.21 | 72.15 | 4.05 | 0.74 | 0.01 | 4.80 | 1.78 | 5.09 | 0.05 | 7.22 | 90.01 | 18.77 |
| | SOISSONS | 525.63 | 58.21 | 2.50 | 0.62 | 0.17 | 3.29 | 1.11 | 4.51 | 1.02 | 6.93 | 75.77 | 22.87 |
| | SPARK | 420.67 | 198.16 | 3.69 | 0.93 | 0.00 | 4.62 | 1.58 | 4.74 | 0.00 | 6.66 | 135.85 | 30.29 |
| | **MEAN** | **451.84** | **109.51** | **3.41** | **0.76** | **0.06** | **4.24** | **1.49** | **4.78** | **0.36** | **6.94** | **100.55** | **23.98** |
| THIRD | CONSORT | 416.66 | 178.84 | 4.04 | 0.74 | 0.00 | 4.77 | 1.79 | 6.94 | 0.00 | 6.94 | 99.67 | 20.54 |
| | SOISSONS | 526.47 | 35.91 | 3.42 | 0.92 | 0.29 | 4.63 | 1.51 | 7.81 | 1.37 | 9.19 | 124.97 | 27.40 |
| | SPARK | 427.01 | 192.54 | 2.40 | 0.79 | 0.00 | 3.19 | 1.47 | 6.47 | 0.00 | 6.47 | 131.39 | 43.28 |
| | **MEAN** | **456.71** | **135.76** | **3.29** | **0.82** | **0.10** | **4.20** | **1.59** | **7.08** | **0.46** | **7.53** | **94.29** | **30.41** |
| FOURTH | CONSORT | 394.75 | 268.04 | 3.69 | 0.55 | 0.00 | 4.24 | 1.60 | 6.26 | 0.00 | 6.26 | 91.52 | 20.58 |
| | SOISSONS | 494.58 | 38.24 | 3.01 | 0.70 | 0.25 | 3.97 | 1.28 | 5.63 | 1.05 | 6.68 | 66.27 | 16.50 |
| | SPARK | 505.11 | 129.61 | 4.14 | 0.78 | 0.00 | 4.92 | 1.58 | 6.44 | 0.00 | 6.44 | 85.47 | 17.49 |
| | **MEAN** | **464.81** | **145.30** | **3.61** | **0.68** | **0.08** | **4.38** | **1.49** | **6.11** | **0.35** | **6.46** | **81.08** | **18.19** |
| FIFTH | CONSORT | 334.66 | 37.78 | 2.70 | 0.32 | 0.00 | 3.01 | 1.31 | 3.60 | 0.00 | 3.60 | 64.90 | 21.68 |
| | SOISSONS | 435.46 | 75.67 | 2.97 | 0.72 | 0.19 | 3.87 | 1.50 | 5.85 | 0.79 | 6.65 | 112.95 | 30.58 |
| | SPARK | 342.67 | 12.55 | 1.43 | 0.22 | 0.00 | 1.66 | 0.74 | 2.10 | 0.00 | 2.10 | 45.09 | 29.13 |
| | **MEAN** | **370.93** | **42.00** | **2.37** | **0.42** | **0.06** | **2.85** | **1.18** | **3.85** | **0.26** | **4.12** | **74.32** | **27.13** |
| SIXTH | CONSORT | 475.04 | 102.32 | 3.11 | 0.33 | 0.00 | 3.44 | 1.41 | 4.59 | 0.00 | 4.59 | 69.09 | 19.98 |
| | SOISSONS | 506.02 | 100.87 | 3.15 | 0.73 | 0.16 | 4.04 | 1.41 | 6.47 | 0.41 | 6.88 | 94.29 | 24.64 |
| | SPARK | 342.95 | 30.62 | 1.93 | 0.28 | 0.00 | 2.20 | 0.91 | 2.73 | 0.00 | 2.73 | 51.18 | 23.31 |
| | **MEAN** | **441.34** | **77.94** | **2.73** | **0.44** | **0.05** | **3.23** | **1.25** | **4.60** | **0.14** | **4.73** | **71.52** | **22.64** |
| GRAND MEAN | | 424.84 | 92.04 | 2.96 | 0.62 | 0.07 | 3.65 | 1.34 | 5.55 | 0.33 | 5.88 | 89.14 | 24.84 |
| Sowing Date s.e.d | | 24.6 | 35.62 | 0.463 | 0.0682 | 0.02614 | 0.5398 | 0.1024 | 0.486 | 0.1119 | 0.546 | | |
| | P value | 0.042 | 0.142 | NS | 0.01 | NS | NS | 0.037 | 0.008 | NS | 0.009 | | |
| | df | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | | |
| Variety s.e.d | | 27.7 | 15.7 | 0.1883 | 0.0423 | 0.01755 | 0.2279 | 0.0858 | 0.345 | 0.082 | 0.36 | | |
| | P value | 0.001 | 0.021 | 0.156 | <0.001 | <0.001 | NS | 0.118 | 0.005 | <0.001 | <0.001 | | |
| Sowing Date x Variety s.e.d | | 60.6 | 47.48 | 0.5969 | 0.1086 | 0.04376 | 0.7065 | 0.1999 | 0.843 | 0.1986 | 0.903 | | |
| | P value | 0.074 | <0.001 | 0.002 | 0.003 | NS | 0.003 | 0.008 | 0.007 | NS | 0.015 | | |
| | df | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | | |

**Sowing date response 1996/7 June biomass summary**

| Sowing Date | Variety | Shoot No.'s /m2 Pot Fertile | Shoot No.'s /m2 Dead & Dying | Green Area Index Lamina | Green Area Index T.stem | Green Area Index Ear | Green Area Index Total | Crop Dry Matters T/Ha Dd+dy Shts | Crop Dry Matters T/Ha Straw | Crop Dry Matters T/Ha Ear | Crop Dry Matters T/Ha Total | Nit Offtake Kg/ha Straw | Nit Offtake Kg/ha Ear | Nit Offtake Kg/ha Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRST | CONSORT | 593.42 | 44.61 | 5.59 | 2.12 | 0.45 | 8.17 | 0.09 | 12.48 | 2.08 | 14.55 | 324.11 | 45.39 | 369.50 |
| | SOISSONS | 810.35 | 96.85 | 5.82 | 2.35 | 0.54 | 8.71 | 0.09 | 14.33 | 3.42 | 17.75 | 162.16 | 70.56 | 232.72 |
| | SPARK | 672.82 | 128.67 | 6.30 | 2.25 | 0.39 | 8.93 | 0.15 | 12.78 | 1.97 | 14.75 | 197.45 | 42.38 | 239.82 |
| | MEAN | **692.19** | **90.05** | **5.90** | **2.24** | **0.46** | **8.60** | **0.11** | **13.19** | **2.49** | **15.69** | **227.91** | **52.77** | **280.68** |
| SECOND | CONSORT | 544.75 | 116.19 | 6.10 | 1.91 | 0.43 | 8.44 | 0.20 | 11.00 | 2.06 | 13.07 | 166.91 | 38.45 | 205.36 |
| | SOISSONS | 640.46 | 62.67 | 5.07 | 1.89 | 0.40 | 7.36 | 0.05 | 12.16 | 3.06 | 15.22 | 110.98 | 65.18 | 176.16 |
| | SPARK | 802.32 | 165.75 | 7.07 | 2.56 | 0.49 | 10.12 | 0.21 | 11.69 | 3.09 | 14.78 | 239.16 | 66.25 | 305.41 |
| | MEAN | **662.51** | **114.87** | **6.08** | **2.12** | **0.44** | **8.64** | **0.15** | **11.62** | **2.74** | **14.36** | **172.35** | **56.63** | **228.98** |
| THIRD | CONSORT | 600.01 | 72.72 | 6.10 | 1.76 | 0.47 | 8.33 | 0.12 | 9.80 | 1.89 | 11.69 | 207.73 | 40.23 | 247.97 |
| | SOISSONS | 578.00 | 6.49 | 4.03 | 1.61 | 0.47 | 6.11 | 0.01 | 10.01 | 2.65 | 12.65 | 147.32 | 52.25 | 199.57 |
| | SPARK | 775.95 | 73.61 | 6.66 | 2.30 | 0.48 | 9.45 | 0.06 | 11.09 | 1.97 | 13.06 | 284.03 | 45.80 | 329.83 |
| | MEAN | **651.32** | **50.94** | **5.60** | **1.89** | **0.47** | **7.96** | **0.06** | **10.30** | **2.17** | **12.47** | **213.03** | **46.09** | **259.12** |
| FOURTH | CONSORT | 621.24 | 195.59 | 6.59 | 1.59 | 0.36 | 8.54 | 0.24 | 9.09 | 1.71 | 10.80 | 157.43 | 35.39 | 192.82 |
| | SOISSONS | 519.97 | 17.21 | 3.79 | 1.45 | 0.44 | 5.68 | 0.00 | 9.19 | 2.41 | 11.61 | 178.46 | 49.72 | 228.18 |
| | SPARK | 799.12 | 45.46 | 5.74 | 2.16 | 0.42 | 8.32 | 0.06 | 10.01 | 1.62 | 11.63 | 165.08 | 37.53 | 202.61 |
| | MEAN | **646.78** | **86.09** | **5.37** | **1.74** | **0.40** | **7.51** | **0.10** | **9.43** | **1.91** | **11.34** | **166.99** | **40.88** | **207.87** |
| FIFTH | CONSORT | 536.99 | 166.96 | 5.78 | 1.24 | 0.18 | 7.19 | 0.18 | 7.34 | 0.79 | 8.13 | 227.29 | 16.41 | 243.70 |
| | SOISSONS | 638.78 | 13.11 | 4.07 | 1.51 | 0.35 | 5.92 | 0.09 | 8.07 | 2.10 | 10.17 | 175.98 | 47.36 | 223.34 |
| | SPARK | 800.49 | 117.64 | 5.42 | 1.73 | 0.43 | 7.58 | 0.03 | 9.43 | 0.75 | 10.18 | 249.75 | 11.75 | 261.49 |
| | MEAN | **658.75** | **99.23** | **5.09** | **1.49** | **0.32** | **6.90** | **0.10** | **8.28** | **1.21** | **9.49** | **217.67** | **25.17** | **242.85** |
| SIXTH | CONSORT | 684.33 | 136.81 | 7.65 | 1.64 | 0.16 | 9.46 | 0.19 | 8.56 | 0.61 | 9.16 | 247.77 | 13.60 | 261.37 |
| | SOISSONS | 617.58 | 26.38 | 3.83 | 1.34 | 0.40 | 5.57 | 0.01 | 6.65 | 1.47 | 8.13 | 150.65 | 31.57 | 182.21 |
| | SPARK | 873.54 | 117.26 | 6.54 | 2.12 | 0.15 | 8.81 | 0.10 | 9.29 | 0.55 | 9.84 | 167.53 | 13.07 | 180.60 |
| | MEAN | **725.15** | **93.48** | **6.01** | **1.70** | **0.24** | **7.95** | **0.10** | **8.17** | **0.88** | **9.04** | **188.65** | **19.41** | **208.06** |
| GRAND MEAN | | 672.78 | 89.11 | 5.68 | 1.86 | 0.39 | 7.93 | 0.10 | 10.17 | 1.90 | 12.07 | 197.77 | 40.16 | 237.93 |
| Sowing Date s.e.d | | 53.20 | 36.74 | 0.54 | 0.19 | 0.05 | 0.74 | 0.03 | 0.52 | 0.24 | 0.73 | 22.70 | 5.38 | 25.00 |
| | P value | ns | ns | ns | 0.063 | 0.024 | ns | ns | 0.001 | 0.003 | 0.001 | ns | 0.005 | 0.152 |
| | df | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Variety s.e.d | | 44.30 | 13.76 | 0.47 | 0.11 | 0.04 | 0.56 | 0.02 | 0.28 | 0.15 | 0.30 | 25.00 | 3.21 | 25.30 |
| | P value | 0.002 | <0.001 | 0.002 | <0.001 | 0.115 | 0.003 | <0.001 | 0.010 | <0.001 | 0.002 | 0.034 | <0.001 | 0.149 |
| Sowing Date x Variety s.e.d | | 103.40 | 45.91 | 1.07 | 0.28 | 0.10 | 1.34 | 0.05 | 0.76 | 0.38 | 0.95 | 54.90 | 8.37 | 56.40 |
| | P value | ns | 0.010 | ns | ns | ns | ns | 0.048 | 0.036 | ns | 0.037 | ns | 0.114 | ns |
| | df | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Sowing date response June biomass summary**

| Sowing Date | Variety | Shoot No.'s /m2 Pot Fertile | Dead & Dying | Green Area Index Leaf | Stem | Ear | Total | Crop Dry Matter T/Ha Green Leaf | Green Stem | Green Ear | Dd+dy Shts | Straw | Ear | Total | Nitrogen offtake kg/ha Straw | Ear | Total | N:green Area Ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRST | CONSORT | 384.68 | 43.46 | 3.27 | 0.98 | 0.33 | 4.58 | 1.54 | 7.27 | 4.65 | 0.06 | 9.01 | 4.81 | 13.82 | 109.54 | 73.79 | 183.33 | 40.53 |
| | SOISSONS | 474.31 | 11.96 | 1.81 | 0.97 | 0.30 | 3.07 | 0.85 | 6.44 | 5.36 | 0.00 | 7.94 | 5.14 | 13.08 | 89.51 | 96.15 | 185.67 | 60.97 |
| | SPARK | 580.01 | 24.54 | 4.01 | 1.47 | 0.44 | 5.92 | 1.82 | 6.67 | 5.28 | 0.04 | 9.93 | 4.27 | 14.21 | 95.04 | 73.66 | 168.70 | 29.54 |
| | **MEAN** | **479.66** | **26.65** | **3.03** | **1.14** | **0.36** | **4.52** | **1.40** | **6.79** | **5.10** | **0.03** | **8.96** | **4.74** | **13.70** | **98.03** | **81.20** | **179.23** | **43.68** |
| SECOND | CONSORT | 334.05 | 6.23 | 3.02 | 0.85 | 0.31 | 4.17 | 1.40 | 5.77 | 4.05 | 0.01 | 8.03 | 3.42 | 11.45 | 71.57 | 56.30 | 127.86 | 30.63 |
| | SOISSONS | 460.24 | 34.21 | 2.05 | 0.96 | 0.30 | 3.30 | 0.92 | 5.32 | 5.08 | 0.39 | 6.77 | 5.17 | 11.94 | 79.92 | 93.17 | 173.09 | 52.40 |
| | SPARK | 479.11 | 27.89 | 3.40 | 1.35 | 0.38 | 5.13 | 1.54 | 8.29 | 4.54 | 0.04 | 10.26 | 4.30 | 14.56 | 174.86 | 77.93 | 252.79 | 49.14 |
| | **MEAN** | **424.46** | **22.78** | **2.82** | **1.05** | **0.33** | **4.20** | **1.29** | **6.46** | **4.56** | **0.15** | **8.35** | **4.30** | **12.65** | **108.78** | **75.80** | **184.58** | **44.06** |
| THIRD | CONSORT | 532.49 | 249.98 | 5.35 | 1.57 | 0.50 | 7.42 | 2.37 | 5.65 | 6.26 | 0.31 | 10.27 | 4.77 | 15.04 | 98.09 | 74.87 | 172.96 | 23.56 |
| | SOISSONS | 657.62 | 0.00 | 3.51 | 1.45 | 0.46 | 5.43 | 1.59 | 5.48 | 8.01 | 0.00 | 8.80 | 6.65 | 15.44 | 76.33 | 114.59 | 190.92 | 36.11 |
| | SPARK | 475.59 | 37.29 | 3.21 | 1.23 | 0.34 | 4.78 | 1.41 | 7.55 | 3.61 | 0.04 | 9.15 | 3.67 | 12.82 | 99.78 | 64.32 | 164.11 | 34.34 |
| | **MEAN** | **555.23** | **95.76** | **4.02** | **1.42** | **0.43** | **5.88** | **1.79** | **6.23** | **5.96** | **0.12** | **9.41** | **5.03** | **14.43** | **91.40** | **84.59** | **176.00** | **31.34** |
| FOURTH | CONSORT | 371.00 | 141.81 | 3.38 | 0.97 | 0.35 | 4.69 | 1.67 | 6.80 | 4.06 | 0.19 | 9.02 | 3.82 | 12.83 | 96.27 | 62.40 | 158.67 | 34.02 |
| | SOISSONS | 538.42 | 74.71 | 2.92 | 1.15 | 0.34 | 4.41 | 1.26 | 3.64 | 5.62 | 0.05 | 6.24 | 4.56 | 10.79 | 65.31 | 83.15 | 148.46 | 37.63 |
| | SPARK | 519.93 | 82.23 | 3.54 | 1.23 | 0.42 | 5.19 | 1.71 | 8.78 | 4.43 | 0.06 | 9.70 | 5.47 | 15.17 | 75.05 | 99.39 | 174.45 | 33.54 |
| | **MEAN** | **476.45** | **99.58** | **3.28** | **1.12** | **0.37** | **4.76** | **1.55** | **6.41** | **4.70** | **0.10** | **8.32** | **4.61** | **12.93** | **78.88** | **81.65** | **160.53** | **35.06** |
| FIFTH | CONSORT | 502.52 | 20.60 | 3.61 | 1.03 | 0.35 | 5.00 | 1.71 | 5.80 | 2.85 | 0.04 | 7.63 | 2.88 | 10.51 | 160.12 | 50.26 | 210.38 | 41.37 |
| | SOISSONS | 433.60 | 19.21 | 2.78 | 0.98 | 0.32 | 4.08 | 1.27 | 6.05 | 4.44 | 0.02 | 7.29 | 4.54 | 11.83 | 84.10 | 80.58 | 164.68 | 41.86 |
| | SPARK | 322.16 | 0.00 | 1.88 | 0.68 | 0.22 | 2.78 | 0.97 | 4.33 | 1.72 | 0.00 | 5.03 | 1.99 | 7.03 | 102.10 | 38.31 | 140.41 | 49.46 |
| | **MEAN** | **419.43** | **13.27** | **2.76** | **0.90** | **0.30** | **3.95** | **1.31** | **5.39** | **3.00** | **0.02** | **6.65** | **3.14** | **9.79** | **115.44** | **56.38** | **171.82** | **44.23** |
| SIXTH | CONSORT | 381.71 | 79.96 | 3.31 | 0.98 | 0.33 | 4.62 | 1.55 | 5.67 | 2.87 | 0.09 | 7.35 | 2.91 | 10.26 | 123.42 | 50.22 | 173.64 | 37.66 |
| | SOISSONS | 652.64 | 18.80 | 2.95 | 1.00 | 0.33 | 4.28 | 1.30 | 6.00 | 4.57 | 0.02 | 7.60 | 4.48 | 12.08 | 112.39 | 79.49 | 191.87 | 44.74 |
| | SPARK | 340.36 | 24.56 | 2.33 | 0.86 | 0.28 | 3.46 | 1.16 | 5.52 | 2.23 | 0.02 | 6.69 | 2.28 | 8.98 | 117.11 | 47.83 | 164.94 | 47.11 |
| | **MEAN** | **458.23** | **41.11** | **2.86** | **0.95** | **0.31** | **4.12** | **1.34** | **5.73** | **3.22** | **0.04** | **7.22** | **3.22** | **10.44** | **117.64** | **59.18** | **176.82** | **43.17** |
| GRAND MEAN | | 468.91 | 49.86 | 3.13 | 1.09 | 0.35 | 4.57 | 1.45 | 6.17 | 4.42 | 0.08 | 8.15 | 4.17 | 12.32 | 101.70 | 73.13 | 174.83 | 40.26 |
| Sowing Date s.e.d | | 76.6 | 25.08 | 0.58 | 0.2057 | 0.0502 | 0.836 | 0.261 | 0.78 | 0.743 | 0.0355 | 1.1883 | 0.594 | 1.69 | 27.53 | 11.19 | 37.48 | 4.13 |
| | P value | NS | 0.059 | NS | NS | NS | NS | NS | NS | 0.059 | 0.069 | NS | 0.09 | NS | NS | NS | NS | 0.089 |
| | df | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Variety s.e.d | | 39.8 | 20.45 | 0.272 | 0.0925 | 0.0252 | 0.0377 | 0.1058 | 0.465 | 0.319 | 0.03 | 0.2268 | 0.272 | 0.379 | 11.25 | 4.39 | 12.11 | 3.44 |
| | P value | 0.032 | 0.016 | 0.011 | NS | NS | NS | 0.002 | 0.038 | <0.001 | 0.045 | <0.001 | <0.001 | NS | 0.065 | <0.001 | NS | 0.025 |
| Sowing Date x Variety s.e.d | | 110.5 | 47.97 | 0.795 | 0.2766 | 0.0711 | 1.126 | 0.3363 | 1.213 | 0.979 | 0.0696 | 1.272 | 0.806 | 1.853 | 35.55 | 14.22 | 44.62 | 8.02 |
| | P value | 0.126 | 0.098 | 0.074 | 0.154 | 0.84 | 0.08 | 0.05 | 0.05 | 0.081 | 0.005 | <0.001 | 0.049 | <0.001 | 0.103 | 0.044 | 0.056 | NS |
| | df | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Sowing date response 1996/7 July biomass summary**

| | | Shoot No.'s /m2 | | Green Area Index | | | | CROP DRY MATTERS T/Ha | | | | Nitrogen offtakes Kg/ha | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sowing Date | Variety | Pot Fertile | Dead & Dying | Lamina | T.stem | Ear | Total | Dd+dy Shts | Straw | Ss2 Ear | Total | Straw | Ear | Total |
| FIRST | CONSORT | 596.22 | 80.53 | 1.68 | 1.14 | 0.36 | 3.19 | 0.08 | 11.08 | 9.41 | 20.49 | 179.02 | 169.8 | 348.89 |
| | SOISSONS | 767.15 | 25.34 | 1.36 | 0.91 | 0.12 | 2.39 | 0.04 | 10.55 | 8.95 | 19.50 | 118.64 | 178.2 | 296.87 |
| | SPARK | 748.76 | 84.99 | 2.01 | 1.29 | 0.40 | 3.70 | 0.07 | 12.17 | 8.32 | 20.49 | 144.55 | 175.9 | 320.47 |
| | **MEAN** | **704.04** | **63.62** | **1.69** | **1.11** | **0.29** | **3.09** | **0.06** | **11.27** | **8.89** | **20.16** | **147.40** | **174.6** | **322.07** |
| SECOND | CONSORT | 579.25 | 53.83 | 1.28 | 0.92 | 0.33 | 2.53 | 0.12 | 10.13 | 9.53 | 19.66 | 157.97 | 169.2 | 327.18 |
| | SOISSONS | 608.63 | 5.89 | 0.14 | 0.20 | 0.01 | 0.36 | 0.01 | 9.07 | 8.09 | 17.16 | 87.44 | 167.1 | 254.55 |
| | SPARK | 738.93 | 103.38 | 1.78 | 0.91 | 0.34 | 3.03 | 0.08 | 11.75 | 8.84 | 20.59 | 165.94 | 173.4 | 339.44 |
| | **MEAN** | **642.27** | **54.37** | **1.07** | **0.68** | **0.23** | **1.97** | **0.07** | **10.32** | **8.82** | **19.14** | **137.12** | **169.9** | **307.05** |
| THIRD | CONSORT | 600.42 | 39.89 | 3.28 | 1.20 | 0.59 | 5.07 | 0.13 | 11.01 | 8.28 | 19.29 | 197.21 | 157.8 | 355.02 |
| | SOISSONS | 683.72 | 19.04 | 2.19 | 1.15 | 0.24 | 3.58 | 0.01 | 9.21 | 11.34 | 20.55 | 97.33 | 202.0 | 299.34 |
| | SPARK | 779.01 | 12.08 | 2.19 | 1.37 | 0.48 | 4.04 | 0.02 | 10.28 | 8.04 | 18.32 | 137.13 | 166.3 | 303.46 |
| | **MEAN** | **687.72** | **23.67** | **2.55** | **1.24** | **0.44** | **4.23** | **0.05** | **10.17** | **9.22** | **19.39** | **143.89** | **175.3** | **319.27** |
| FOURTH | CONSORT | 494.39 | 81.36 | 2.76 | 0.87 | 0.49 | 4.12 | 0.19 | 8.71 | 7.02 | 15.73 | 213.39 | 128.3 | 341.75 |
| | SOISSONS | 593.98 | 24.03 | 2.13 | 0.91 | 0.26 | 3.30 | 0.01 | 8.03 | 9.14 | 17.17 | 75.11 | 165.5 | 240.67 |
| | SPARK | 657.93 | 62.02 | 1.74 | 1.01 | 0.40 | 3.15 | 0.07 | 9.21 | 6.28 | 15.50 | 135.42 | 132.8 | 268.25 |
| | **MEAN** | **582.10** | **55.80** | **2.21** | **0.93** | **0.38** | **3.52** | **0.09** | **8.65** | **7.48** | **16.13** | **141.31** | **142.2** | **283.56** |
| FIFTH | CONSORT | 475.48 | 101.36 | 4.29 | 0.99 | 0.53 | 5.81 | 0.21 | 9.91 | 6.31 | 16.21 | 216.87 | 118.9 | 335.82 |
| | SOISSONS | 492.72 | 12.01 | 1.89 | 0.64 | 0.28 | 2.81 | 0.01 | 6.50 | 7.23 | 13.74 | 78.05 | 132.8 | 210.85 |
| | SPARK | 637.76 | 74.16 | 2.79 | 1.05 | 0.42 | 4.25 | 0.12 | 8.47 | 4.99 | 13.46 | 192.93 | 97.81 | 290.75 |
| | **MEAN** | **535.32** | **62.51** | **2.99** | **0.89** | **0.41** | **4.29** | **0.11** | **8.29** | **6.18** | **14.47** | **162.62** | **116.5** | **279.14** |
| SIXTH | CONSORT | 468.17 | 147.82 | 3.57 | 0.94 | 0.46 | 4.97 | 0.48 | 8.94 | 5.38 | 14.33 | 195.05 | 110.4 | 305.54 |
| | SOISSONS | 550.88 | 0.00 | 2.29 | 0.77 | 0.29 | 3.36 | 0.00 | 6.90 | 6.11 | 13.01 | 85.63 | 115.7 | 201.39 |
| | SPARK | 765.77 | 89.39 | 3.41 | 1.31 | 0.48 | 5.20 | 0.26 | 10.05 | 5.20 | 15.24 | 164.22 | 102.6 | 266.86 |
| | **MEAN** | **594.94** | **79.07** | **3.09** | **1.01** | **0.41** | **4.51** | **0.25** | **8.63** | **5.56** | **14.19** | **148.30** | **109.6** | **257.93** |
| GRAND MEAN | | 624.40 | 56.51 | 2.27 | 0.98 | 0.36 | 3.60 | 0.11 | 9.56 | 7.69 | 17.25 | 146.77 | 148.0 | 294.84 |
| Sowing Date s.e.d | | 54.80 | 28.99 | 0.43 | 0.14 | 0.02 | 0.55 | 0.03 | 0.84 | 0.33 | 1.00 | 21.37 | 10.75 | 24.60 |
| | P value | 0.139 | ns | 0.028 | 0.084 | 0.001 | 0.036 | 0.010 | 0.075 | <0.001 | 0.006 | ns | 0.005 | ns |
| | df | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Variety s.e.d | | 39.10 | 16.92 | 0.31 | 0.07 | 0.03 | 0.36 | 0.02 | 0.51 | 0.30 | 0.66 | 19.84 | 5.43 | 17.49 |
| | P value | 0.002 | 0.003 | 0.010 | <0.001 | <0.001 | 0.002 | <0.001 | 0.006 | <0.001 | ns | <0.001 | 0.008 | 0.001 |
| Sowing Date x Variety s.e.d | | 95.50 | 44.56 | 0.75 | 0.20 | 0.06 | 0.91 | 0.55 | 1.32 | 0.69 | 1.66 | 45.06 | 15.28 | 42.77 |
| | P value | ns | ns | ns | ns | ns | ns | 0.013 | ns | 0.028 | ns | ns | ns | ns |
| | df | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**Sowing date response July biomass summary**

| Sowing Date | Variety | Shoot No.'s /m2 Pot Fertile | Shoot No.'s /m2 Dead & Dying | Green Area Index Leaf | Green Area Index Stem | Green Area Index Ear | Green Area Index Total | Biomass t/ha Straw | Biomass t/ha Ear | Biomass t/ha Total | Nitrogen Offtakes kg/ha Straw | Nitrogen Offtakes kg/ha Ear | Nitrogen Offtakes kg/ha Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **FIRST** | **CONSORT** | 369.21 | 6.32 | 0.028 | 0.097 | 0.021 | 0.146 | 6.22 | 12.12 | 18.34 | 40.87 | 196.62 | 237.50 |
| | **SOISSONS** | 497.88 | 20.69 | 0.019 | 0.008 | 0.006 | 0.033 | 6.17 | 6.14 | 12.30 | 40.53 | 127.34 | 167.87 |
| | **SPARK** | 458.49 | 12.23 | 0.000 | 0.001 | 0.000 | 0.001 | 6.80 | 10.90 | 17.70 | 48.86 | 237.79 | 286.65 |
| | **MEAN** | **441.86** | **13.08** | **0.016** | **0.035** | **0.009** | **0.060** | **6.40** | **9.72** | **16.12** | **43.42** | **187.25** | **230.67** |
| **SECOND** | **CONSORT** | 378.98 | 0.00 | 0.057 | 0.077 | 0.010 | 0.144 | 5.37 | 11.61 | 16.98 | 33.07 | 191.09 | 224.16 |
| | **SOISSONS** | 430.19 | 59.22 | 0.010 | 0.007 | 0.004 | 0.021 | 4.46 | 8.21 | 12.67 | 29.68 | 158.91 | 188.59 |
| | **SPARK** | 415.18 | 41.89 | 0.004 | 0.152 | 0.013 | 0.169 | 5.67 | 9.96 | 15.63 | 36.49 | 185.60 | 222.09 |
| | **MEAN** | **408.12** | **33.70** | **0.024** | **0.079** | **0.009** | **0.111** | **5.17** | **9.93** | **15.09** | **33.08** | **178.53** | **211.62** |
| **THIRD** | **CONSORT** | 392.87 | 25.40 | 0.060 | 0.069 | 0.014 | 0.143 | 5.22 | 10.71 | 15.94 | 33.94 | 169.69 | 203.64 |
| | **SOISSONS** | 473.54 | 18.63 | 0.021 | 0.018 | 0.005 | 0.044 | 5.95 | 9.72 | 15.66 | 55.36 | 180.55 | 235.91 |
| | **SPARK** | 491.18 | 24.88 | 0.000 | 0.040 | 0.000 | 0.040 | 6.75 | 11.62 | 18.37 | 41.90 | 195.12 | 237.02 |
| | **MEAN** | **452.53** | **22.97** | **0.027** | **0.042** | **0.006** | **0.075** | **5.97** | **10.68** | **16.66** | **43.73** | **181.79** | **225.52** |
| **FOURTH** | **CONSORT** | 398.21 | 12.65 | 0.145 | 0.177 | 0.027 | 0.348 | 5.66 | 11.83 | 17.49 | 41.11 | 192.09 | 233.20 |
| | **SOISSONS** | 470.21 | 12.76 | 0.000 | 0.004 | 0.003 | 0.007 | 5.07 | 9.16 | 14.23 | 62.46 | 170.87 | 233.33 |
| | **SPARK** | 430.35 | 12.30 | 0.014 | 0.059 | 0.052 | 0.126 | 6.47 | 11.18 | 17.65 | 44.58 | 184.61 | 229.19 |
| | **MEAN** | **432.92** | **12.57** | **0.053** | **0.080** | **0.027** | **0.160** | **5.73** | **10.73** | **16.46** | **49.38** | **182.52** | **231.91** |
| **FIFTH** | **CONSORT** | 386.73 | 18.72 | 1.117 | 0.606 | 0.293 | 2.016 | 6.31 | 10.77 | 17.08 | 52.02 | 206.78 | 258.79 |
| | **SOISSONS** | 420.80 | 12.01 | 0.021 | 0.096 | 0.009 | 0.126 | 5.62 | 10.14 | 15.76 | 39.56 | 120.39 | 159.95 |
| | **SPARK** | 223.20 | 0.00 | 0.464 | 0.315 | 0.224 | 1.003 | 3.67 | 3.65 | 7.32 | 47.70 | 73.98 | 121.67 |
| | **MEAN** | **343.58** | **10.24** | **0.534** | **0.339** | **0.175** | **1.048** | **5.20** | **8.18** | **13.39** | **46.42** | **133.71** | **180.14** |
| **SIXTH** | **CONSORT** | 411.04 | 0.00 | 0.573 | 0.489 | 0.062 | 1.124 | 5.75 | 11.60 | 17.35 | 41.48 | 188.89 | 230.37 |
| | **SOISSONS** | 684.93 | 43.84 | 0.056 | 0.053 | 0.021 | 0.130 | 6.48 | 10.79 | 17.28 | 40.95 | 214.66 | 255.61 |
| | **SPARK** | 477.27 | 0.00 | 0.368 | 0.382 | 0.214 | 0.964 | 6.14 | 10.82 | 16.96 | 48.31 | 195.21 | 243.51 |
| | **MEAN** | **524.41** | **14.61** | **0.332** | **0.308** | **0.099** | **0.739** | **6.12** | **11.07** | **17.20** | **43.58** | **199.59** | **243.17** |
| **GRAND MEAN** | | 433.90 | 17.86 | 0.164 | 0.147 | 0.054 | 0.366 | 0.10 | 10.05 | 15.82 | 43.27 | 177.23 | 220.50 |
| **Sowing Date s.e.d** | | 30.4 | 13.94 | 0.1858 | 0.0383 | 0.0357 | 0.238 | 0.2054 | 0.513 | 0.694 | 8.08 | 26.26 | 29 |
| | **P value** | 0.022 | NS | 0.145 | 0.001 | 0.022 | 0.032 | 0.008 | 0.0183 | 0.02 | NS | NS | NS |
| | **df** | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| **Variety s.e.d** | | 29.7 | 8.26 | 0.107 | 0.0338 | 0.0248 | 0.1449 | 0.21 | 0.311 | 0.502 | 4.07 | 15.57 | 16.96 |
| | **P value** | 0.01 | 0.137 | 0.041 | <0.001 | 0.026 | 0.005 | NS | <0.001 | <0.001 | NS | NS | NS |
| **Sowing Date x Variety s.e.d** | | 66.7 | 21.62 | 0.2834 | 0.0777 | 0.0611 | 0.375 | 0.4675 | 0.805 | 1.22 | 11.46 | 40.74 | 44.62 |
| | **P value** | NS | NS | NS | 0.023 | 0.067 | 0.098 | 0.004 | <0.001 | <0.001 | NS | 0.133 | 0.13 |
| | **df** | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**1996/7 Photosynthetically active radiation interception from Ceptometer readings**

| Sowing Date | Variety | APRIL | MAY | JUNE | JULY |
|---|---|---|---|---|---|
| **FIRST** | **CONSORT** | 75.42 | 98.44 | 99.08 | 94.35 |
| | **SOISSONS** | 75.01 | 99.56 | 99.25 | 91.23 |
| | **SPARK** | 67.83 | 98.46 | 98.78 | 88.43 |
| | **MEAN** | **72.75** | **98.82** | **99.04** | **91.34** |
| **SECOND** | **CONSORT** | 69.02 | 97.00 | 98.82 | 83.88 |
| | **SOISSONS** | 74.92 | 98.19 | 98.50 | 89.71 |
| | **SPARK** | 68.00 | 97.72 | 97.89 | 93.40 |
| | **MEAN** | **70.65** | **97.64** | **98.40** | **89.00** |
| **THIRD** | **CONSORT** | 34.58 | 93.31 | 97.77 | 95.95 |
| | **SOISSONS** | 56.18 | 96.55 | 96.47 | 97.36 |
| | **SPARK** | 43.85 | 93.98 | 96.97 | 91.42 |
| | **MEAN** | **44.87** | **94.62** | **97.07** | **94.91** |
| **FOURTH** | **CONSORT** | 14.50 | 88.99 | 97.21 | 94.96 |
| | **SOISSONS** | 27.13 | 85.99 | 94.58 | 95.56 |
| | **SPARK** | 10.27 | 87.15 | 95.34 | 94.34 |
| | **MEAN** | **17.30** | **87.38** | **95.71** | **94.96** |
| **FIFTH** | **CONSORT** | 13.70 | 83.12 | 94.76 | 92.91 |
| | **SOISSONS** | 14.51 | 73.97 | 91.36 | 88.94 |
| | **SPARK** | 10.10 | 80.20 | 93.30 | 97.12 |
| | **MEAN** | **12.77** | **79.10** | **93.14** | **92.99** |
| **SIXTH** | **CONSORT** | 8.78 | 76.94 | 96.51 | 96.89 |
| | **SOISSONS** | 7.49 | 66.76 | 83.90 | 96.30 |
| | **SPARK** | 15.78 | 73.98 | 96.33 | 95.44 |
| | **MEAN** | **10.68** | **72.56** | **92.24** | **96.21** |
| | **MEAN** | **38.17** | **88.35** | **95.93** | **93.23** |

**1997/8 Photosynthetically active radiation interception from Ceptometer readings**

| Sowing Date | Variety | APRIL | MAY | JUNE | JULY |
|---|---|---|---|---|---|
| FIRST | CONSORT | 43.1 | 89.7 | 91.8 | 82.9 |
| | SOISSONS | 47.9 | 82.6 | 88.9 | 80.5 |
| | SPARK | 37.6 | 92.0 | 94.6 | 85.0 |
| | MEAN | **42.9** | **88.1** | **91.7** | **82.8** |
| SECOND | CONSORT | 13.6 | 81.8 | 92.6 | 74.9 |
| | SOISSONS | 8.8 | 75.9 | 85.4 | 69.2 |
| | SPARK | 12.8 | 87.2 | 91.2 | 76.3 |
| | MEAN | **11.7** | **81.6** | **89.7** | **73.5** |
| THIRD | CONSORT | 38.7 | 88.5 | 93.0 | 80.6 |
| | SOISSONS | 44.3 | 94.0 | 92.1 | 75.9 |
| | SPARK | 25.9 | 91.0 | 92.5 | 82.8 |
| | MEAN | **36.3** | **91.2** | **92.5** | **79.8** |
| FOURTH | CONSORT | 39.1 | 86.7 | 87.2 | 70.2 |
| | SOISSONS | 33.7 | 88.4 | 91.3 | 78.7 |
| | SPARK | 23.8 | 78.9 | 88.3 | 69.0 |
| | MEAN | **32.2** | **84.7** | **88.9** | **72.6** |
| FIFTH | CONSORT | -13.7 | 46.2 | 78.4 | 70.9 |
| | SOISSONS | 23.7 | 42.2 | 81.5 | 70.8 |
| | SPARK | -28.9 | 22.5 | 58.4 | 46.4 |
| | MEAN | **-6.3** | **36.9** | **72.8** | **62.7** |
| SIXTH | CONSORT | -9.5 | 75.7 | 82.6 | 71.2 |
| | SOISSONS | 19.6 | 64.8 | 86.0 | 70.1 |
| | SPARK | -11.5 | 24.9 | 67.4 | 55.5 |
| | MEAN | **-0.5** | **55.1** | **78.6** | **65.6** |
| | MEAN | **9.9** | **66.1** | **82.1** | **69.2** |
| **Sowing Date s.e.d** | | 14.78 | 8.65 | 1.386 | 4.121 |
| | **P value** | 0.082 | 0.007 | <0.001 | 0.025 |
| | **df** | 5 | 5 | 5 | 5 |
| **Variety s.e.d** | | 5.95 | 2.72 | 0.658 | 2.08 |
| | **P value** | 0.02 | 0.002 | <0.001 | 0.031 |
| **Sowing Date x Variety s.e.d** | | 18.98 | 10.21 | 1.912 | 5.855 |
| | **P value** | NS | 0.002 | <0.001 | 0.011 |
| | **df** | 12 | 12 | 12 | 12 |

## 1996/7 Pre-harvest biomass results

| Sowing Date | Variety | Straw & Chaff | Grain (Biomass t/ha) | Total | Harvest Index | Nitrogen Harvest Index | Offtake kg/ha |
|---|---|---|---|---|---|---|---|
| FIRST | BRIGADIER | 10.30 | 6.12 | 16.42 | 37.31 | 45.74 | 312.19 |
| | BUSTER | 7.91 | 8.44 | 16.35 | 51.42 | 68.11 | 293.49 |
| | CADENZA | 12.36 | 4.35 | 16.70 | 25.67 | 46.02 | 324.52 |
| | CONSORT | 8.42 | 6.00 | 14.43 | 41.59 | 60.54 | 321.13 |
| | SOISSONS | 9.83 | 5.65 | 15.48 | 36.50 | 54.75 | 200.08 |
| | SPARK | 11.40 | 6.37 | 17.77 | 35.86 | 52.78 | 324.37 |
| | **MEAN** | **10.04** | **6.16** | **16.19** | **38.06** | **54.66** | **295.96** |
| SECOND | BRIGADIER | 8.26 | 8.04 | 16.30 | 49.19 | 67.77 | 282.27 |
| | BUSTER | 9.20 | 9.59 | 18.79 | 51.21 | 68.40 | 332.08 |
| | CADENZA | 9.14 | 5.37 | 14.51 | 37.00 | 57.62 | 275.21 |
| | CONSORT | 8.81 | 6.32 | 15.13 | 42.12 | 62.87 | 354.86 |
| | SOISSONS | 8.01 | 4.66 | 12.67 | 36.82 | 60.59 | 230.55 |
| | SPARK | 10.63 | 7.20 | 17.83 | 40.28 | 60.13 | 335.17 |
| | **MEAN** | **9.01** | **6.86** | **15.87** | **42.77** | **62.90** | **301.69** |
| THIRD | BRIGADIER | 7.68 | 8.18 | 15.86 | 51.50 | 68.17 | 292.64 |
| | BUSTER | 8.31 | 8.56 | 16.87 | 50.82 | 69.77 | 311.78 |
| | CADENZA | 9.18 | 6.07 | 15.26 | 40.67 | 61.64 | 329.05 |
| | CONSORT | 6.47 | 6.49 | 12.96 | 49.93 | 69.90 | 282.60 |
| | SOISSONS | 7.48 | 8.95 | 16.43 | 54.50 | 72.96 | 273.82 |
| | SPARK | 10.95 | 7.71 | 18.66 | 41.12 | 63.70 | 312.41 |
| | **MEAN** | **8.34** | **7.66** | **16.01** | **48.09** | **67.69** | **300.38** |
| FOURTH | BRIGADIER | 7.55 | 8.68 | 16.23 | 53.39 | 70.04 | 264.57 |
| | BUSTER | 7.69 | 8.79 | 16.49 | 53.34 | 73.12 | 291.61 |
| | CADENZA | 8.88 | 8.34 | 17.23 | 48.45 | 69.59 | 284.67 |
| | CONSORT | 6.76 | 5.79 | 12.54 | 46.14 | 66.17 | 294.14 |
| | SOISSONS | 6.96 | 9.08 | 16.04 | 56.77 | 77.60 | 260.13 |
| | SPARK | 8.44 | 7.14 | 15.58 | 45.84 | 71.27 | 265.39 |
| | **MEAN** | **7.71** | **7.97** | **15.68** | **50.66** | **71.30** | **276.75** |
| FIFTH | BRIGADIER | 7.31 | 8.15 | 15.45 | 52.69 | 65.99 | 258.57 |
| | BUSTER | 7.91 | 9.17 | 17.08 | 53.74 | 69.79 | 304.99 |
| | CADENZA | 8.34 | 7.68 | 16.02 | 47.84 | 69.89 | 297.29 |
| | CONSORT | 7.78 | 6.86 | 14.64 | 46.79 | 64.91 | 292.32 |
| | SOISSONS | 7.44 | 10.46 | 17.90 | 58.43 | 75.99 | 250.81 |
| | SPARK | 8.11 | 7.15 | 15.26 | 47.12 | 69.93 | 287.20 |
| | **MEAN** | **7.82** | **8.24** | **16.06** | **51.10** | **69.42** | **281.86** |
| SIXTH | BRIGADIER | 6.43 | 7.65 | 14.08 | 54.29 | 72.35 | 245.96 |
| | BUSTER | 7.32 | 9.23 | 16.55 | 55.75 | 72.26 | 273.26 |
| | CADENZA | 6.83 | 7.96 | 14.79 | 53.86 | 73.95 | 263.67 |
| | CONSORT | 6.53 | 6.53 | 13.06 | 49.96 | 68.36 | 285.01 |
| | SOISSONS | 7.23 | 9.31 | 16.54 | 56.26 | 71.88 | 244.18 |
| | SPARK | 8.59 | 7.38 | 15.97 | 46.46 | 65.29 | 285.82 |
| | **MEAN** | **7.16** | **8.01** | **15.17** | **52.76** | **70.68** | **266.32** |
| | **GRAND MEAN** | **8.35** | **7.48** | **15.83** | **47.24** | **66.11** | **287.16** |
| **Sowing Date s.e.d** | | 0.45 | 0.29 | 0.63 | 1.43 | 3.05 | 12.51 |
| | **P value** | 0.011 | 0.013 | NS | <0.001 | 0.016 | NS |
| | **df** | 5 | 5 | 5 | 5 | 5 | 5 |
| **Variety s.e.d** | | 0.46 | 0.36 | 0.62 | 1.69 | 2.22 | 14.00 |
| | **P value** | <0.001 | <0.001 | <0.001 | <0.001 | 0.023 | 0.001 |
| **Sowing Date x Variety s.e.d** | | 1.12 | 0.86 | 1.51 | 4.05 | 5.83 | 33.71 |
| | **P value** | NS | 0.005 | NS | 0.026 | 0.208 | NS |
| | **df** | 30 | 30 | 30 | 30 | 30 | 27 |

## Sowing date response 1997/98 pre-harvest biomass summary

| Sowing Date | Variety | Ear No. m2 | Grain no. Per ear | Crop Dry Matters T/Ha Straw | Ear | Grain | Chaff | Total | Harvest Index | Nitrogen Offtakes Kg/ha Straw | Chaff | Grain | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FIRST | BRIGADIER | 482.2 | 51.8 | 5.57 | 11.67 | 9.64 | 2.04 | 17.24 | 55.98 | 32.85 | 11.78 | 195.97 | 240.61 |
| | BUSTER | 495.1 | 48.1 | 5.71 | 10.36 | 8.81 | 1.55 | 16.06 | 54.82 | 34.54 | 10.57 | 195.99 | 241.10 |
| | CADENZA | 396.9 | 35.1 | 6.35 | 7.02 | 5.82 | 1.21 | 13.37 | 38.59 | 43.52 | 7.26 | 135.92 | 186.70 |
| | CONSORT | 454.0 | 54.2 | 5.60 | 11.37 | 9.53 | 1.84 | 16.98 | 56.19 | 38.04 | 11.78 | 179.19 | 229.01 |
| | SOISSONS | 435.8 | 39.6 | 5.73 | 6.90 | 5.86 | 1.04 | 12.64 | 45.56 | 43.40 | 5.69 | 136.43 | 185.52 |
| | SPARK | 626.3 | 42.3 | 6.94 | 11.15 | 9.54 | 1.61 | 18.10 | 52.76 | 34.52 | 9.11 | 197.03 | 240.65 |
| | **MEAN** | **481.7** | **45.2** | **5.98** | **9.75** | **8.20** | **1.55** | **15.73** | **50.65** | **37.81** | **9.36** | **173.42** | **220.60** |
| SECOND | BRIGADIER | 486.8 | 46.9 | 5.19 | 11.00 | 9.36 | 1.64 | 16.19 | 57.90 | 26.83 | 9.74 | 179.06 | 215.63 |
| | BUSTER | 530.4 | 42.0 | 4.97 | 9.88 | 8.33 | 1.54 | 14.84 | 56.18 | 30.01 | 9.22 | 176.99 | 216.22 |
| | CADENZA | 473.1 | 41.7 | 6.23 | 9.85 | 8.14 | 1.72 | 16.08 | 50.66 | 31.28 | 9.20 | 174.24 | 214.73 |
| | CONSORT | 454.3 | 55.4 | 4.81 | 11.49 | 9.98 | 1.51 | 16.30 | 61.24 | 26.36 | 9.20 | 182.69 | 218.25 |
| | SOISSONS | 532.2 | 43.5 | 5.09 | 8.93 | 7.60 | 1.33 | 14.03 | 54.29 | 39.44 | 7.81 | 170.70 | 217.95 |
| | SPARK | 487.8 | 52.3 | 5.49 | 10.36 | 8.94 | 1.43 | 15.85 | 56.49 | 27.93 | 8.18 | 174.52 | 210.63 |
| | **MEAN** | **494.1** | **47.0** | **5.30** | **10.25** | **8.72** | **1.53** | **15.55** | **56.13** | **30.31** | **8.89** | **176.37** | **215.57** |
| THIRD | BRIGADIER | 509.0 | 47.6 | 5.37 | 11.09 | 9.38 | 1.71 | 16.46 | 57.12 | 35.37 | 10.11 | 182.21 | 227.69 |
| | BUSTER | 500.3 | 45.8 | 5.48 | 9.94 | 8.41 | 1.52 | 15.42 | 54.64 | 35.66 | 10.26 | 181.41 | 227.34 |
| | CADENZA | 511.3 | 38.7 | 6.61 | 9.81 | 8.28 | 1.53 | 16.41 | 50.43 | 37.86 | 8.12 | 174.51 | 220.49 |
| | CONSORT | 469.0 | 52.6 | 4.93 | 11.61 | 10.10 | 1.51 | 16.54 | 61.05 | 30.20 | 9.79 | 186.09 | 226.08 |
| | SOISSONS | 608.4 | 39.3 | 5.21 | 9.51 | 8.12 | 1.39 | 14.72 | 55.16 | 34.85 | 8.60 | 183.50 | 226.95 |
| | SPARK | 633.7 | 46.0 | 7.00 | 11.83 | 10.12 | 1.70 | 18.83 | 53.89 | 41.77 | 10.20 | 198.80 | 250.77 |
| | **MEAN** | **538.6** | **45.0** | **5.77** | **10.63** | **9.07** | **1.56** | **16.40** | **55.38** | **35.95** | **9.51** | **184.42** | **229.89** |
| FOURTH | BRIGADIER | 567.3 | 45.5 | 5.44 | 11.85 | 10.08 | 1.77 | 17.30 | 58.40 | 38.04 | 10.63 | 191.64 | 240.30 |
| | BUSTER | 570.8 | 44.5 | 5.10 | 11.13 | 9.36 | 1.77 | 16.24 | 57.70 | 28.80 | 11.87 | 195.37 | 236.05 |
| | CADENZA | 479.4 | 41.9 | 5.67 | 10.07 | 8.45 | 1.61 | 15.73 | 53.64 | 29.07 | 8.58 | 175.97 | 213.62 |
| | CONSORT | 513.3 | 54.6 | 5.03 | 12.15 | 10.60 | 1.55 | 17.18 | 61.76 | 32.07 | 10.68 | 195.66 | 238.41 |
| | SOISSONS | 630.8 | 38.1 | 5.07 | 9.66 | 8.26 | 1.40 | 14.73 | 56.02 | 29.24 | 7.55 | 189.26 | 226.05 |
| | SPARK | 521.1 | 51.0 | 5.70 | 10.38 | 8.84 | 1.54 | 16.08 | 55.01 | 39.09 | 11.53 | 175.88 | 226.50 |
| | **MEAN** | **547.1** | **46.0** | **5.34** | **10.87** | **9.27** | **1.61** | **16.21** | **57.09** | **32.72** | **10.14** | **187.30** | **230.15** |
| FIFTH | BRIGADIER | 503.3 | 50.1 | 4.74 | 11.21 | 9.49 | 1.72 | 15.95 | 59.56 | 34.55 | 12.84 | 207.34 | 254.73 |
| | BUSTER | 494.6 | 47.0 | 4.74 | 10.62 | 9.03 | 1.59 | 15.36 | 58.74 | 37.77 | 12.86 | 206.61 | 257.24 |
| | CADENZA | 354.2 | 40.7 | 4.44 | 7.07 | 5.85 | 1.22 | 11.51 | 50.50 | 30.78 | 10.92 | 135.24 | 176.94 |
| | CONSORT | 528.2 | 44.2 | 5.37 | 9.98 | 8.22 | 1.76 | 15.35 | 52.42 | 45.37 | 14.99 | 172.58 | 232.95 |
| | SOISSONS | 649.8 | 38.8 | 5.19 | 10.32 | 8.66 | 1.66 | 15.51 | 56.04 | 34.61 | 14.50 | 207.55 | 256.66 |
| | SPARK | 410.4 | 47.3 | 3.35 | 6.81 | 5.43 | 1.38 | 10.17 | 52.73 | 23.13 | 19.32 | 135.79 | 178.24 |
| | **MEAN** | **490.1** | **44.7** | **4.64** | **9.34** | **7.78** | **1.56** | **13.97** | **55.00** | **34.37** | **14.24** | **177.52** | **226.13** |
| SIXTH | BRIGADIER | 525.1 | 48.5 | 4.63 | 11.25 | 9.59 | 1.67 | 15.88 | 60.30 | 36.05 | 11.21 | 191.58 | 238.83 |
| | BUSTER | 496.6 | 48.4 | 4.78 | 10.54 | 9.08 | 1.46 | 15.32 | 59.21 | 34.29 | 11.18 | 199.62 | 245.09 |
| | CADENZA | 351.2 | 39.2 | 3.99 | 6.72 | 5.67 | 1.05 | 10.71 | 50.66 | 24.02 | 6.69 | 116.78 | 147.49 |
| | CONSORT | 508.7 | 41.7 | 4.44 | 8.29 | 6.95 | 1.34 | 12.72 | 52.99 | 34.89 | 11.83 | 142.44 | 189.16 |
| | SOISSONS | 601.7 | 34.6 | 4.71 | 8.80 | 7.47 | 1.33 | 13.52 | 55.48 | 35.96 | 8.36 | 174.08 | 218.40 |
| | SPARK | 575.8 | 44.7 | 4.66 | 9.09 | 7.46 | 1.62 | 13.74 | 54.15 | 26.96 | 17.72 | 174.79 | 219.47 |
| | **MEAN** | **509.9** | **42.8** | **4.53** | **9.11** | **7.70** | **1.41** | **13.65** | **55.46** | **32.03** | **11.17** | **166.55** | **209.74** |
| | **MEAN** | **510.3** | **45.1** | **5.26** | **9.99** | **8.46** | **1.53** | **15.25** | **54.95** | **33.86** | **10.55** | **177.60** | **222.01** |
| **Sowing Date s.e.d** | | 16.89 | 2.308 | 0.2823 | 0.759 | 0.688 | 0.0872 | 0.902 | 2.578 | 2.575 | 1.261 | 13.6 | 12.82 |
| | **P value** | 0.011 | NS | 0.002 | NS | NS | NS | 0.05 | NS | 0.127 | 0.016 | NS | NS |
| | **df** | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| **Variety s.e.d** | | 25.74 | 1.898 | 0.2433 | 0.563 | 0.494 | 0.0983 | 0.748 | 1.53 | 2.157 | 1.119 | 10.95 | 12.19 |
| | **P value** | <0.001 | <0.001 | NS | <0.001 | <0.001 | 0.002 | 0.008 | <0.001 | NS | 0.002 | 0.007 | 0.009 |
| **Sowing Date x Variety s.e.d** | | 59.85 | 4.832 | 0.6129 | 1.47 | 1.301 | 0.2364 | 1.9 | 4.282 | 5.468 | 2.801 | 28.01 | 30.12 |
| | **P value** | 0.043 | NS | 0.025 | 0.15 | 0.125 | NS | 0.108 | NS | 0.008 | NS | NS | NS |
| | **df** | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |

## Appendix 2

## MANAGEMENT WITH GOOD AND POOR FINISHING

### INTRODUCTION

'Finishing' is the crops ability to continue assimilate production during the latter stages of grain fill. This will be affected by the available water capacity, as defined by soil type, and the incidence and severity of take-all root loss which affects non-first wheats most. About 20% of UK wheat is grown on light soil (Foulkes *et al.*, 1994) and Austin (1978) has estimated that each year drought reduces yield by about 17 %. Over the period 1989-96 non-first wheats have accounted for between 36 and 59 % of the UK wheat crop. The percentage has been lower in the years 1995 and 1996 following the widespread introduction of set-aside. However, a large amount of set-aside is natural regeneration, which is not a complete take-all break (Jones *et al.*, 1996), and a larger proportion than at first sight might be at risk to take-all infection. Vaiydanathan *et al.* (1987) reported that, overall in non-first wheat crops after discounting the effects of N, mean yield loss due to take-all was in the order of 1 t $ha^{-1}$.

Objectives of the experimental programme are to test the benefit of altering husbandry in contrasting finishing environments, specifically nitrogen fertiliser management in relation to irrigated and unirrigated conditions, and variety choice in relation to first and second wheat environments.

### *2.1. INTERACTION BETWEEN VARIETY AND ROTATIONAL POSITION*

### MATERIALS & METHODS

**Rotational Position experiment**

Varietal responses to rotational position in first and second wheat treatments for nine varieties will be compared with their predicted performance according to hypotheses developed in HGCA Project Report No. 184 'Exploitation of Varieties' (HGCA, 1998). The varieties selected together with the rationale for predicted performances are outlined below. In addition, varieties are described quantitatively for target indicative traits in Table 2.1.1 from data collected in the Typing Trials at ADAS Rosemaund 1993-94 & 1994-95 and Sutton Bonington 1994-95 undertaken as part of the HGCA Project Report No. 184.

Brigadier: Early-intermediate development, poor economy of tillering, moderate-high stem reserves : predicted suitability - similar performance as a first or second wheat.

Drake: Late development, but highest stem reserves in NIAB Additional

Character Assessments RL trials 1995-96 (HGCA, 1998): Predicted suitability - potential to perform relatively better as a second wheat.

M. Huntsman : Intermediate development, good economy of tillering, low stem reserves: predicted suitability - relatively worse performance as a second wheat.

Lynx: Early-intermediate development, intermediate-high stem reserves, poor economy of tillering: predicted suitability - similar performance in first and second wheat conditions.

Mercia : Early development, intermediate economy of tillering, low stem reserves : predicted suitability - relatively worse performance as a second wheat.

Mercia *Rht2* : Isogenic *Rht2* semi dwarf line for Mercia (height reduction found to be associated with greater stem reserves in HGCA (1998)) : predicted suitability - relatively better performance as a second wheat compared to Mercia control.

Rialto: Early-intermediate development, poor-intermediate economy of tillering, high stem reserves: predicted suitability - relatively better performance as a second wheat.

Soissons : Early development, good economy of tillering, moderate-high stem reserves: predicted suitability - relatively better performance as a second wheat.

Spark : Late development, intermediate economy of tillering; low stem reserves : predicted suitability - relatively worse performance as a second wheat.

**Table 2.1.1. Physiological traits for varieties in HGCA Project Report No. 184 (HGCA, 1998).**

| | GS31 Fertile Shoot no $m^{-2}$ | Harvest Shoot no $m^{-2}$ | GS31 date | GS61 date | Stem reserves@ GS61+75°Cd t $ha^{-1}$ |
|---|---|---|---|---|---|
| Brigadier | 1266 | 523 | 18 Apr | 16 Jun | 3.6 |
| *Drake* | *1350* | *540* | *22 Apr* | *17 Jun* | *4.5* |
| Lynx | 1150 | 481 | 16 Apr | 17 Jun | 3.6 |
| M. Huntsman | 1007 | 390 | 19 Apr | 15 Jun | 2.9 |
| Mercia | 915 | 542 | 12 Apr | 13 Jun | 2.9 |
| Mercia Rht2 | - | - | - | - | - |
| Rialto | 1107 | 454 | 9 Apr | 15 Jun | 4.5 |
| Soissons | 1048 | 570 | 5 Apr | 8 Jun | 3.5 |
| Spark | 1220 | 625 | 24 Apr | 19 Jun | 2.7 |

**Experimental details**

Site details

Location: The University Farm, Sutton Bonington, nr Loughborough, Leics.

Soil type : Light to medium stony medium loam to 80 cm over keuper marl clay; available water capacity to 1.2 m = 160 mm..

Seed rate : 325/80 seeds per $m^2$.

Sowing dates : 1996 - 12 October; and 1997 - 10 October

**Experimental design**

Design : Randomised split-plot

Main plots : Two rotational positions as main plots (10 x 120 m) (first wheat after spring oilseed rape, second wheat after winter wheat).

Sub-plots : 9 varieties as split-plots (10 x 10 m) :

1. [1]Brigadier
2. Drake
3. [1]Maris Huntsman
4. Lynx
5. Mercia
6. Mercia Rht2
7. Rialto
8. Soissons
9. Spark.

Replicates : 3

Total no. plots : 66

*Note[1] Duplicate plots of Brigadier and Maris Huntsman were sown at a low seed rate of 80 seeds* $m^{-2}$. *The aim was to manipulate source/sink relations (i.e. increasing source relative to sink at the lower seed rate), the broad hypothesis being that a crop with a greater source: sink ratio will perform better in poor finishing conditions.*

**Crop management**

In the set-up years the aim was to balance residual N across first and second wheat treatments. Balancing N in this way allows take-all root loss tolerance effects to be detected without the complication of any confounding effect of differential varietal responses to N residues. Measurements of soil N taken before ploughing in September 1996 and 1997 showed small differences in N residue which did not require intervention. All pesticides, PGRs and fertilisers were using a prophylactic approach to exclude any external pest or disease interference (see Appendix 1).

**Assessments**

i) Take-all

Take-all was assessed using the index method. This involved the removal of 20 plants from random locations within the plot to account for the inherent variation of the disease. The roots of each plant were washed and the proportion of the root system which showed visible symptoms of the disease were recorded in one of six categories:

0= no disease
1= 1-10% of root system infected
2= 10=25% "
3= 25-50% "
4=50-75% "
5=75-100% "

a take-all index is then calculated;

$$\text{index} = \frac{1*n1 + 2*n2 + 3*n3 + 4*n4 + 5*n5}{5 * nt/100}$$

Where : n1-n5 are the number of plants in each category and nt the total number of plants assessed.

Take-all index was assessed monthly between January and harvest on the Spark plots.

ii) Crop growth

Crop samples were taken from 0.72 $m^2$ quadrats at GS 31, GS 33, GS 39, GS 61+75°Cd (mid-anthesis) and pre-harvest, and crop biomass, shoot number and green area index were measured according to standard protocols (Sylvester-bradley *et al.*, 1997-98). In 1997-98, measurements of crop growth were taken according to tiller hierarchy, thus the main stem, tiller 1, tiller 2, tiller 3 and remaining tillers were analysed separately. Mineral N was assessed in 0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm soil horizons at GS 31, mid-anthesis and harvest. The percentage water soluble stem carbohydrate was determined for eight stems per plot at mid-anthesis (stage of maximum reserves (Austin, 1977)) and harvest. The quantity of stem reserves (t $ha^{-1}$) was calculated from the percentage water soluble stem carbohydrate and the stem biomass of the 0.72 $m^2$ crop sample. Combine yield was taken from an area of not less than 20 $m^2$ from which thousand grain weight, grain specific weight and grain N% were measured.

**Demonstration experiment.**

Specific objective

To demonstrate how N and fungicide inputs for two varieties with different tolerances of poor finishing conditions could be optimised using crop intelligence.

Experimental details

| | |
|---|---|
| Site details | |
| Location: | The University Farm, Sutton Bonington. |
| Soil type : | Light to medium stony medium loam to 80 cm over keuper marl clay;<br>available water capacity to 1.2 m = 160 mm.. |
| Seed rate : | 325 seeds per $m^2$. |
| Sowing date : | 1996 - October<br>1997 - 23 October |
| Design : | Randomised split-plot |
| Main plots : | Two varieties as main plots (10 x 20 m)<br>1. Rialto (good 'finishing').<br>2. Spark (poor 'finishing'). |
| Sub-plot : | Two management systems as split-plots (10 x 10 m)<br>1. Crop Intelligence N and fungicide<br>2. Conventional N and fungicide |
| Replicates : | 2 |
| Total no. plots : 8 | |

Crop management

N was applied to the Intelligence treatment according to Canopy Management rules (Sylvester-bradley *et al.*, 1997) with a target GAI of five for Rialto (high stem reserves) and six for Spark (low stem reserves), see Appendix 2 for N applications. Where buffering capacity is greater for Rialto, an insurance application of late fungicide was omitted in 1997-98. In 1996-97, when incidence of foliar disease was greater and forecasted soil moisture deficit greater, the late fungicide was applied to Rialto. PGRs and fertilisers were using a prophylactic approach to exclude any external pest or disease interference (see Appendix 2).

Experimental measurements

Crop biomass and harvest index was measured pre-harvest. Combine yield was taken from an area of not less than 20 $m^2$ from which thousand grain weight, grain specific weight and grain N% were measured.

## RESULTS AND DISCUSSION

### Take-all

Take-all indices (TAIs) were low during 1996-97 and 1997-98 (Figure 2.1.1) and differences between the levels of infection for the 1st and 2nd wheats did not rise above five until after June in both years. Work done at ADAS Rosemaund in the 1982-83 and 1984-85 seasons have shown that an increase in take-all index of 10 (0-100 scale) measured during the winter reduced grain yield by almost 0.9 t $ha^{-1}$. Dry periods during late winter and spring (Table 2.1.2) may have retarded disease progress in both years. Double the amount of rainfall normally experienced in June probably helped increase the levels of take-all later in the season in both years.

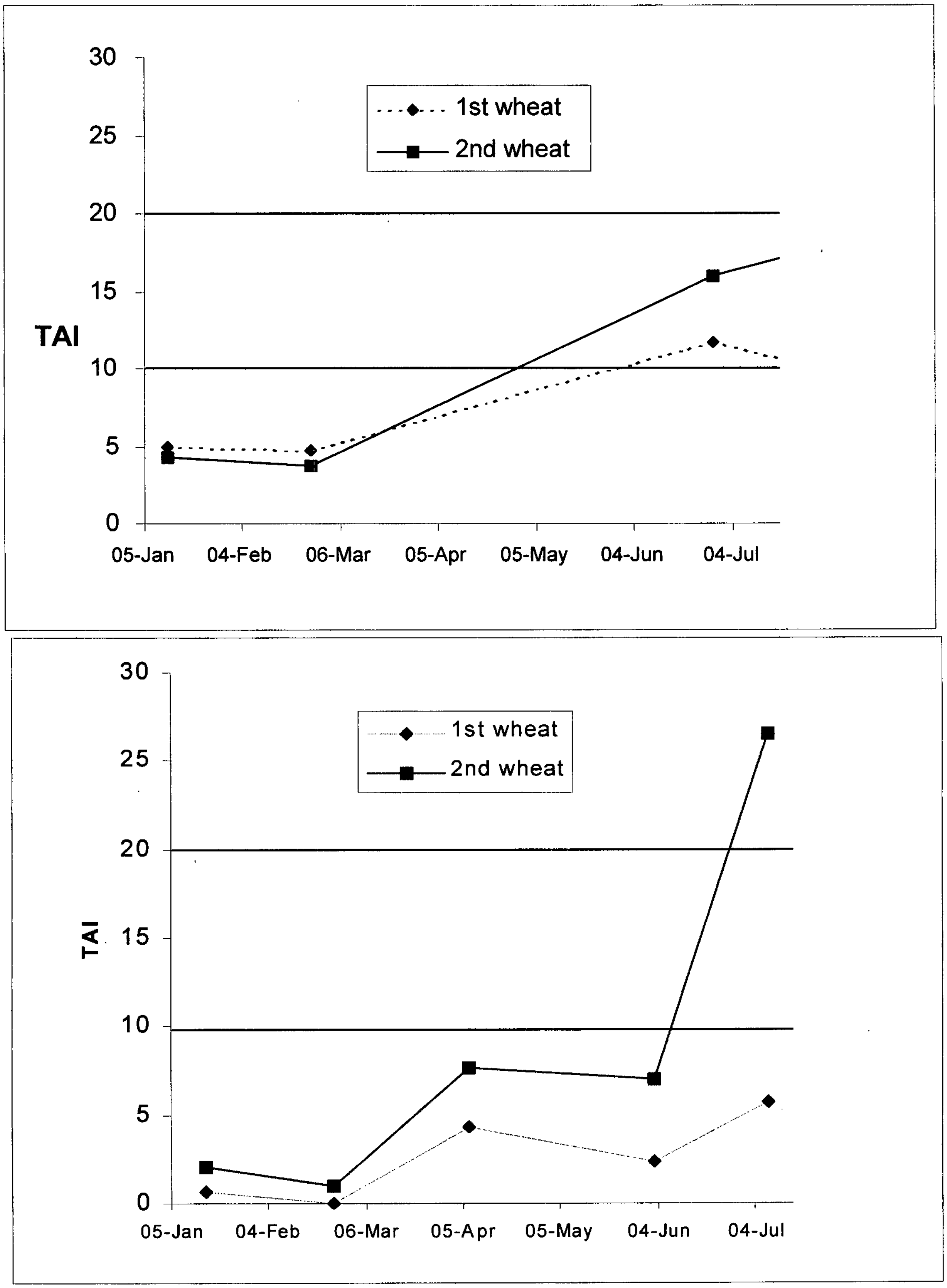



Figure 2.1.1. Take-all index (TAI) progression expressed as an index for 1st and 2nd wheats in 1996-97 (a - top), 1997-98 (b - bottom).

Table 2.1.2. Monthly weather data for Sutton Bonington in 1996-98 and for the 30 year long term mean (LTM)

| | **Mean Temperature (°C)** | | | **Rainfall (mm)** | | | **RADIATION (MJ M$^{-2}$)** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **96-97** | **97-98** | **LTM** | **96-97** | **97-98** | **LTM** | **96-97** | **97-98** | **LTM** |
| *September* | 13.6 | 13.6 | **13.5** | 7 | 12 | **49** | 276 | 307 | **291** |
| **October** | 11.6 | 9.7 | **10.4** | 46 | 37 | **48** | 194 | 191 | **171** |
| **November** | 5.6 | 8.4 | **6.3** | 77 | 71 | **52** | 99 | 73 | **81** |
| **December** | 2.8 | 6.0 | **4.4** | 48 | 44 | **56** | 58 | 54 | **53** |
| **January** | 2.1 | 5.2 | **3.6** | 19 | 91 | **50** | 66 | 70 | **68** |
| **February** | 7.0 | 7.6 | **3.7** | 50 | 9 | **43** | 120 | 149 | **132** |
| **March** | 8.3 | 7.9 | **5.6** | 14 | 58 | **45** | 269 | 216 | **223** |
| **April** | 8.9 | 7.8 | **7.8** | 21 | 105 | **46** | 329 | 326 | **333** |
| **May** | 11.1 | 12.4 | **10.9** | 46 | 19 | **47** | 572 | 509 | **465** |
| **June** | 13.6 | 14.5 | **14.0** | 114 | 126 | **55** | 423 | 420 | **492** |
| **July** | 16.8 | 15.7 | **15.8** | 43 | 17 | **48** | 546 | 489 | **487** |
| **August** | 19.1 | 16.5 | **15.7** | 48 | 45 | **61** | 434 | 472 | **406** |

**Yield**

Rotational Position experiment

On average, 2nd wheats yielded 0.3 t ha$^{-1}$ less than the 1st wheats in both seasons; $P<0.05$ in 1996-97 but not significant in 1997-98 (Table 2.1.3). The small yield difference between rotational positions is consistent with the low level of take-all measured in these experiments (HGCA, 1998). Any effect of take-all on yield was likely to have been further reduced by the abundant water supply during grain filling in both years caused by the greater than normal June rainfall. As a result of the small 2nd wheat yield reductions, no significant interaction between rotational position and variety was observed in either season (Table 2.1.3). Nonetheless in 1996-97, the mean 2nd wheat yield loss of varieties predicted to perform relatively better as 2nd wheats (Rialto, Soissons, Drake and Mercia $Rht_2$) were smaller, at 0.15 t ha$^{-1}$, than the mean 2nd wheat yield loss of those predicted to perform worse (Maris Huntsman, Mercia and Spark) at 0.43 t ha$^{-1}$. However, this trend was not repeated in 1997-98, probably because the 2nd wheat TAI did not exceed 10 until June. It should also be noted that in 1997-98 Maris Huntsman lodged severely at anthesis, explaining its low yield in this year.

Demonstration experiment

In the 1997-98 demonstration experiment, the Spark intelligence treatment yielded almost 1 t ha$^{-1}$ more than the conventional treatment, with no yield differences observed for the Spark treatments in 1996-97. Taking into account the reduced cost of smaller N applications to the Spark Intelligence treatment (Nix, 1999) and a grain price of £80 ha$^{-1}$, the Intelligence treatment would increase profit margins by £106 ha$^{-1}$ in 1997-98 and by £18 ha$^{-1}$ in 1996-97. Savings in fertiliser N and late fungicides for Rialto Intelligence were outweighed by yield reductions. It appears that inadequate N was supplied to maintain enough shoots with which to build an optimum sized canopy. This was demonstrated by the 1997-98 Intelligence treatment which had a final ear number of 310 shoots m$^{-2}$ compared with 424 ears m$^{-2}$ for the Conventional treatment.

**Table 2.1.3. Grain yield @85% dm (t ha$^{-1}$)**

| variety | 1996-97 | | | 1997-98 | | |
|---|---|---|---|---|---|---|
| | **First** | **Second** | *Yield loss* (1$^{st}$ – 2$^{nd}$) | **First** | **Second** | *Yield loss* (1$^{st}$ – 2$^{nd}$) |
| Rialto | 9.87 | 9.54 | **0.33** | 10.90 | 9.99 | **0.91** |
| Soissons | 8.15 | 8.27 | **-0.12** | 9.85 | 8.70 | **1.15** |
| Drake | 9.59 | 8.70 | **0.89** | 9.53 | 9.20 | **0.33** |
| Mercia Rht2 | 7.10 | 7.60 | **-0.50** | 9.53 | 9.05 | **0.48** |
| Lynx | 8.88 | 9.09 | **-0.21** | 10.73 | 10.47 | **0.26** |
| Brigadier (80) | 8.48 | 7.76 | **0.72** | 10.53 | 10.40 | **0.13** |
| Brigadier | 9.54 | 8.98 | **0.56** | 10.67 | 9.46 | **1.21** |
| Spark | 8.65 | 8.14 | **0.51** | 8.61 | 9.17 | **-0.56** |
| Mercia | 8.10 | 7.59 | **0.51** | 8.41 | 8.71 | **-0.30** |
| Maris Huntsman (80) | 7.60 | 7.20 | **0.40** | 6.31 | 6.64 | **-0.33** |
| Maris Huntsman | 8.02 | 7.71 | **0.31** | 5.86 | 5.77 | **0.09** |
| **mean** | **8.54** | **8.23** | **0.31** | **9.18** | **8.87** | **0.31** |
| | | | | | | |
| Position SED (2df) | 0.066 | | | 0.132 | | |
| **P value** | **0.043** * | | | **0.146** | | |
| Variety SED (40df) | 0.233 | | | 0.370 | | |
| **P value** | **<0.001** *** | | | **<0.001** *** | | |
| Interaction SED (40df) | 0.320 | | | 0.516 | | |
| **P value** | **0.134** | | | **0.270** | | |

**Physiological traits**

***Water soluble stem carbohydrates (WSCs)***
In 1996-97, the amount of WSCs at mid-anthesis showed significant varietal differences (P<0.001). Drake and Rialto had the greatest levels of WSC at over 2.8 t ha$^{-1}$ and Mercia the least at 1.7 t ha$^{-1}$ (Table 2.1.4). In 1997-98, the varietal differences for WSCs were similar to the previous year, but were not statistically significant. This was because variable results from laboratory analysis resulted in a larger than normal S.E.D. for this trait. The rankings for WSC over the two years were very similar to those predicted, although Spark had unusually large reserves in 1997-98 that could not be explained. In general, the WSCs measured in this study had similar values to those reported in the NIAB Recommended List of Varieties (HGCA, 1996; HGCA, 1999), except for Rialto which NIAB measured at 3.3 to 3.5 t ha$^{-1}$. WSCs observed in this study were about 1 t ha$^{-1}$ smaller than observed in the Typing trials of HGCA Project Report No. 184 (HGCA, 1998) (Table 2.1.4). This difference may have been because the stem biomass in the HGCA (1998) calculation was based on a smaller sample of 10 stems rather than a 0.72 m$^2$ quadrat sample. Rotational position did not cause a significant effect on this trait. Thus, varietal differences in WSCs of over 1.1 t ha$^{-1}$ have been consistently observed. Austin *et al.*, (1977) estimated that 39% of WSCs are relocated from the stem to the grain. In a poor finishing environment (e.g. severe take-all) in which grain fill from current photosynthesis would be limited, a variety with 1.1 t ha$^{-1}$ more WSC could supply its grain with 0.43 t ha$^{-1}$ more dry matter. Therefore it's performance relative to varieties with small WSCs would improve by 0.43 t ha$^{-1}$. From another view point, a variety with 1.1 t ha$^{-1}$ more stem reserves may be considered to require 9 mm less water during grain filling to achieve its potential yield, assuming a water use efficiency of 5 g m$^{-2}$ mm$^{-1}$ (Green *et al.*, 1983). Recent work described in HGCA (1998) suggested that the advantage of using varieties with greater WSCs may be enhanced in drought conditions because the stem reserves appeared to be utilised earlier which should result in a greater proportion of WSCs re-mobilised to the grains under stressed conditions.

**Table 2.1.4. Water soluble stem carbohydrate (t ha$^{-1}$) measured at GS61 + 75 °Cd**

| | 1996-97 | 1997-98 | *HGCA (1998) Mean 1993-95* | Prediction |
|---|---|---|---|---|
| **Drake** | 2.95 | 3.18 | ***4.47*** | High |
| **Rialto** | 2.82 | 2.81 | ***4.47*** | High |
| **Lynx** | 2.70 | - | ***3.60*** | Moderate-high |
| **Brigadier** | 2.39 | 2.44 | ***3.61*** | Moderate-high |
| **Brigadier 80** | 2.30 | - | - | **Moderate-high** |
| **Soissons** | 2.13 | 2.48 | ***3.48*** | Moderate-high |
| **Spark** | 2.06 | 2.69 | ***2.71*** | Low |
| **Mercia** | 1.70 | 2.08 | ***2.90*** | Low |
| **Maris Huntsman** | 1.85 | - | ***2.91*** | Low |
| **Maris Huntsman 80** | 1.84 | - | - | Low |
| Variety SED (40df) | 0.217 (36 df) | 0.418 (20df) | | |
| P value | <0.001 | 0.348 | | |

***Developmental rate***

In both years, Soissons reached GS 61+75°Cd 11 to 14 days before the slowest developing varieties (Spark and Drake) (Table 2.1.5). The rankings for the other varieties (in terms of date of GS 61+75°Cd) were consistent for both years of this study and for information collected in HGCA (1998). Rapidly developing varieties would be expected to be more tolerant to take-all because they use less water between GS 31 and GS 61, thereby reserving greater water supplies in the soil for grain filling when take-all most commonly restricts uptake. The amount of water transpired by each variety between GS 31 and GS 61+75°Cd was calculated using the AFRCWHEAT2 model (Porter, 1993; Jamieson *et al.*, 1998) for evapotranspiration. These calculations were based on long term daily Potential Evapotranspiration (PE) at Sutton Bonington and daily Leaf Area Index (LAI) interpolated from measurements taken in the 1997-98 experiment. This showed that between GS 31 and GS 61, the most rapidly developing variety (Soissons) transpired 11 mm less water than the slowest developing variety (Spark) (Table 2.1.6). This was mainly a result of Spark transpiring for more days in June when PE was high. This was in agreement with Innes *et al.* (1985), who showed that 9 days difference in the date of ear emergence between early and late wheat lines selected from the same parental cross resulted in the early developing lines using 10 mm less water during May, June and July. Assuming a water use efficiency of 5 g m$^{-2}$ mm$^{-1}$, 11 mm water may be used in the production of 0.55 t ha$^{-1}$ dry matter, which at the time of grain fill would be mainly grain yield. However, extraction of this saved water maybe impaired by smaller root systems which are often associated with rapidly developing crops (Barraclough and Leigh, 1984). Also, it should be noted that WUE is infrequently a good predictor of yield in UK conditions.

**Table 2.1.5. Date of GS61 + 75d°C**

| | 1996-97 | 1997-98 | *HGCA (1998) Mean 1993-95* | Prediction |
|---|---|---|---|---|
| | **GS61** | **GS61** | ***GS61*** | |
| **Soissons** | **2 June** | **31 May** | ***8 June*** | Very early |
| **Mercia** | **6 June** | **6 June** | ***13 June*** | Early |
| **Mercia Rht2** | **6 June** | **6 June** | - | Early |
| **Rialto** | **6 June** | **7 June** | ***15 June*** | Early-intermediate |
| **Lynx** | **9 June** | **9 June** | ***15 June*** | Early-intermediate |
| **Brigadier** | **9 June** | **8 June** | ***16 June*** | Early-intermediate |
| **Maris Huntsman** | **10 June** | **8 June** | ***15 June*** | Intermediate |
| **Drake** | **13 June** | **13 June** | ***17 June*** | Late |
| **Spark** | **13 June** | **14 June** | ***19 June*** | Late |

**Table 2.1.6. Amount of water transpired between GS31 and GS61 (mm) in 1997-98**

| Variety | GS61 date | mm water transpired between GS31 and GS61 |
|---|---|---|
| **Soissons** | 31 May | 110 |
| **Mercia** | 6 June | 118 |
| **Rialto** | 7 June | 117 |
| **Brigadier** | 8 June | 117 |
| **Spark** | 14 June | 121 |

***Tiller economy***

As predicted Soissons had the most economic tillering pattern, losing only 312 shoots in 1996-97 and 232 shoots in 1997-98 between GS 31 and harvest (Table 2.1.7). Mercia lost about 400 shoots in both experiments and was the second most economic variety. Spark, Rialto, Brigadier and Drake all lost between 500 and 800 shoots. It is important to remember that the value of economic tillering depends not only on the number of shoots lost, but also on the growth stage at which they die. For example, shoots which die at a later growth stage would be expected to have a larger biomass and to have transpired (and wasted (Thorne and Wood, 1987)) more water. The timing of shoot death varied for each variety, e.g. Brigadier and Rialto lost similar numbers of shoots between GS 31 and harvest, but Rialto had lost all its shoots by GS 39 whereas Brigadier lost more than 200 shoots $m^{-2}$ between GS 39 and harvest (Figure 2.1.2). It is very likely that the amount of water transpired by the late abortion of the Brigadier shoots was greater than that transpired by the aborted shoots of Rialto. This was investigated in 1997-98 by comparing the amount of water transpired by the shoots destined to die (Table 2.1.8). This was calculated by subtracting the water transpired by the shoots destined to survive from the water transpired by all shoots. This showed that the shoots destined to die of Brigadier transpired 20 mm water compared with 16 mm for Rialto. The importance of the size of tiller which is aborted was further illustrated by Spark for which the loss of 568 tillers only wasted 5 mm water (Table 2.1.8). This was because Spark mainly aborted $4^{th}$ and $5^{th}$ order tillers which had a small LAI compared with the other varieties which mainly aborted $2^{nd}$ and $3^{rd}$ order tillers with larger LAIs. These results were very similar to initial work done in (HGCA, 1998). Thus, choosing a variety with economical tillering may save up to 15 mm water through not producing aborted shoots. At times of severe water shortage, e.g. during severe take-all infection, this extra water may be used in the production of 0.75 t $ha^{-1}$ dry matter. It should also be noted that abortion of tillers mainly occurs in the lower canopy and thus their contribution to total water loss is likely to be less that proportional to their LAI.

Varietal differences in tiller abortion are unlikely to have any effect on the crop's capacity for water uptake because all roots associated with an aborted tiller die (Gregory, 1978). Therefore, two varieties which achieved the same final number of shoots per plant, but which had different patterns of tiller economy, would be expected to have a similar number of roots per shoot. However, the potential for water uptake may be affected by varietal differences in the number of remaining shoots per plant as a result of different numbers of roots per shoot. Lower order tillers have the potential to develop fewer roots than main shoots and high order tillers (Klepper *et al.,* 1984). Therefore varieties with many tillers such as Spark may be expected to have fewer roots per shoot and a reduced capacity for water uptake. Berry (1998) has shown that plants with many shoots (brought about by low seed rate) had fewer crown roots per shoot than plants with few shoots (brought about by higher seed rate). Azam-ali *et al.* (1984) showed that the roots of pearl millet sown in wide rows were shallower than sowings in narrow rows. This suggests that varieties with many low order tillers may also have shallower root systems.

**Table 2.1.7. Number of shoots lost per m$^2$ between GS31 and harvest**

| | 1996-97 | 1997-98 | *HGCA (1998) Mean 1993-95* | Prediction |
|---|---|---|---|---|
| | Shoots lost between GS31 and harvest | Shoots lost between GS31 and harvest | *shoots lost* | |
| Soissons | 312 | 232 | *478* | Good |
| Mercia | 444 | 402 | *367* | Inter |
| Spark | 810 | 568 | *595* | Inter |
| Rialto | 523 | 723 | *653* | Poor-inter |
| Brigadier | 549 | 710 | *743* | Poor |
| Drake | 807 | 566 | *810* | Poor |

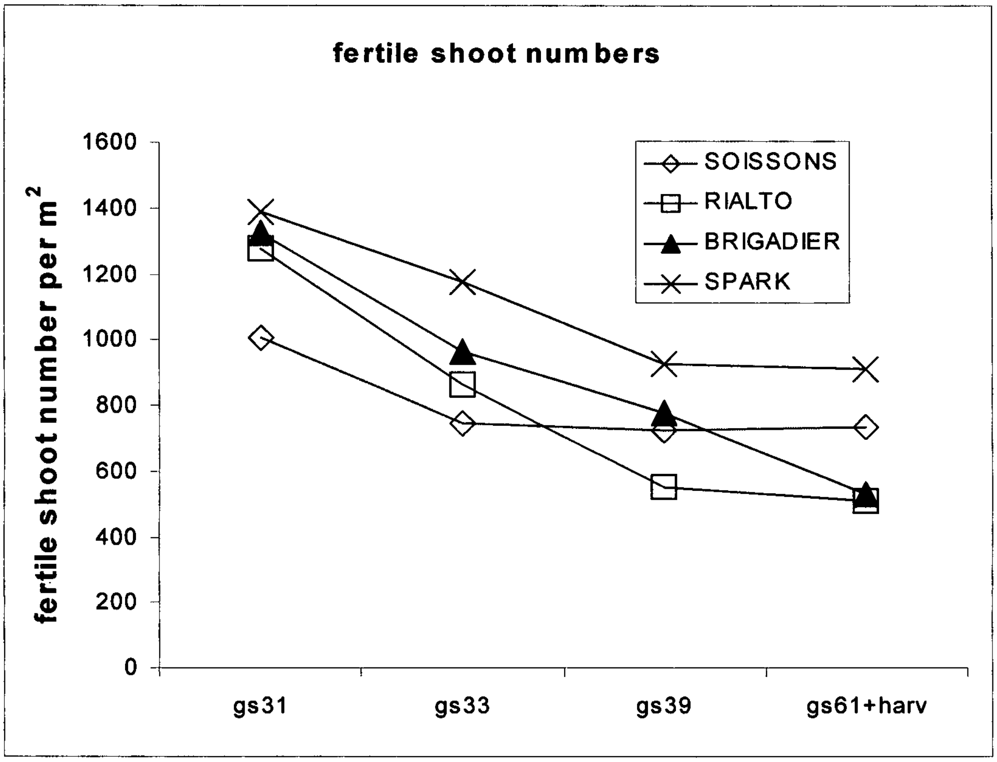



**Figure 2.1.2. Decline of fertile shoot numbers $m^{-2}$ between GS31 and harvest in 1997-98**

**Table 2.1.8. Amount of water transpired (mm) between GS31 and GS61 in 1997-98 by all shoots (including those destined to die) and the shoots destined to survive.**

| Variety | USING TOTAL LAI mm water transpired between GS31 and GS61 | USING LAI OF TILLERS DESTINED TO SURVIVE mm water transpired between GS31 and GS61 | WATER WASTED |
|---|---|---|---|
| Soissons | 110 | 104 | 6 mm |
| Spark | 121 | 116 | 5 mm |
| Rialto | 117 | 101 | 16 mm |
| Brigadier | 117 | 97 | 20 mm |

## Annex 1

### Rotational position experiment 1996-97

| | |
|---|---|
| Field name : | Field 26 |
| **Previous cropping :** | **1995-96 - winter wheat/ spring oilseed rape** |
| | 1994-95 - Maize |
| | 1993-94 – Sugar beet |
| | 1992-1993 – winter wheat (plots) |
| **Cultivations :** | **Ploughed/pressed** |
| | Spring tined |
| **Fertiliser :** | **11 March 45 kg N $ha^{-1}$** |
| | 15 April 160 kg N $ha^{-1}$ |
| | 20 March cutonic Manganese (1.25l/ha) |
| PGR applications : | 9 April Chlormequat 70 (2.3 l/ha) Chlormequat |
| Fungicide applications : | 9 April Sportak sierra HF (0.9l/ha) Cyproconazole with prochloraz |
| | 9 April Tern (0.75l/ha) Fenpropidin |
| | 15 May Opus Team (1.5l/ha) Fenpropidin |
| | 15 May Corbel (0.50l/ha) Fenpropimorph |
| | 17 June Silvacur (1l/ha) Tebucanozole + Tridimenol |
| Herbicide applications : | 13 March Oyster (0.5/ha) Isoproturon + DSS |
| | 13 March Toppel 10 (0.25l/ha) cypermethrin |
| | 13 March MSS Iprofile (0.75l/ha) Isoproturon |
| | 13 March Mecoprop (2.0l/ha) CMPP |
| | 9 April Starane (1.0l/ha) fluroxypyr |
| Insecticide : | 9 June Portman primicarb (280g/ha) carbamate |
| Harvest : | 17 August |

## Rotational position experiment 1997-98

| | |
|---|---|
| Field name : | Field 10 |
| **Previous cropping :** | **1996-97 - winter wheat** |
| | 1995-96 - sugar beet |
| | 1994-95 - set-aside |
| | 1993-94 - winter wheat |
| **Cultivations :** | **Ploughed/pressed** |
| | Spring tined twice |
| **Fertiliser :** | **4 March 40 kg N ha$^{-1}$** |
| | 30 March 170 kg N ha$^{-1}$ |
| | 12/1/98 Cutonic manganese (2l/ha) |
| | 29/1/98 Cutonic manganese (1l/ha) |
| | 31/3/98 Cutonic manganese (1l/ha) |
| PGR applications : | 21/3/98 Chlormequat (2.3l/ha) Chlormequat |
| Fungicide applications : | 27/1/98 Tern (0.5l/ha) Fenpropidin |
| | 21/3/98 Tern (0.75l/ha) Fenpropidin |
| | 21/3/98 Sportak Sierra (0.9l/ha) Cyproconazole with prochloraz |
| | 14/3/98 Opus Team (1.5l/ha) Fenpropidin |
| | 1/6/98 Tern (0.5l/ha) Fenpropidin |
| | 1/6/98 Garnett (Silvacur) (1l/ha) Tebucanozole + Tridimenol |
| Herbicide applications : | 23/1/98 Oyster (0.5/ha) Isoproturon + DSS |
| | 23/1/98 Steffes IPU (2.5l/ha) Isoproturon |
| | 23/1/98 Toppel 10 (0.25l/ha) cypermethrin |
| Insecticide: | 31/3/98 Ally (20g/ha) Metsulfuron-methyl |
| | 31/3/98 Oxytril CM (0.5l/ha) Bromoxymil + ioxynil |
| Harvest : | 19/8/98 |

# Annex 2

## Demonstration experiment 1996-97

Field name : Field 4

| | | |
|---|---|---|
| **Previous cropping :** | **1995-96** | **Oats** |
| | 1994-95 | Sugar beet |
| | 1993-94 | Winter wheat |
| | 1992-93 | Set-aside |

N applications :

| Conventional | Intelligence | |
|---|---|---|
| | Rialto | Spark |
| 40 | 100 | 125 |
| 160 | nil | nil |
| nil | nil | nil |
| nil | nil | nil |
| nil | 30 | 30 |

PGR applications :

Fungicide applications :

NB Late fungicide applied to Rialto and Spark Intelligence treatments

Herbicide applications :

Insecticide :

Others:

Harvested :

## Demonstration experiment 1997-98

| | | | | |
|---|---|---|---|---|
| Field name : | Field 2 | | | |
| **Soil analysis :** | **pH** | **7.2** | | |
| | P | 76 mg/l | | |
| | K | 453 mg/l | | |
| | Mg | 193 mg/l | | |
| **Previous cropping :** | **1996-97** | **winter oats** | | |
| | 1995-96 | set-aside | | |
| | 1994-95 | sugar beet | | |
| | 1993-94 | winter wheat (whole crop silage) | | |

N applications :

| | Conventional | Intelligence | |
|---|---|---|---|
| | | Rialto | Spark |
| 9/3/98 | 40 | nil | nil |
| 25/3/98 | 120 | nil | nil |
| 1/5/98 | nil | nil | 50 |
| 20/5/98 | nil | 30 | 30 |
| 15/6/98 | nil | 30 | 30 |

Fertiliser :

PGR applications :
21/3/98 Chlormequat (2.3l/ha) Chlormequat
19/5/98 Banshee (1l/ha) 2_chloroethyl phosphonic acid mepiquat choride

Fungicide applications :
27/1/98 Tern (0.5l/ha) Fenpropidin
21/3/98 Tern (0.75l/ha) Fenpropidin
21/3/98 Sportak Delta (1.25l/ha) Cyproconazole with prochloraz
19/5/98 Opus Team (1.5l/ha) Fenpropidin
12/6/98 Tern (0.5l/ha) Fenpropidin
12/6/98 Folicur (0.5l/ha) Tebucanazole

NB No fungicide to Rialto Intelligence on 12/6/98

Herbicide applications :
26/1/98 Oyster (0.5/ha) Isoproturon + DSS
26/1/98 Steffes IPU (2.5l/ha) Isoproturon

Insecticide :
26/1/98 Toppel 10 (0.25l/ha) cypermethrin
31/3/98 Ally (20g/ha) Metsulfuron-methyl
31/3/98 Oxytril CM (0.5l/ha) Bromoxynil + ioxynil

Others:
14/2/98 Cutonic manganese (2l/ha)
12/3/98 Cutonic manganese (1l/ha)
31/3/98 Cutonic manganese (1l/ha)

Harvested : 29/8/98

## 2.2. *CANOPY MANAGEMENT WITH DROUGHT-PRONE SOIL TYPES*

### MATERIALS AND METHODS

#### Experimental design and treatments

There was one experiment of standard design in each of two seasons, 1996-7 and 1997-8. The site at University of Nottingham Farm, Leicestershire was a medium loam to 80 cm over clay (Dunnington Heath series) of available water (AW) of 192 mm to 1.2 m, and moderately prone to drought. The variety used was Mercia in both years. Two trickle-irrigation treatments (1. Fully irrigated up to end of grain filling (taken as complete canopy senescence) and 2. Irrigated up to GS 59 only) were randomised as main plots (60 x 10 m) and five fertiliser N treatments as sub-plots (12 x 10 m) in a split-plot randomised block design.

Water was applied using a trickle irrigation system to maintain soil moisture deficit (SMD) calculated using the ADAS Irriguide model (Bailey & Spackman, 1996) (assuming 1.2 m soil depth) < 75 mm up to end of the period designated for irrigation. The Irriguide SMD of 75 mm was equivalent to 40% of AW. Application dates and amounts of water applied in each experimental season are shown in Table 2.2.1.

*Table 2.2.1. Amounts of water applied in the two irrigation treatments*

| | | Fully irrigated | Irrigated to GS 59 |
|---|---|---|---|
| 1997 | 2 May | 10 | 10 |
| | 13 May | 15 | 0 |
| | 19 May | 20 | 10 |
| | 27 May | 20 | 0 |
| | 3 June | 20 | 5 |
| | 8 June | 25 | 0 |
| | 10 July | 20 | 0 |
| | 23 July | 20 | 0 |
| | Total | 150 | 0 |
| 1998 | 23 May | 20 | 0 |
| | 26 June | 20 | 0 |
| | 24 July | 15 | 0 |
| | Total | 55 | 0 |

The five N treatments were : 1. Nil N; and 2. – 5. each as four equal splits of N applied fortnightly starting in mid March, late March, early April and late April, respectively. The total amount of N prill applied to treatments 2. – 5. was the same in any one year and calculated as : 300 kg N ha$^{-1}$ – soil N (Feb) kg ha$^{-1}$ – crop N (Feb) kg ha$^{-1}$. This amount of N was 220 kg ha$^{-1}$ in 1997 and 180 kg ha$^{-1}$ in 1998. Application dates and amounts of N applied in each season to treatments 2. – 5. are shown in Table 2.2.2. The amount of residual soil N in the experiments in February before any fertiliser had been applied in treatment 2. – 5. was 67 kg ha$^{-1}$ in 1997 and 111 kg ha$^{-1}$ in 1998.

*Table 2.2.2. N fertiliser amounts applied in treatments N1 – N5 ( kg ha$^{-1}$) in 1997 and 1998*

| 1997<br>Treatment No. | 10 Mar | 24 Mar | 7 Apr | 21 Apr | 5 May | 19 May | 2 Jun | TOTAL |
|---|---|---|---|---|---|---|---|---|
| N1 (Nil) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N2 (Early) | 55 | 55 | 55 | 55 | 0 | 0 | 0 | 220 |
| N3 (Early – Intermediate) | 0 | 55 | 55 | 55 | 55 | 0 | 0 | 220 |
| N4 (Intermediate – late) | 0 | 0 | 55 | 55 | 55 | 55 | 0 | 220 |
| N5 (Late) | 0 | 0 | 0 | 55 | 55 | 55 | 55 | 220 |

| 1998<br>Treatment No. | 9 Mar | 23 Mar | 6 Apr | 20 Apr | 4 May | 18 May | 1 Jun | TOTAL |
|---|---|---|---|---|---|---|---|---|
| N1 (Nil) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| N2 (Early) | 45 | 45 | 45 | 45 | 0 | 0 | 0 | 180 |
| N3 (Early – Intermediate) | 0 | 45 | 45 | 45 | 45 | 0 | 0 | 180 |
| N4 (Intermediate – late) | 0 | 0 | 45 | 45 | 45 | 45 | 0 | 180 |
| N5 (Late) | 0 | 0 | 0 | 45 | 45 | 45 | 45 | 180 |

***Site details***

Plots were treated with fungicides at GS 31, GS 39 and GS 61 to keep diseases to very low levels and with pesticides and herbicides as necessary to minimise the effects of pests and weeds. The cultivar sown was Mercia. Seed rate was adjusted according to 1,000 grain weight to achieve a target seed number of 325 m$^{-2}$. Details of sowing dates, previous cropping, PGR applications and overwinter top soil analysis for the individual experiments are given in Table 2.2.3.

**Crop measurements**

*2.3.1 Growth analysis*

2.3.1.1 Sample size and sampling times

Growth measurements were carried out in all sub-plots on above-ground plant material in one 1.2 x 0.6 m quadrat per sub-plot, every three weeks from the beginning of March until final harvest.

2.3.1.2 Plant and shoot numbers, green area index (GAI) and above-ground crop dry weight

All plants per 1.2 x 0.6 m quadrat were counted at the first sample time in spring.

*2.3.1.3 Green area index (GAI), fertile shoot number, above-ground crop dry Weight and crop N offtake*

GAI was assessed from a 10% sub-sample (by fresh weight) from all above-ground material sampled within the initial 0.72 m$^2$ quadrat area (HGCA, 1998e). Fertile shoot number was recorded in the 10% sub-sample. Components of GAI were recorded separately for i) leaf lamina, ii) stem (plus attached leaf sheath) and iii) ear (after GS 51), and green areas for the three fractions summed in the calculation of GAI. Crop dry weight was assessed from a 20% sub-sample (by fresh weight) from all material within the 0.72 m$^2$ quadrat, which was dried to constant weight at 80$^o$C. The components of total dry matter were assessed from the 10% sub-sample, separated into i) leaf lamina, ii) stem (plus attached leaf sheath) and iii) ear (after GS 51). Plant material from the 20% sub-sample was submitted for chemical analysis of %N.

2.3.1.4 Stem soluble carbohydrate

Percentage water soluble carbohydrate of stems and attached leaf sheaths was assessed on 2 and 23 June 1997 and 10 June and 6 July 1998 in ten randomly selected fertile shoots (those with an ear) per sub-plot. The ten shoots were dried at 100°C for 2 h and then submitted for chemical analysis of the %WSC. Stem (plus leaf sheath) dry matter was obtained from quadrat growth analysis measurements at concurrent sample times.

**Environmental assessments**

*Soil mineral N assessments*

Soil mineral N was assessed in each sub-plot in February, in June and at harvest in each year. Six cores per sub-plot were taken to 90 cm. Cores were separated into 0 - 30 cm, 30 - 60 cm and 60 - 90 cm horizons. For each of the three horizons, the six cores were bulked to provide three samples per sub-plot for submission for chemical analysis for $NH_4^+$ and $N0_3^-$ concentration.

*Volumetric soil water content*

In each year, volumetric soil water content to 1.65 m soil depth was measured at 7 d intervals from early April to harvest using a Wallingford neutron probe in one aluminium access tube per sub-plot. Neutron probe readings were taken at 0.1m depth intervals. Cumulative water use from April onwards was calculated assuming that all rain and irrigation water entered the soil system and that none was lost to drainage.

*Table 2.2.3. Husbandry inputs, previous cropping and top soil analysis for 1996-7 and 1997-8*

| | | 1996-7 | 1997-8 |
|---|---|---|---|
| Sowing date | | 10 October 1996 | 30 September 1997 |
| Previous cropping | 1995-6 | Spring oilseed rape | Spring oilseed rape |
| | 1994-5 | Maize | Sugar beet |
| | 1993-4 | Sugar beet | Set-aside |
| | 1992-3 | Winter wheat | **Winter wheat** |
| Cultivations | | Ploughed, pressed, spring-tined | Ploughed, pressed, spring-tined twice |
| Manganese fertiliser | | 18 March Cutonic manganese (1.25l $ha^{-1}$) | 2 January Cutonic manganese (2l $ha^{-1}$)<br>29 January Cutonic manganese (1l $ha^{-1}$)<br>31 March Cutonic manganese (1l $ha^{-1}$) |
| Plant Growth Regulator | | 9 April Chlormequat 70 (2.3 l $ha^{-1}$) Chlormequat | 21/3/98 Chlormequat (2.3l/ha) Chlormequat |
| Fungicide | | 9 April Sportak sierra HF (0.9l $ha^{-1}$) Cyproconazole with prochloraz<br>9 April Tern (0.75l $ha^{-1}$) Fenpropidin<br>15 My Opus Team (1.5l $ha^{-1}$) Fenpropidin<br>15 May Corbel (0.50l $ha^{-1}$) Fenpropimorph<br>17 June Silvacur (1l $ha^{-1}$) Tebucanozole + Tridimenol | 27 January Tern (0.5l $ha^{-1}$) Fenpropidin<br>1 March Tern (0.75l $ha^{-1}$) Fenpropid<br>1 June Tern (0.5l $ha^{-1}$) Fenpropidin<br>1 June Garnett (Silvacur) (1l $ha^{-1}$) Tebucanozole + Tridimenol |
| Insecticide | | 9 June Portman primicarb (280g $ha^{-1}$) carbamate 13 March Toppel 10 (0.25l $ha^{-1}$) cypermethrin | 23/1/98 Toppel 10 (0.25l/ha) cypermethrin<br>31 March Ally (20g/ha) Metsulfuron-methyl<br>31 March Oxytril CM (0.5l/ha) Bromoxymil + ioxynil |
| Herbicide | | 13 March Oyster (0.5 l $ha^{-1}$) Isoproturon + DSS<br>13 March MSS Iprofile (0.75l $ha^{-1}$) Isoproturon<br>13 March Mecoprop (2.0l $ha^{-1}$) CMPP<br>9 April Starane (1.0l $ha^{-1}$) fluroxypyr | 23/1/98 Oyster (0.5/ha) Isoproturon + DSS<br>23/1/98 Steffes IPU (2.5l/ha) Isoproturon |
| Harvest | | 17 August | 19 August |
| Top soil analysis | | | |
| pH | | 7.3 | 7.6 |
| Lime t $ha^{-1}$ | | 0 | 0 |
| Phosphorous mg $l^{-1}$ | | 81 | 65 |
| Potassium mg $l^{-1}$ | | 359 | 402 |
| Magnesium mg $l^{-1}$ | | 205 | 219 |
| Organic matter % | | 3.1 | 2.8 |
| $CaC0_3$ % | | 1.2 | 1.0 |

## RESULTS AND DISCUSSION

### Soil moisture deficit (SMD) and rainfall

Available water at field capacity of the experimental site (to 1.2 m) was 192 mm. The limiting deficit (LD) for grain yield on soil of AW of 250 mm at Rothamsted has been observed to be as high as 140 mm (French & Legg, 1979). Alternatively, Bailey (1990) and Porter (1993) defined onset of drought to coincide with SMD of 0.5 and 0.6 AW, respectively. Taking these previous reports on-board, onset of drought in the current experiment would have occurred at SMD in the region of 100 mm.

In 1997, in the fully irrigated treatment, SMD (calculated from neutron probe measurements) > 60 mm did not occur during the season and drought stress was absent (Fig. 2.2.1). In the treatment irrigated to GS 59, SMD > 96 mm (0.5 AW) only occurred for a short period from 7 - 11 June and then from 20 July onwards. The duration and severity of drought were minimal and did not relate to meaningful differences between treatments. The lack of drought was associated with greater than average June rainfall of 114 mm (Fig. 2.2.2).

In 1998, SMD differences between irrigation treatments were always small (Fig. 2.2.1). June rainfall was large at 127 mm, and late drought was absent in the treatment irrigated up to GS 59. Present interpretation of results therefore focuses mainly on the effects of N treatments averaged across the two irrigation treatments.

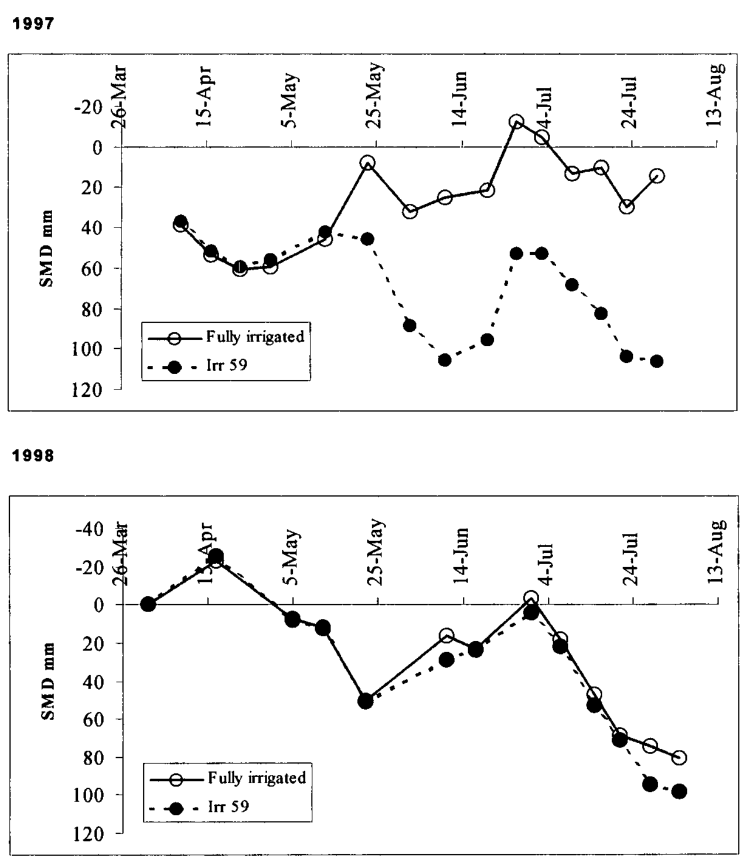
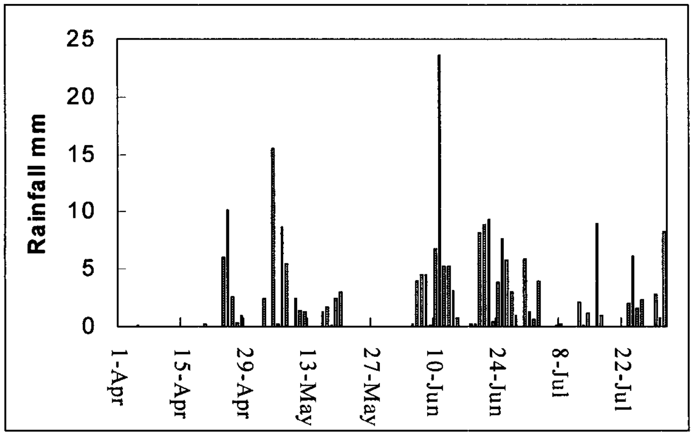



Fig. 2.2.1 Soil moisture deficit to 1.65 m in 1997 and 1998

1997




1998

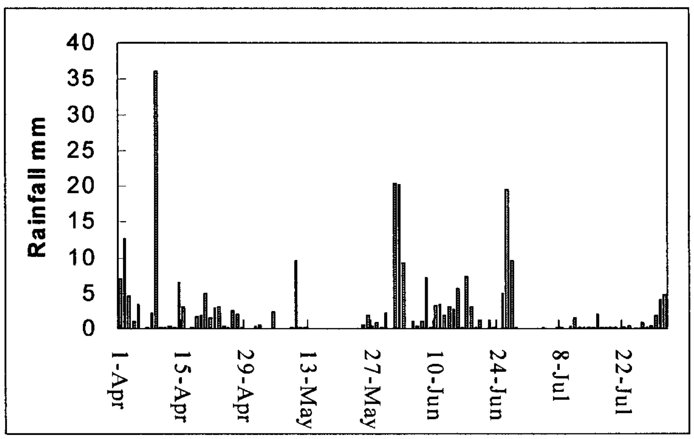



Fig. 2.2.2. Daily rainfall April – July in 1997 and 1998

**Crop development**

*1997*

All sub-plots were sown on 10 October 1996 with 50% crop emergence occurring on 21 October. There was no effect of irrigation or N treatment on date of reaching respective stages (Table 2.2.4). Compared to the norm for Mercia from an early October sowing date at Sutton Bonington (HGCA, 1998b), the crop was about 8 d earlier to respective stages throughout.

*1998*

Sub-plots were sown on 30 September 1997 with 50% crop emergence occurring on 12 October. There was no effect of irrigation or N treatment on dates of reaching respective stages (Table 2.2.4). The crop was well advanced at GS 31, with this stage occurring about 20 d before the Sutton Bonington norm (HGCA, 1998b). This was associated with temperatures well above the long-term mean in December, January, February and March (Table 2.2.5). The crop was about 8 d ahead of the site norm at GS 39 and GS 61 as in 1997.

*Table 2.2.4. Development stages (Tottman,, 1987) in 1997 and 1998*

| Growth stage | 1997 | 1998 |
|---|---|---|
| GS31 | 11 April | 22 March |
| GS39 | 13 May | 15 May |
| GS59 | 2 June | 30 May |
| GS61 | 7 June | 7 June |

*Table 2.2.5. Monthly weather data for Sutton Bonington in 1996-98 and for the 30 year long term mean (LTM)*

| | Mean Temperature (°C) | | | Rainfall (mm) | | | *Radiation ($MJ\ m^{-2}$)* | | |
|---|---|---|---|---|---|---|---|---|---|
| | 96-97 | 97-98 | LTM | 96-97 | 97-98 | LTM | 96-97 | 97-98 | LTM |
| *September* | 13.6 | 13.6 | 13.5 | 7 | 12 | 49 | 276 | 307 | 291 |
| **October** | 11.6 | 9.7 | 10.4 | 46 | 37 | 48 | 194 | 191 | 171 |
| November | 5.6 | 8.4 | 6.3 | 77 | 71 | 52 | 99 | 73 | 81 |
| December | 2.8 | 6.0 | 4.4 | 48 | 44 | 56 | 58 | 54 | 53 |
| January | 2.1 | 5.2 | 3.6 | 19 | 91 | 50 | 66 | 70 | 68 |
| February | 7.0 | 7.6 | 3.7 | 50 | 9 | 43 | 120 | 149 | 132 |
| March | 8.3 | 7.9 | 5.6 | 14 | 58 | 45 | 269 | 216 | 223 |
| April | 8.9 | 7.8 | 7.8 | 21 | 105 | 46 | 329 | 326 | 333 |
| May | 11.1 | 12.4 | 10.9 | 46 | 19 | 47 | 572 | 509 | 465 |
| June | 13.6 | 14.5 | 14.0 | 114 | 126 | 55 | 423 | 420 | 492 |
| July | 16.8 | 15.7 | 15.8 | 43 | 17 | 48 | 546 | 489 | 487 |
| August | 19.1 | 16.5 | 15.7 | 48 | 45 | 61 | 434 | 472 | 406 |

**Shoot number, green area index and crop dry matter**

*Shoot number*

There was no difference between irrigation treatments in shoot numbers at any sample time in 1997 or 1998 (Fig. 2.2.3a). N treatment effects are therefore considered, as the average of effects in the two irrigation treatments (Fig. 2.2.3b).

In 1997, there were differences amongst N treatments: on 1 April, 13 May and at all subsequent sample times ($P< 0.05$) (Fig. 2.2.3b). Ear number $m^{-2}$ at harvest for N1 (nil N) was in the region of 150 per $m^2$ fewer than for treatments N2 – N5. Timing of N application affected shoot survival, with the rank order for ear number at harvest broadly reflecting N2 (early) > N3 > N4 > N5 (late). N2 maintained about 80 more ears $m^{-2}$ than N5.

In 1998, although differences in ears $m^{-2}$ were never statistically significant, there was a consistent pattern for the nil N treatment to have slightly fewer at about 600 $m^{-2}$ compared to the other treatments in the region of 640 $m^{-2}$. Final shoot number was similar amongst treatments N2 – N5, but tiller death occurred later in N2 (early) than in the remaining treatments.

*Green Area Index*

There was no statistically significant effect of irrigation treatment on green canopy area at any sample time in 1997 and 1998 (Fig 2.2.4a). Differences were always < 0.3 GAI units. N treatments are therefore considered, as the main effect averaged over the two irrigation treatments (Fig. 2.2.4b).

Amongst N treatments in 1997, there were differences from 21 April - 7 July inclusive ($P < 0.05$) (Fig. 2.2.4b). With nil N, GAI was smaller than in other N treatments, peaking at 3.9 compared to 5.7 - 6.4. The rank order for N2 – N5 for maximum GAI broadly reflected that for shoots : N2 (6.2) and N3 (6.4) > N4 (5.9) and N5 (5.7). N timing had no effect on rate of senescence.

Maximum GAI was reached on 18 May in 1998 compared to 2 June in 1997. GAIs were generally higher in 1998. Although the onset of senescence was earlier in 1998, rates of senescence were broadly similar in the two seasons. N treatments differed from 24 April onwards in 1998, with nil N GAI diminished by about 1.5 compared to other treatments. Early phasing of N increased maximum GAI ($P < 0.05$) with values progressively decreasing from 8.6 (N2, early) to 7.3 (N5, late). During the grain filling period the situation was reversed and GAI was smaller with earlier phasing of N, due to more rapid rates of senescence ($P < 0.05$).

*Crop dry matter*

In 1997, irrigation treatment differences were never significant (Fig. 2.2.5a). Although from 2 June onwards there was a trend for slightly smaller biomass fully irrigated, differences were never large, ranging from 43 g $m^{-2}$ in June to 143 g $m^{-2}$ in August. From 21 April, N treatment differences were significant ($P < 0.05$). Biomass on 4 August was smaller with nil N compared to the average of N2 – N5 treatments by about 300 g $m^{-2}$ (Fig. 2.2.5b). Amongst N2 - N5, differences were initially small, but for the last three sample times there was a trend for greater biomass with early N. On 4 August, biomass was *c.* 150 g $m^{-2}$ greater for N2 (early) than N5 (late).

Differences between irrigation treatments were always non-significant and less than 50 g $m^{-2}$ in 1998. Overall final biomass was 60 g $m^{-2}$ greater than in 1997. Smallest biomass of 1560 g $m^{-2}$ occurred at nil N. Differences amongst N treatments were always non-significant. However, by harvest there was a trend for greater biomass with later N, values ranging from 1610 g $m^{-2}$ at N2 (early) to 1680 g $m^{-2}$ at N5 (late).

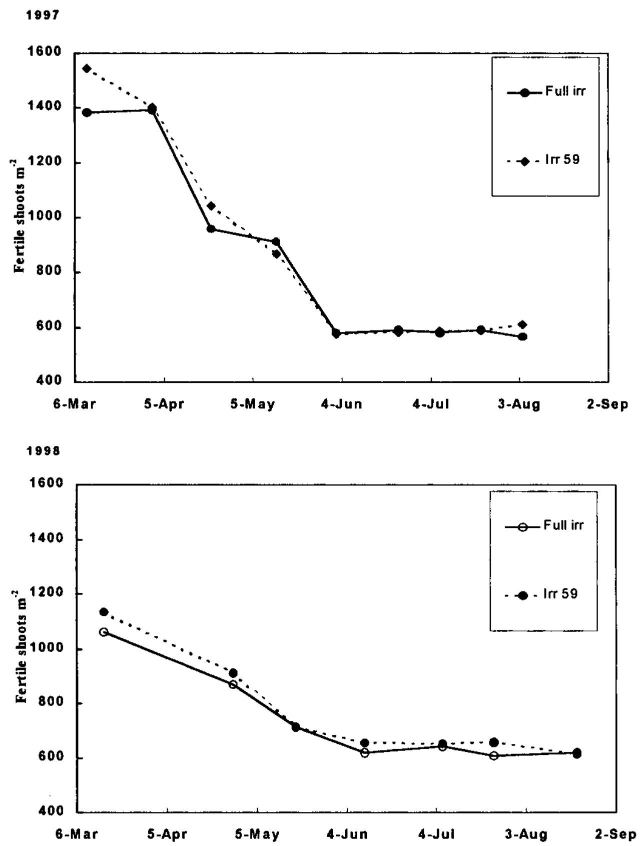



*Fig. 2.2.3a. Potentially fertile shoots $m^{-2}$ for two irrigation treatments : fully irrigated and irrigated up to GS 59 only in 1997 and 1998.*

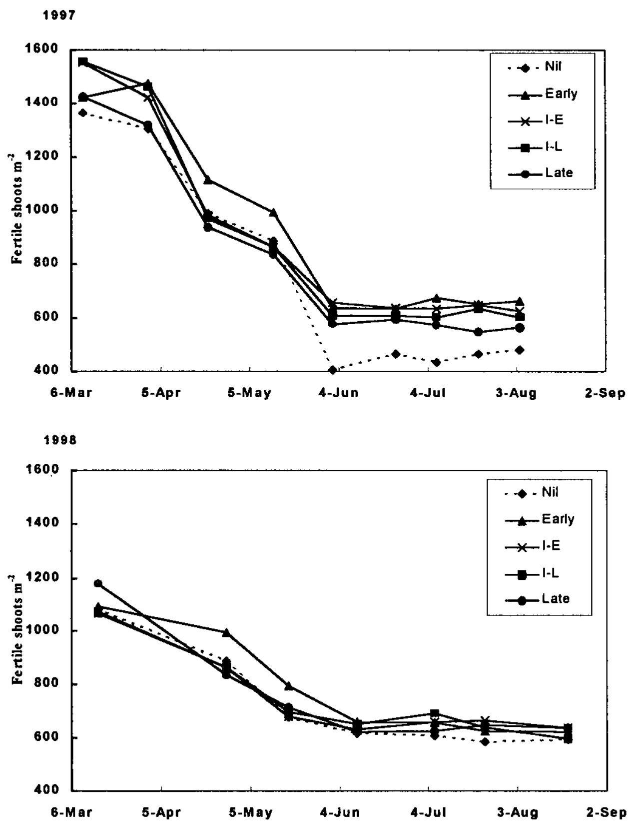



*Fig. 2.2.3b. Potentially fertile shoots $m^{-2}$ for five N treatments : N1 (nil N), N2 (early N), N3 (early to intermediate N), N4 (intermediate to late N) and N5 (late N) in 1997 and 1998.*

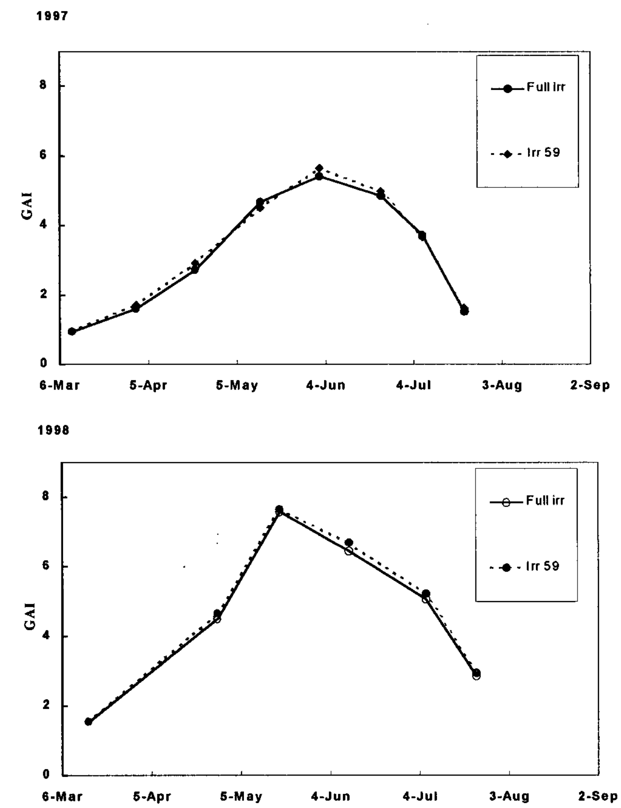



*Fig. 2.2.4a. Green area index for two irrigation treatments : fully irrigated and irrigated up to GS 59 only in 1997 and 1998.*

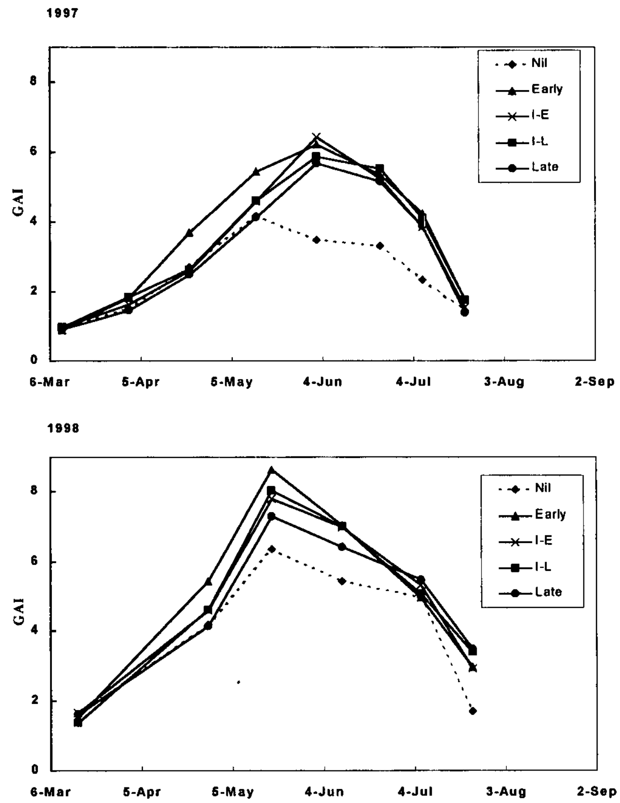



*Fig. 2.2.4b. Green area index for five N treatments : N1 (nil N), N2 (early N), N3 (early to intermediate N), N4 (intermediate to late N) and N5 (late N) in 1997 and 1998.*

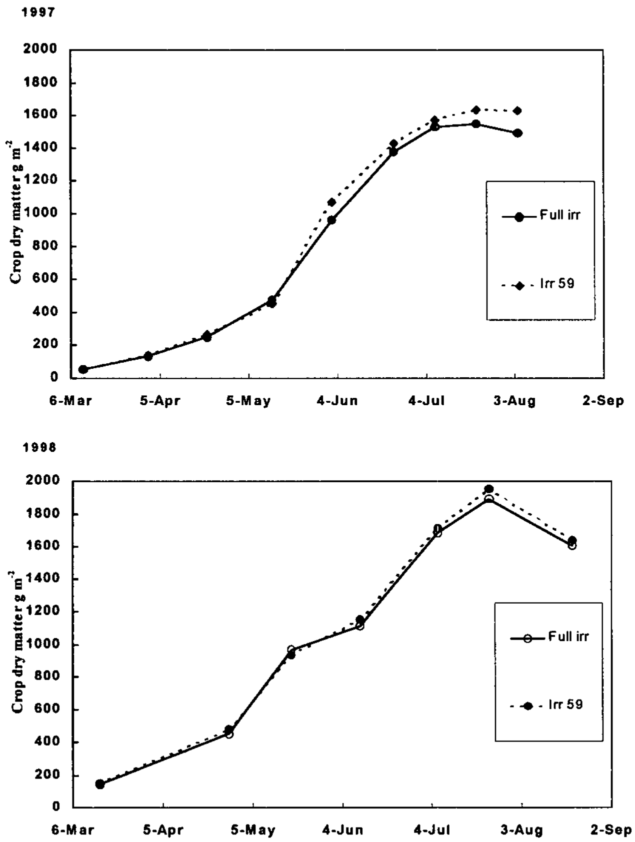



*Fig. 2.2.5a. Crop dry matter (g m$^{-2}$) for two irrigation treatments : fully irrigated and irrigated up to GS 59 only in 1997 and 1998.*

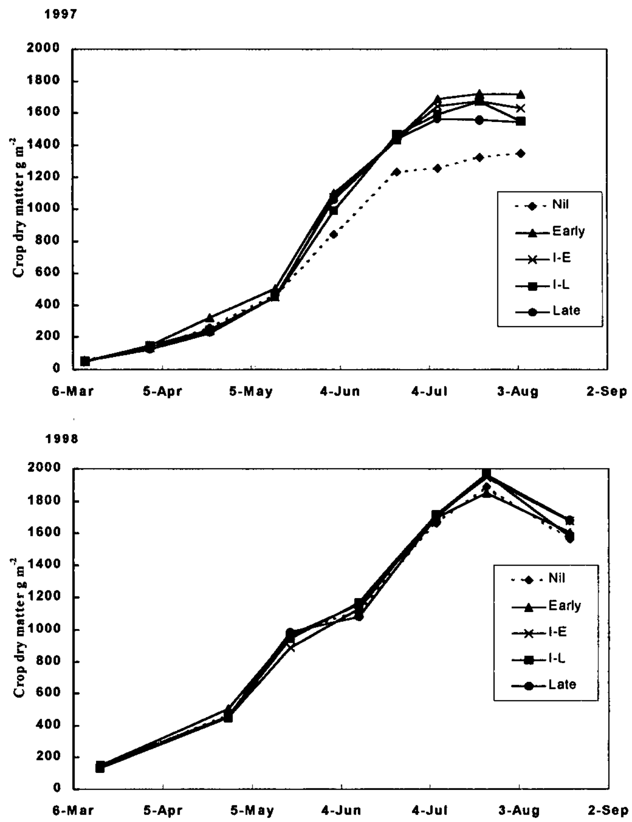



*Fig. 2.2.5b. Crop dry matter (g $m^{-2}$) for five N treatments : N1 (nil N), N2 (early N), N3 (early to intermediate N), N4 (intermediate to late N) and N5 (late N).*

*Table 2.2.6. S.E.D. and probability of significance for growth analysis assessments* in 1997

Potentially fertile shoots m$^{-2}$

| | 10 Mar | 1 Apr | 21 Apr | 13 May | 2 Jun | 23 Jun | 7 Jul | 21 Jul | 4 Aug |
|---|---|---|---|---|---|---|---|---|---|
| S.E.D. Irr | 125.1 | 98.2 | 175.4 | 27.7 | 20.4 | 23.0 | 20.67 | 18.41 | 23.05 |
| Prob. D.F. = 2 | 0.326 | 0.932 | 0.670 | 0.444 | 0.886 | 0.749 | 0.837 | 0.843 | 0.184 |
| S.E.D. N | 84.2 | 49.9 | 95.6 | 66.5 | 44.9 | 34.7 | 29.83 | 27.38 | 27.75 |
| Prob. D.F. = 16 | 0.130 | <0.01 | 0.440 | 0.<0.01 | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| S.E.D. Irr/N | 164.3 | 116.8 | 213.0 | 88.6 | 60.3 | 49.6 | 43.02 | 39.22 | 41.99 |
| Prob. D.F. = 16 | 0.325 | <0.05 | 0.899 | 0.307 | 0.529 | 0.110 | 0.067 | 0.126 | 0.017 |
| CV% | 10.0 | 6.2 | 16.6 | 16.7 | 16 | 10.2 | 8.8 | 8.0 | 8.2 |

GAI

| | 10 Mar | 1 Apr | 21 Apr | 13 May | 2 Jun | 23 Jun | 7 Jul | 21 Jul |
|---|---|---|---|---|---|---|---|---|
| S.E.D. Irr | 0.032 | 0.181 | 0.490 | 0.687 | 0.490 | 0.391 | 0.271 | 0.150 |
| Prob. D.F. = 2 | 0.377 | 0.632 | 0.716 | 0.973 | 0.661 | 0.789 | 0.850 | 0.565 |
| S.E.D. N | 0.054 | 0.158 | 0.349 | 0.395 | 0.537 | 0.316 | 0.242 | 0.147 |
| Prob. D.F. = 16 | 0.364 | 0.088 | 0.019 | <0.001 | <0.001 | <0.001 | <0.001 | 0.067 |
| S.E.D. Irr/N | 0.076 | 0.270 | 0.660 | 0.849 | 0.838 | 0.560 | 0.271 | 0.239 |
| Prob. D.F. = 16 | 0.190 | 0.244 | 0.744 | 0.126 | 0.178 | 0.173 | 0.409 | 0.242 |
| CV% | 10.0 | 16.6 | 21.4 | 13.7 | 16.8 | 11.1 | 11.4 | 16.3 |

Crop dry matter g m$^{-2}$

| | 10 Mar | 1 Apr | 21 Apr | 13 May | 2 Jun | 23 Jun | 7 Jul | 21 Jul | 4 Aug |
|---|---|---|---|---|---|---|---|---|---|
| S.E.D. Irr | 1.81 | 10.39 | 31.00 | 56.6 | 64.9 | 60.1 | 88.9 | 59.6 | 54.5 |
| Prob. D.F. = 2 | 0.306 | 0.710 | 0.701 | 0.789 | 0.229 | 0.472 | 0.658 | 0.279 | 0.125 |
| S.E.D. N | 2.76 | 10.30 | 23.88 | 35.9 | 58.7 | 52.5 | 65.6 | 80.1 | 72.0 |
| Prob. D.F. = 16 | 0.253 | 0.129 | <0.001 | <0.01 | <0.01 | <0.01 | <0.001 | <0.01 | <0.01 |
| S.E.D. Irr/N | 3.93 | 16.66 | 43.28 | 72.6 | 98.6 | 89.5 | 121.6 | 117.6 | 106.2 |
| Prob. D.F. = 16 | 0.108 | 0.277 | 0.541 | 0.071 | 0.775 | 0.116 | 0.341 | 0.632 | 0.056 |
| CV% | 9.0 | 13.1 | 16.0 | 9.9 | 10.0 | 6.5 | 7.3 | 8.7 | 8.0 |

Crop N offtake kg ha$^{-1}$

| | 10 Mar | 1 Apr | 21 Apr | 13 May | 2 Jun | 7 Jul | 21 Jul | 4 Aug |
|---|---|---|---|---|---|---|---|---|
| S.E.D. Irr | | 6.89 | 15.31 | 21.34 | 9.65 | 12.44 | 10.21 | 6.18 |
| Prob. D.F. = 2 | | 0.740 | 0.708 | 0.868 | 0.104 | 0.695 | 0.987 | 0.098 |
| S.E.D. N | | 4.93 | 7.66 | 17.38 | 25.54 | 24.49 | 15.10 | 11.40 |
| Prob. D.F. = 16 | | < 0.05 | 0.155 | <0.01 | <0.001 | <0.01 | <0.001 | <0.001 |
| S.E.D. Irr/N | | 9.29 | 18.12 | 30.64 | 33.72 | 17.86 | 21.65 | 15.69 |
| Prob. D.F. = 16 | | 0.212 | 0.421 | 0.305 | 0.917 | 0.976 | 0.404 | 0.151 |
| CV% | | 18.0 | 30.3 | 23.3 | 24.0 | 20.5 | 11.2 | 8.1 |

*Table 2.2.7. S.E.D. and probability of significance for growth analysis assessments* in 1998

*Potentially fertile shoots m$^{-2}$*

| | 16 Mar | 27 Apr | 18 May | 10 Jun | 6 Jul | 23 Jul | 20 Aug |
|---|---|---|---|---|---|---|---|
| S.E.D. Irr | 87.3 | 73.7 | 25.7 | 48.38 | 36.3 | 45.3 | 13.38 |
| Prob. D.F. = 2 | 0.560 | 0.605 | 0.960 | 0.557 | 0.850 | 0.397 | 0.808 |
| S.E.D. N | 88.7 | 59.8 | 34.4 | 27.12 | 50.3 | 31.2 | 28.9 |
| Prob. D.F. = 16 | 0.706 | 0.125 | < 0.05 | 0.438 | 0.517 | 0.169 | 0.402 |
| S.E.D. Irr/N | 142.2 | 105.6 | 50.5 | 59.3 | 73.3 | 60.2 | 38.9 |
| Prob. D.F. = 16 | 0.303 | 0.686 | 0.076 | 0.166 | 0.523 | 0.145 | 0.603 |
| CV% | 11.4 | 11.6 | 8.4 | 7.4 | 13.5 | 8.6 | 8.1 |

*GAI*

| | 16 Mar | 27 Apr | 18 May | 10 Jun | 6 Jul | 23 Jul |
|---|---|---|---|---|---|---|
| S.E.D. Irr | 0.210 | 0.205 | 0.332 | 0.277 | 0.148 | 0.109 |
| Prob. D.F. = 2 | 0.961 | 0.519 | 0.871 | 0.492 | 0.462 | 0.407 |
| S.E.D. N | 0.175 | 0.324 | 0.408 | 0.367 | 0.529 | 0.401 |
| Prob. D.F. = 16 | 0.600 | 0.007 | < 0.001 | < 0.01 | 0.813 | < 0.01 |
| S.E.D. Irr/N | 0.304 | 0.458 | 0.613 | 0.540 | 0.686 | 0.519 |
| Prob. D.F. = 16 | 0.856 | 0.168 | 0.372 | 0.636 | 0.949 | 0.454 |
| CV% | 16.0 | 12.2 | 9.3 | 9.7 | 17.8 | 24.0 |

*Crop dry matter g m$^{-2}$*

| | 16 Mar | 27 Apr | 18 May | 10 Jun | 6 Jul | 23 Jul | 20 Aug |
|---|---|---|---|---|---|---|---|
| S.E.D. Irr | 14.39 | 10.12 | 43.2 | 52.9 | 45.0 | 57.1 | 46.3 |
| Prob. D.F. = 2 | 0.730 | 0.148 | 0.530 | 0.570 | 0.676 | 0.388 | 0.574 |
| S.E.D. N | 15.39 | 30.85 | 59.1 | 55.5 | 61.9 | 92.9 | 67.8 |
| Prob. D.F. = 16 | 0.673 | 0.444 | 0.514 | 0.568 | 0.903 | 0.656 | 0.319 |
| S.E.D. Irr/N | 24.21 | 40.32 | 85.3 | 87.9 | 90.3 | 130.6 | 97.5 |
| Prob. D.F. = 16 | 0.929 | 0.505 | 0.703 | 0.358 | 0.605 | 0.405 | 0.625 |
| CV% | 14.8 | 11.5 | 10.7 | 8.5 | 6.3 | 8.4 | 7.2 |

*Crop N offtake kg ha$^{-1}$*

| | 16 Mar | 27 Apr | 10 Jun | 6 Jul | 20 Aug |
|---|---|---|---|---|---|
| S.E.D. Irr | 4.54 | 1.61 | 39.0 | 9.6 | 41.14 |
| Prob. D.F. = 2 | 0.720 | < 0.05 | 0.678 | 0.164 | 0.869 |
| S.E.D. N | 4.04 | 20.49 | 42.6 | 44.7 | 23.52 |
| Prob. D.F. = 16 | 0.423 | < 0.05 | 0.274 | < 0.05 | < 0.01 |
| S.E.D. Irr/N | 6.84 | 25.97 | 66.5 | 57.4 | 36.81 |
| Prob. D.F. = 16 | 0.909 | 0.600 | 0.505 | 0.487 | 0.601 |
| CV% | 15.8 | 20.6 | 28.9 | 28.0 | 8.5 |

### Stem soluble carbohydrate

In 1997, the larger water deficit during May and June in the treatment irrigated only to GS 59 depressed the amount of stem reserves accumulated by about 30 g m$^{-2}$ (Table 2.2.8). In 1998, the difference between irrigation treatments was never greater than 20 g m$^{-2}$. The overall amount of stem sugars accumulated was less than in the previous year by about 55 g m$^{-2}$. Shoot numbers were greater in 1998 by about 60 m$^{-2}$, and this may have increased the proportion of stem dry matter as non-structural carbohydrate in 1998. The smaller incident solar radiation in May 1998 of 509 MJ m$^{-2}$ compared to May 1997 of 572 MJ m$^{-2}$ may also have contributed to this difference.

Of the four treatments where N fertiliser was applied, N3 (early to intermediate) amassed most stem reserves in both years. The decrease with later phasing of N at N4 and N5 or earlier phasing of N at N2 was only marginal, however, in the order of 10 – 20 g m$^{-2}$. It was noticeable that at nil N (N1) most stem reserves were amassed of the five N treatments in both years, the advantage being *c.* 40 g m$^{-2}$ compared to the average of N2 – N5 (Table 2.2.8). Deficiency of N may depress protein synthesis contributing indirectly to an increase in the pool of simple sugars available for storage in the stem.

*Table 2.2.8. Stem soluble carbohydrate (g m⁻²) in 1997 and 1998*

| | 2 June 97 | 23 June 97 | 10 June 98 | 6 July 98 | Mean |
|---|---|---|---|---|---|
| Fully irrigated | | | | | |
| N1 Nil | 1.23 | 2.85 | 2.09 | 1.54 | 1.93 |
| N2 Early | 1.43 | 2.06 | 1.12 | 1.00 | 1.40 |
| N3 E-I | 2.17 | 2.71 | 1.04 | 1.40 | 1.83 |
| N4 I-L | 1.81 | 1.50 | 1.01 | 1.24 | 1.39 |
| N5 Late | 1.72 | 2.05 | 0.97 | 1.09 | 1.46 |
| Mean | 1.67 | 2.24 | 1.24 | 1.25 | 1.60 |
| Irrigated to GS59 | | | | | |
| N1 Nil | 1.50 | 2.41 | 1.55 | 1.68 | 1.79 |
| N2 Early | 1.53 | 1.88 | 1.10 | 1.12 | 1.41 |
| N3 E-I | 1.41 | 1.59 | 0.90 | 1.42 | 1.33 |
| N4 I-L | 1.03 | 1.67 | 1.01 | 1.30 | 1.25 |
| N5 Late | 1.38 | 2.00 | 1.24 | 1.22 | 1.46 |
| Mean | 1.37 | 1.91 | 1.16 | 1.35 | 1.45 |
| L.S.D. Irr | 0.227 | 0.504 | 0.766 | 0.048 | 0.055[1] |
| Prob. | < 0.05 | 0.108 | 0.686 | < 0.05 | 0.023 |
| L.S.D. N | 0.851 | 0.510 | 0.241 | 0.344 | 0.127 |
| Prob. | 0.849 | < 0.01 | < 0.001 | < 0.05 | < 0.001 |
| L.S.D. Irr/N | 0.511 | 0.686 | 0.582 | 0.435 | 0.170 |
| Prob. | 1.081 | 0.124 | < 0.05 | 0.994 | 0.276 |

[1] S.E.D. for cross-site/season mean, D.F. Irr = 8; D.F. N and Irr/N = 64.

**Water use**

*Total water use*

1997

Water use to 10 June (close to date of GS 61 on 7 June) for plots irrigated to GS 59 was 4 mm less than fully irrigated, and to 1 August 33 mm less (Fig 2.2.6a). With regard to N treatments, compared to N3 (early to intermediate), the saving in water use to 10 June by restricting maximum canopy size with late N at N5 was 20 mm, and with N4 (intermediate to late) 17 mm (Fig. 2.2.6b). With nil N the reduction was 45 mm.

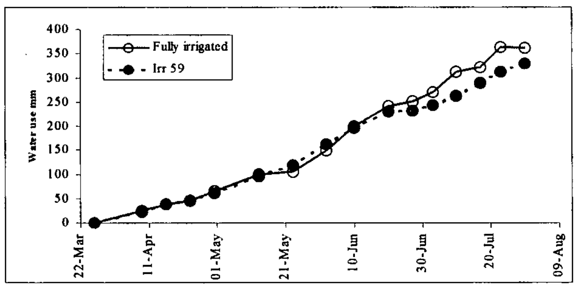
1998

In the treatment irrigated to GS 59 water use to 10 June (as in 1997, close to GS 61) was 8 mm less than fully irrigated (Fig. 2.2.6a) and 52 mm less at harvest. Compared to N3, the saving in water use with later phasing of N was 9 mm for both N4 and N5 (Fig. 2.2.6b).

*Pattern of extraction of soil water with depth*

In the treatment irrigated to GS 59, in the slightly drier year dry of 1997, the pattern of water uptake with depth provides a guide to any N treatment effects on root density with depth. In this irrigation treatment, actual water uptake will have reflected the above-ground demand for water, as affected by canopy size, rate of senescence and radiation interception. With lower root density in the upper profile relatively more water uptake might be expected to occur at depth. This was observed in the nil N treatment, where extraction was significantly less than N3 (early to intermediate) at all depths to 0.7 m, but not below this (Fig. 2.2.7b). Amongst the N2 – N5 treatments, there was no discernible difference in the distribution of water uptake with depth or the maximum depth of extraction. Differences in extraction were not significant at any depth. In N3, where total uptake was larger, this was uniformly expressed at all depths within the profile. This provides indirect evidence that any differences in root density in the upper profile amongst N2 – N5 were not large.

1997




1998

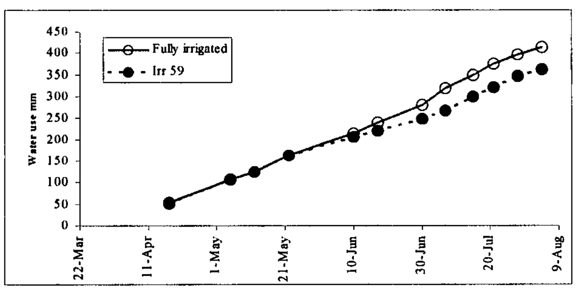
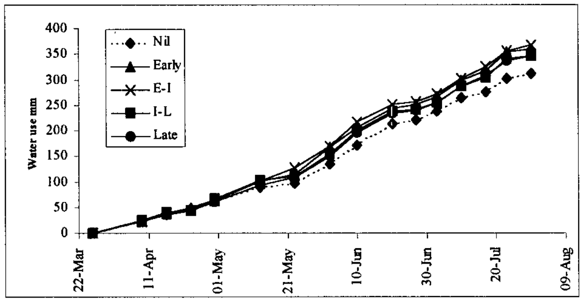



*Fig.2.2.6a. Water use (mm) from 26 March in 1997 and 1 April in 1998 for two irrigation treatments : fully irrigated and irrigated up to GS 59.*

1997




1998

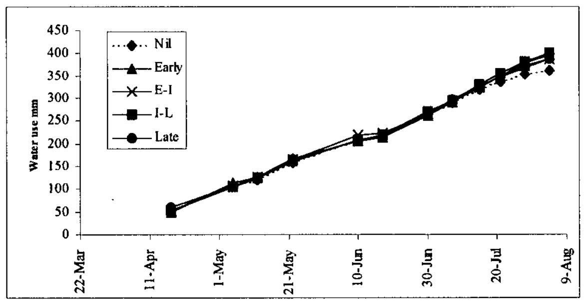
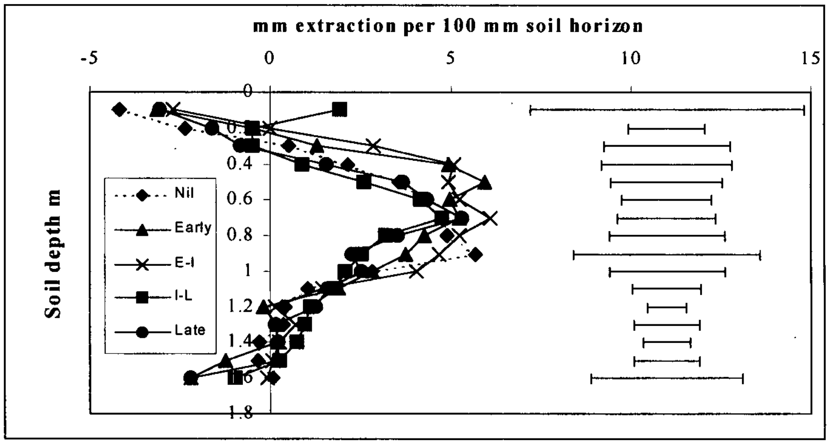



*Fig.2.2.6b. Water use (mm) from 26 March in 1997 and 1 April in 1998 for five N treatments : N1 (nil N), N2 (early N), N3 (early to intermediate N), N4 (intermediate to late N) and N5 (late N).*

**26 March - 13 May**




**26 March - 30 July**

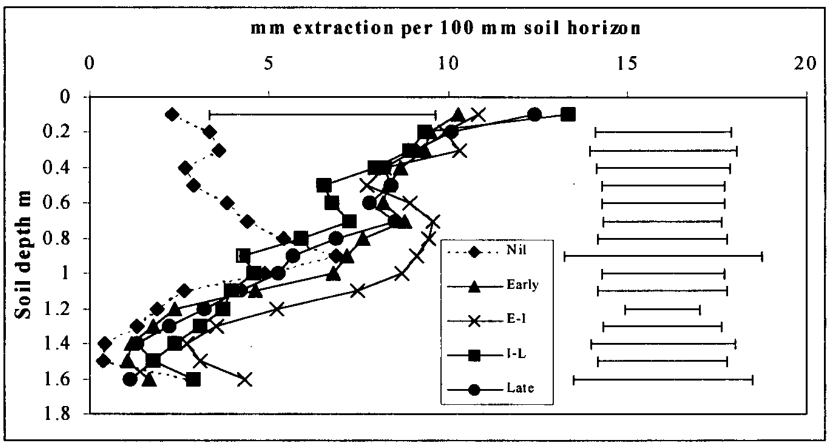



Fig. 2.2.7 Soil water extraction from 26 March to (top) 13 May and (bottom) 30 July in the treatment irrigated to GS 59 for five N treatments in 1998. Error bars = L.S.D. for N treatments.

### Crop N uptake

N uptake did not differ between irrigation treatments at any sample time in 1997 and only on 27 April in 1998 (Fig 2.2.8a, Table 2.2.6 and 2.2.7), where uptake was 5 kg $ha^{-1}$ greater in irrigated to GS 59. In 1997, N treatment differences were significant from 13 May onwards ($P< 0.001$). Uptake was lower with nil N compared to treatments N2 – N5, the difference amounting to about 75 kg $ha^{-1}$ on 4 August. There was a trend for N offtake to be lower with later phasing of N. On both 21 July and 4 August, N offtake was about 20 kg $ha^{-1}$ smaller for N5 (late) compared to N2 (early). In 1998, effects were significant on 27 April, 6 July and 20 August, with nil N taking up about 50 kg $ha^{-1}$ less N than the average of the N2 – N5 treatments. With regard to N timing, the situation was reversed compared to 1998 with N5 showing a trend for greater uptake than N2. This differential amounted to about 25 kg $ha^{-1}$ at harvest.

### Soil mineral N

In 1997 the soil N status at the start of N fertiliser applications in early spring was 67 kg $ha^{-1}$ in 1997 and 111 kg $ha^{-1}$ in 1998. In the nil N treatment, the soil N actually increased during the season in 1997 from 67 kg $ha^{-1}$ in February to 135 kg $ha^{-1}$ in September, shortly after harvest. At the same time about 140 kg $ha^{-1}$ was taken up in the nil N crop. It follows that significant mineralization must have occurred from organic residues in the soil during the season. A similar effect, although not as large, was observed in 1998. Here the nil N crop took up in the region of 170 kg $ha^{-1}$ N from early March to harvest, where the soil N status remained unchanged at *c.* 100 kg $ha^{-1}$.

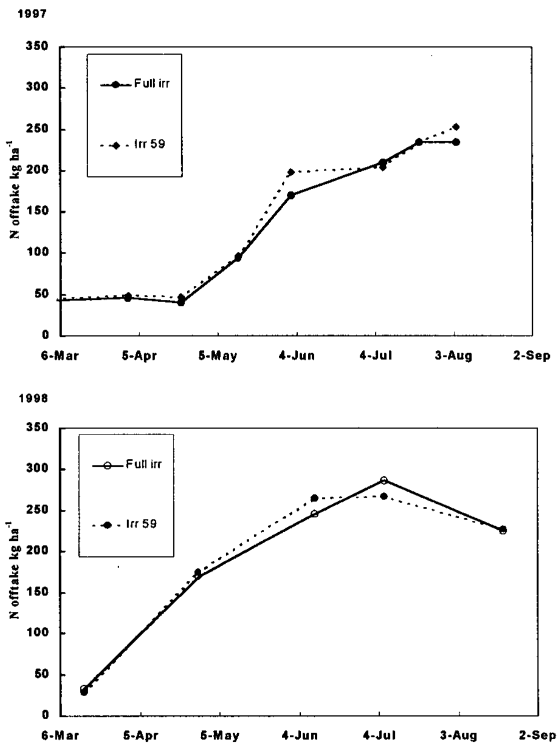



*Fig. 2.2.8a. N offtake (kg ha$^{-1}$) for two irrigation treatments : fully irrigated and irrigated up to GS 59 only in 1997 and 1998.*

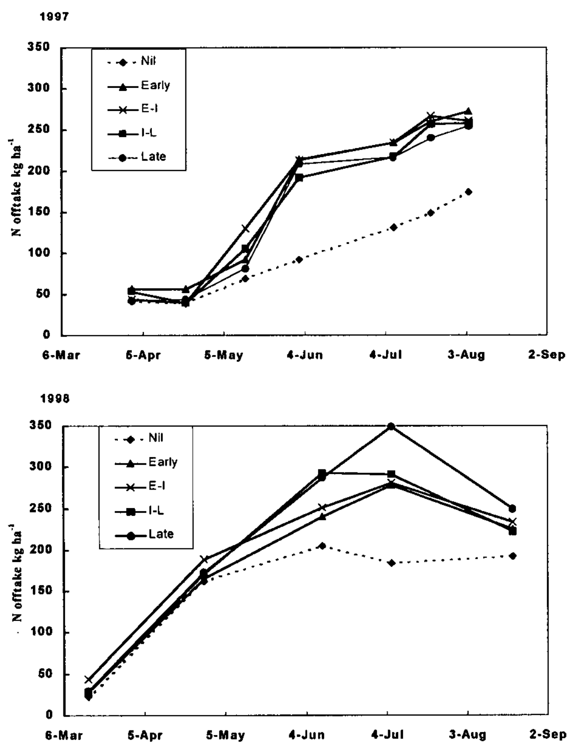
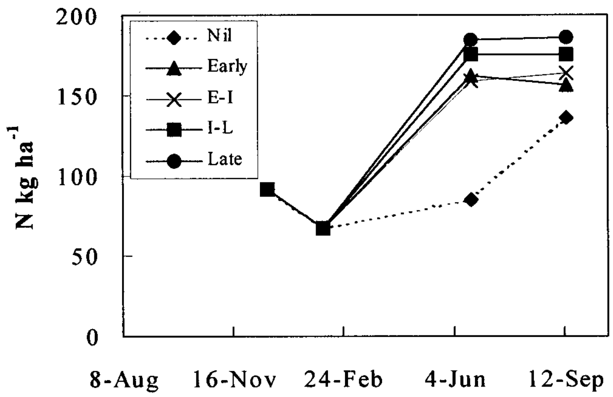
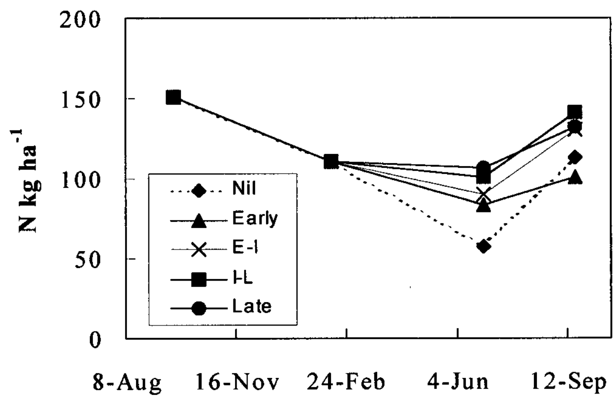



*Fig. 2.2.8b. N offtake (g m$^{-2}$) for five N treatments : N1 (nil N), N2 (early N), N3 (early to intermediate N), N4 (intermediate to late N) and N5 (late N).*

1997




1998




**Grain yield and yield components**

There was a trend for greater yield irrigated to GS 59 in 1997, with a difference of 0.5 t ha$^{-1}$ between irrigation treatments at harvest ($P < 0.07$) (Table 2.2.9). Averaged across irrigation treatments, the nil N treatment yielded about 1.5 t ha$^{-1}$ more than N2 - N5, which yielded broadly similarly in the range 8.17 - 8.31 t ha$^{-1}$. In 1998, there was no difference between irrigation treatments in yield. There was, however, a significant effect of N timing, with the late N (N5) yielding greater than the nil N treatment or the treatments with earlier phasing of N, N2 and N3 (Table 2.2.9).

*Table 2.2.9. Combine grain yield and yield components* in *1997 and 1998*

| | | **Combine** yield 85% DM | | Ears $m^{-2}$ | | Grains $ear^{-1}$ | | 1000 grain weight 85% DM g | |
|---|---|---|---|---|---|---|---|---|---|
| | | 1997 | 1998 | 1997 | 1998 | 1997 | 1998 | 1997 | 1998 |
| Fully irrigated | N 1 | 6.79 | 9.13 | 427 | 598 | 32.6 | 33.4 | 37.3 | 50.7 |
| | N 2 | 8.04 | 8.90 | 697 | 623 | 32.1 | 32.2 | 30.9 | 45.3 |
| | N 3 | 7.80 | 8.98 | 646 | 631 | 29.8 | 31.2 | 31.4 | 46.8 |
| | N 4 | 8.09 | 9.62 | 589 | 623 | 32.9 | 31.8 | 32.6 | 48.4 |
| | N 5 | 7.78 | 9.89 | 551 | 618 | 34.9 | 30.4 | 32.7 | 50.2 |
| | Mean | 7.70 | 9.19 | 582 | 618 | 32.4 | 31.8 | 33.0 | 48.2 |
| Irrigated to GS 59 | N 1 | 6.92 | 8.40 | 496 | 589 | 34.6 | 29.3 | 38.2 | 51.2 |
| | N 2 | 8.59 | 8.75 | 614 | 619 | 39.0 | 30.6 | 31.7 | 47.8 |
| | N 3 | 8.45 | 9.15 | 627 | 641 | 30.1 | 30.2 | 33.2 | 46.6 |
| | N 4 | 8.27 | 9.28 | 635 | 568 | 31.4 | 29.3 | 33.9 | 49.3 |
| | N 5 | 8.56 | 9.82 | 587 | 657 | 36.6 | 31.8 | 35.2 | 50.1 |
| | Mean | 8.16 | 9.08 | 592 | 615 | 34.3 | 30.3 | 34.5 | 49.1 |
| S.E.D Irr | | 0.123 | 0.145 | 20.3 | 13.4 | 0.99 | 0.839 | 0.300 | 0.254 |
| Prob. | | 0.07 | 0.268 | 0.68 | 0.808 | 0.19 | 0.209 | 0.04 | 0.138 |
| S.E.D. N | | 0.247 | 0.279 | 16.6 | 28.9 | 2.05 | 1.419 | 0.846 | 0.658 |
| Prob. | | <0.001 | < 0.01 | <0.001 | 0.402 | 0.06 | 0.964 | <0.001 | <0.001 |
| S.E.D. Irr/N | | 0.336 | 0.381 | 29.2 | 38.9 | 2.78 | 1.981 | 1.100 | 0.871 |
| Prob. | | 0.614 | 0.583 | <0.01 | 0.603 | 0.36 | 0.420 | 0.83 | 0.417 |

## CONCLUSIONS

### Hypotheses tested

The overall hypothesis under test was that Canopy Management predisposes crops to risk of drought, and this management system is therefore unsuitable for drought-prone soil types.

Reported effects of Canopy Management N compared to conventional N on crop growth in the MAFF Project CSA2194/HGCA Project 0070/1/91 were :

- to diminish GAI from 7.1 to 6.0
- to reduce total crop dry matter at GS 61 by about 1 t $ha^{-1}$.
- To reduce ears $m^{-2}$ at harvest by about 60 $m^{-2}$.

The aim in the present experiments was to produce a range of maximum GAI, including values representative of those attained by typical Canopy Management N and Conventional N crops, through manipulating timing of N and to examine effects on :

- rooting depth and activity (from measurements of soil water uptake)
- water use to GS 61
- accumulation of stem sugars
- grain yield performance with and without late drought.

By examining these processes it was hoped that conclusions could be reached as to whether Canopy Management N worked less well on soils of low available water in dry years.

### Test-bed established in 1997 and 1998

In the two test years, April – July rainfall was significantly above the long-term mean. For this reason, large soil moisture deficits never occurred during grain filling in either season in the treatment irrigated to GS 59, and grain yield was not significantly reduced compared to the fully irrigated control. With respect to examining effects of different canopy sizes on performance under late drought at the level of grain yield, the present experiments were thus of restricted usefulness.

In relation to N treatment differences established : in 1997, amongst the four treatments receiving fertiliser N, the range in maximum GAI was 6.4 (N3) to 5.7 (N5). The reduction from N3 to N5 was therefore similar to the overall effect of Canopy Management N compared to conventional N. The reduction in ear number at harvest from N3 to N5 of 61 $m^2$ was also similar to the effect of Canopy Management N. Therefore, a satisfactory test-bed was established in 1997 with regard to canopy differences achieved. In 1998, the soil mineral residue of the experimental site in February was 111 kg $ha^{-1}$. This led to a maximum GAI of 6.4 in the nil N treatment, and N2 - N5 varying in the range 7.3 – 8.6. Since a GAI of 6 is sufficient to intercept *c.* 90% of incident radiation and green areas above this produce diminishing returns in terms of additional interception, GAI differences in 1998 were unlikely to contribute to large differences in intercepted radiation and biomass growth pre-flowering. For this reason, canopies in 1998 were not ideal for testing the specific hypotheses postulated and the present analysis deals mainly with 1997 data. For 1997, the effect of contrasting maximum GAI is examined in relation to :

- accumulation of stem sugars
- water use to GS 61
- rooting depth (indirectly, from measurements of soil water uptake)

N.B. With respect to the high soil mineral N of the experimental site in 1998, only 40 kg $ha^{-1}$ of fertiliser N was added to the previous spring oilseed rape crop. The organic matter content in the topsoil of the field was moderate at 2.8%. Soil N data in the nil N treatment indicate (Fig. 2.2.9) that considerable mineralization took place during the season in 1997-8. The source of the organic residues fuelling this unusually large mineralization during the season may relate to high amounts of organic manures applied to fields on the Sutton Bonington Farm in the 1980s, still presumably present to some extent as organic matter in the sub-soil.

*Table 2.2.10. Summary of N treatment effects on maximum GAI and harvest ear number $m^{-2}$ in 1997 and 1998*

| | Ears $m^{-2}$ harvest | | Maximum GAI | |
|---|---|---|---|---|
| | 1997 | 1998 | 1997 | 19988 |
| N1 (Nil ) | 480 | 594 | 3.5 | 6.4 |
| N2 (Early) | 664 | 621 | 6.2 | 8.6 |
| N3 (Early - int.) | 626 | 636 | 6.4 | 7.8 |
| N4 (Int. – late) | 603 | 595 | 5.9 | 8.0 |
| N5 (Late) | 565 | 637 | 5.7 | 7.3 |
| LSD N | 58.8 | 61.2 | 1.14 | 0.86 |

**Stem soluble carbohydrate**

Of the four treatments where fertiliser N was applied, N3 amassed most stem reserves in both years. The decrease with later phasing of N at N5 was, however, only marginal. It was 0.13 t $ha^{-1}$ on 23 June in 1997. Overall the amounts of soluble carbohydrate accumulated in treatments N2 – N5 in 1997 were broadly typical of Mercia at about 2.0 t $ha^{-1}$ (HGCA, 1998d). In 1998, the decrease from N3 to N5 was again in the region of 0.1 t $ha^{-1}$. This order of difference is unlikely to have resulted in different tolerances of late drought for the treatments concerned. Assuming a water use efficiency of 5 g $m^2$ $mm^{-1}$ (Green *et al.*, 1983), and stem reserves to re-translocated to the grain with 100% efficiency, it would relate to a saving in water use of only 2 mm in the pre-grain filling period. This is when considering stem reserves as water used in vegetative growth which can effectively be redistributed to the ear for grain filling.

It was noticeable that at nil N most stem reserves were amassed of the five N treatments in both years, the advantage being *c.* 0.4 t/ha compared to the average N2 – N5. Deficiency of N depresses protein synthesis thus indirectly contributing to an increase in the pool of simple sugars available for storage in the stem as fructans.

### Water use to flowering

Canopy differences were largest in 1997 and this year provided the best test of the effects of adjusting canopy size on pre-flowering water use. Diminishing maximum GAI from 6.4 to 5.7 (N3 vs N5) conserved 20 mm more water in the soil profile on 10 June (GS 61 occurring on 7 June) (Appendix Fig. 2.2.6b). This saving equates to an additional 1.0 t $ha^{-1}$ of grain in a dry year, assuming a water use efficiency of 5 g $m^{-2}$ $mm^{-1}$. Decreasing the maximum GAI from 6.4 (N3) to 5.9 (N4) again resulted in a saving of water use to 10 June, in this case of 17 mm. The biomass depression at flowering observed in the Canopy Management Project (HGCA, 1998a) of 1 t $ha^{-1}$ compared to conventional practice is consistent with the 20 mm decrease in pre-flowering water use in the present experiment (N5 vs N3).

The restricted water consumption to flowering with smaller maximum GAI in N5 would be advantageous on lighter, drought-prone soils in dry years where total water supply is limited. Against this, maximum partitioning of assimilate to roots occurs from GS 31 to GS 61 (Gregory *et al.*, 1978), and the smaller canopy size and vegetative growth with N5 could be postulated to lead to the production of a smaller root system and reduced ability to access soil water. In order to examine whether this was the case, the pattern of water extraction with soil depth was examined in the treatment irrigated to GS 59 in 1997.

### Water uptake with soil depth

The wet summer meant that total water uptake was largely independent of rooting depth and density, as the upper soil profile was continually replenished. Season-long water uptake in these circumstances will have been defined by above-ground demand related to green canopy survival as affected by prevailing temperatures and grain N demand for canopy N. The distribution of water uptake with soil depth, however, may provide clues as to effects on N treatments on rooting depth and density.

During grain filling from 10 June to 30 July, N5 (late N, smaller canopy) extracted a similar amount of water to N3 (early N, larger canopy) (Fig.2.2.1; Appendix Fig. 2.2.6). This is consistent with green canopy area during grain fill being broadly similar for N3 and N5, despite the larger maximum GAI for N3. The maximum depth of extraction was unaffected by the depressed canopy size in N5 (Fig.2.2.1; Appendix Fig. 2.2.7). Furthermore, water uptake for N5 was generally similarly distributed with respect to soil depth to that in N3. There was thus no evidence for proportionately more water uptake deeper in the profile for N5, indicating root density in the upper profile was not reduced compared to N3 to the extent that it became necessary to draw more water from deeper to satisfy crop demand. In summary, the evidence was for any effect of diminished canopy size to depress root growth to be small. It seems unlikely that it would have been sufficient to negate the advantage of the extra 20 mm of water left in the soil profile at the onset of grain fill for N5. In analogous findings, where early flowering reduced pre-flowering water use by 20 mm, although season-long water uptake was smaller with early flowering under drought indicating a slightly smaller root system, water uptake during grain filling was always greater (HGCA, 1998c). This indicated that in this case the benefit of saving water pre-flowering outweighed the disbenefit of a slightly smaller rooting system and reduced water uptake overall. The same seems likely to be the case with regard to the present comparison of canopy sizes commensurate with Canopy Management and conventional practice.

## Appendix 3

## HOST NUTRIENT STATUS:FUNGICIDE DOSE INTERACTION.

### INTRODUCTION.

The hypothesis investigated in these experiments was developed following the completion of two earlier projects funded by MAFF and HGCA.

MAFF Open Contract. CSA 2149 (yellow rust experiment). - Effects of fertiliser derived changes in structure and composition of leaf canopies of winter wheat on the population dynamics of *Puccinia striiformis.*

In this study it was established that using the yellow rust:winter wheat pathosystem it was possible to achieve disease epidemics in every cropping season by artificial inoculation of the experiment with yellow rust spores. By manipulating winter wheat canopies with differential applications of nitrogen it was found that increased inputs of nitrogen resulted in crop canopies > GAI 7.0. Disease severity, assessed as the percentage of leaf area expressing symptoms, increased with increased inputs of nitrogen. It was demonstrated in this study that the nitrogen status of the crop was the major driving force of the disease epidemic and not the changes in canopy micro-climate resulting from canopy structural differences.

HGCA - Appropriate Fungicide Dose for Winter Wheat - Experiment 3.
Project No. 0051/01/92.

In this study both fungicide dose and timing of application were investigated in order to establish economically optimal treatments for the control of yellow rust and *Septoria* on winter wheat. The effectiveness of both fungicide timing and dose was found to be dependent on both the level of severity of the disease epidemic at a given time, and the sensitivity of the fungal population to the fungicide applied.

The main objective of the experiment described here was to determine whether the effects of amounts of N applied to a winter wheat crop interact with fungicide dose response. The hypothesis is that optimal size crop canopies (i.e. approx. GAI 6) will be less conducive to disease than larger crop canopies and will therefore require lower fungicide doses to achieve effective disease control. From the response surface obtained, i.e. the effect on grain yield of the interaction between nitrogen input and fungicide dose, it is envisaged that it will be possible to determine an economic optimum for fungicide input in relation to the nitrogen status of the crop.

The majority of recent studies on the effect of host nutrition on disease progress funded by HGCA and MAFF have focused on the biotroph, yellow rust (*Puccinia striiformis*) (Bryson *et al.*, 1997a). In order to relate previous work to other pathosystems and to attempt to make comparisons with the nitrogen/fungicide dose interaction studies on yellow rust described here, two subsidiary experiments were also carried out in 1997. These experiments investigated the effect of host nutrition on *Septoria* and mildew and are also briefly described below.

## MATERIALS AND METHODS

### Section 1. Nitrogen and fungicide dose interaction.

### Experiment design

The experiment was set up in a fully randomised block design with three replicate blocks. The treatments were the factorial combination of five levels of nitrogen (Table 3.1) and six fungicide treatments (Table 3.2). Fertiliser nitrogen was hand applied as Ammonium nitrate. Fungicide applications in 1997 were Tebuconazole as Folicur (full dose 1.0l/ha) and Fenpropimorph as Corbel (full dose 0.75 l/ha) and in 1998, Epoxiconazole as Opus (full dose 1.0l/ha) and Fenpropidin as Patrol (full dose 0.75 l/ha) applied in a three spray programme. Soil mineral nitrogen levels were between 80 and 100 kg N/ha in each year. Nitrogen treatments were designed to achieve approximate canopy sizes of green area index (GAI) 3.0, 4.5, 6.0, 7.5 and 9.0. The yellow rust susceptible varieties, Slejpner and Brigadier, were tested in the 1996/97 and 1997/98 season respectively. All remaining inputs, growth regulators, aphicides and herbicides were applied as conventional farm treatments.

**Table 3.1.** Nitrogen inputs (kg N/ha)

| | Feb./Mar | April (early) | April (late) | Total |
|---|---|---|---|---|
| N1 | 0 | 0 | 0 | 0 |
| N2 | 20 | 30 | 30 | 80 |
| N3 | 40 | 60 | 60 | 160 |
| N4 | 80 | 80 | 80 | 240 |
| N5 | 100 | 120 | 100 | 320 |

**Table 3.2.** Fungicide treatments applied.

| | Fungicide | GS 32 | GS33 | GS39 | Proportion of full dose |
|---|---|---|---|---|---|
| F1 | Untreated | 0 | 0 | 0 | 0 |
| F2 | Triazole | 0.04 | 0.04 | 0.04 | 0.125 |
| | Morpholine | 0.03 | 0.03 | 0.03 | |
| F3 | Triazole | 0.08 | 0.08 | 0.08 | 0..25 |
| | Morpholine | 0.06 | 0.06 | 0.06 | |
| F4 | Triazole | 0.16 | 0.16 | 0.16 | 0.5 |
| | Morpholine | 0.12 | 0.12 | 0.12 | |
| F5 | Triazole | 0.33 | 0.33 | 0.33 | 1.0 |
| | Morpholine | 0.25 | 0.25 | 0.25 | |
| F6 | Triazole | 0.67 | 0.67 | 0.67 | 2.0 |
| | Morpholine | 0.50 | 0.50 | 0.50 | |

**Disease and leaf area assessments**

Disease assessments were carried out weekly on 10 randomly selected shoots per plot. Each leaf layer, starting from L1 (the uppermost fully expanded leaf ), was assessed for the presence of yellow rust (*Puccinia striiformis*), brown rust (*Puccinia recondita*), *Septoria* spp. (*Septoria nodorum* and *S. tritici*) and mildew (*Erysiphe graminis f.sp. tritici* ) Disease was assessed as a percentage of the total leaf area expressing symptoms according to the MAFF Manual of Plant Growth Stage and Disease Assessment Keys (Anon, 1976). Green area remaining was also assessed and expressed as a percentage.

Leaf area was determined by taking two shoots as a sub sample of those randomly selected. Leaf length and width for each leaf layer were then measured and actual area calculated by using the form factor 0.83 described in Bryson *et al.*, 1997b.

**Crop growth analysis.**

**Field sampling**

Samples were taken from the F1 and F6 fungicide treatments at the five nitrogen levels. For crop growth analysis samples of 0.50 $m^2$ were taken from each field plot at GS 39, 61 and 75 from pre-determined areas to avoid local bias with a gap of at least 50 cm between sample areas. Plants were cut at ground level and all the above ground material stored in plastic bags for a maximum of three days in a cold room at 4-6 $^{0}$C prior to processing. The total sample fresh weight was recorded and two sub-samples randomly selected; sample 1 (SS1) (approximately 15%) for growth analysis and sample 2 (SS2) (approximately 20%) for dry weight and % N determination.

**Growth analysis in the laboratory.**

The SS1 sample was analysed to determine shoot number $m^{-2}$, green area index (GAI) and green leaf area index (GLAI) and the SS2 subsample to determine crop dry weight.

For both samples the fresh weight was recorded. The SS2 sample was cut into 10cm lengths and oven dried at 80° C for 48h. At GS 61 and 75 stem and ears were oven dried separately. The dry weight of SS2 was then recorded.

SS1 1 was divided into fertile and/or potentially fertile shoots, and dead and non-fertile (dying) shoots, and the respective numbers recorded. Shoots were considered to be non-fertile when the newest expanding leaf had begun to turn yellow at the tip or the flag leaf had fully emerged but there was no evidence of booting. All green plant material was separated into stem, leaves and ears and the planar area measured using a calibrated leaf area meter (Delta-T Devices, Cambs.). All remaining non-green material was retained. Green and non-green material was then oven dried at 80°C for 48 h and the dry weight recorded.

## Harvest analysis.

### Pre-harvest grab samples.

Samples were taken from all plots prior to harvest to determine dry matter harvest index, nitrogen harvest index, thousand grain weight, specific weight, mean grain weight and grain number per ear. Approximately 100 shoots per plot were randomly selected from the whole plot area. Total fresh weight was then recorded in the lab.. All the ears were removed from the shoots and the fresh weight recorded. A sub sample of stems was selected, the fresh weight recorded and then oven dried at 80°C for 48h to determine dry weight. Total ear number was recorded, the ears were then also oven dried to determine their dry weight. After drying the ears were threshed and total grain weight recorded. A sub-sample of grain was then taken (approx. 40g), weighed and then grain number determined. A sub-sample of grain and the dried stems were then analysed in the lab. for % nitrogen.

### Combine samples.

All plots were combined using a Sampo plot combine harvester. A 1kg sample of grain was taken from each plot and analysed for % moisture, % N and specific weight. Final plot yield was corrected to 15% dry weight.

## Section 2. The effect of host nutrition on *Septoria* and mildew development.

### Experiment design.

The experiment was set up in a randomised block design with three replicate blocks. Two experiments were set up at ADAS Rosemaund one with the mildew susceptible variety, Buster and the other the *Septoria* susceptible variety, Riband. Both varieties were treated with six levels of nitrogen as shown in Table 3.3. No fungicide was applied throughout the duration of the experiment. All remaining inputs, growth regulators, aphicides and herbicides were applied as conventional farm treatments.

**Table 3.3.** Nitrogen inputs (kgN/ha)

| | Feb./Mar | April (early) | April (late) | Total |
|---|---|---|---|---|
| N1 | 0 | 0 | 0 | 0 |
| N2 | 20 | 40 | 0 | 60 |
| N3 | 40 | 40 | 40 | 120 |
| N4 | 80 | 60 | 40 | 180 |
| N5 | 100 | 100 | 40 | 240 |
| N6 | 120 | 100 | 80 | 300 |

**Disease assessments**

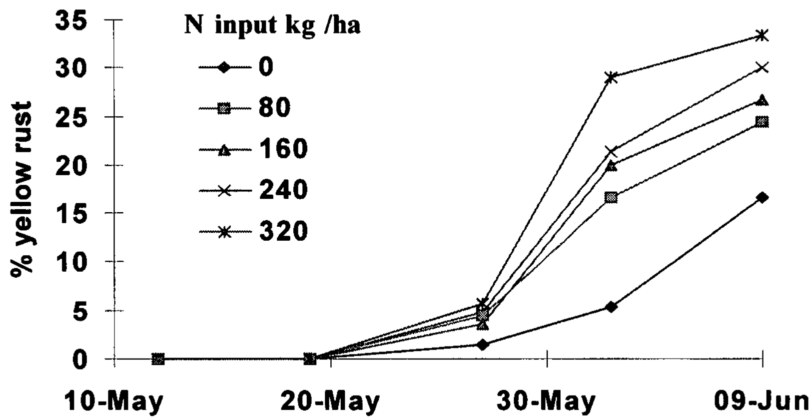
Disease assessments were carried out weekly on 10 randomly selected shoots per plot. Each leaf layer, starting from L1 (the uppermost fully expanded leaf ), was assessed for the presence of yellow rust (*Puccinia striiformis*), brown rust (*Puccinia recondita*), *Septoria* spp. (*Septoria nodorum* and *S. tritici*) and mildew (*Erysiphe graminis f.sp. tritici* ) Disease was assessed as a percentage of the total leaf area expressing symptoms according to the MAFF Manual of Plant Growth Stage and Disease Assessment Keys (Anon, 1976). Green area remaining was also assessed and expressed as a percentage.

**Combine samples.**
All plots were combined using a plot combine harvester. A 1kg sample of grain was taken from each plot and analysed for % moisture, % N and specific weight. Final plot yield was corrected to 15% dry weight.

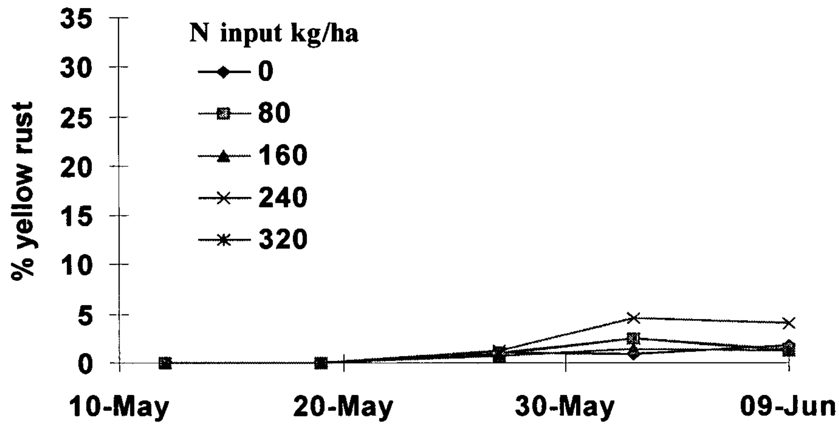
**RESULTS AND DISCUSSION.**

**Disease severity**
In both 1997 and 1998 the primary disease present on Slejpner and Brigadier respectively was yellow rust. Mildew was present at low levels on lower leaves (leaves 4 & 5) early in the season in both years but did not exceed 2% of the total leaf area. *Septoria* was also present on leaves 2 and 3 in both years but did not exceed 7% and 5% on any leaf layer in either 1997 or 1998. In both years, the severity of yellow rust was found to increase with increasing inputs of nitrogen in the untreated plots (Figure 3.1) with severity increasing from 4.5 - 13%, 17 - 32% (Figure 3.1) and 4-20% between N inputs of 0 and 320 kg N/ha on leaves 1,2 and 3 respectively.

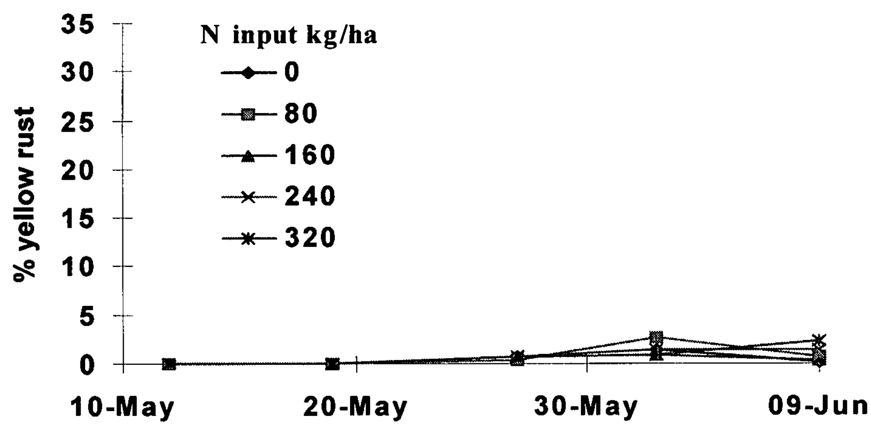
Low doses of fungicide were found to provide a high level of control of yellow rust in both years with maximum disease severity levels of 4% and 3% on leaf 2 following treatment with 0.125 and 0.25 doses (Figure 3.1). The fungicide treatments applied also controlled the low levels of *Septoria* and mildew present although lower doses were less effective at controlling *Septoria* than yellow rust.




a) Untreated




b) 0.125 dose

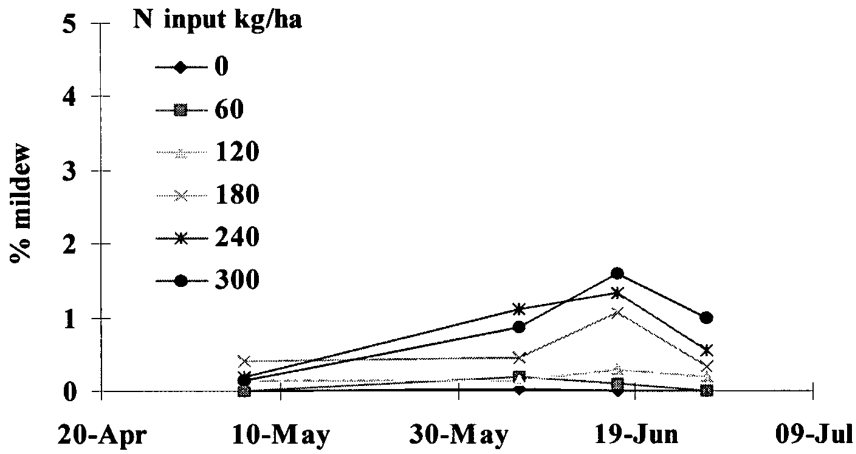



c) 0.25 dose

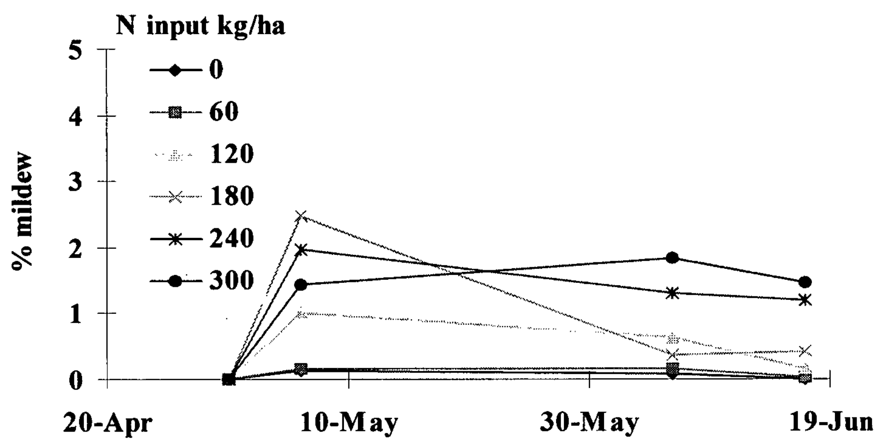
**Figure 3.1.** Percent yellow rust severity on Leaf 2 in 1997 following a) Untreated, b) 0.125 dose and c) 0.25 dose.

Disease levels on the untreated variety, Buster at ADAS Rosemaund were generally low with mildew as the predominant pathogen species. Maximum disease levels were recorded on leaf 3 with 2% of the leaf area affected. Although disease severity did appear to increase in relation to the increasing amount of nitrogen applied, disease levels were too low to determine whether this was a significant effect (Figure 3.2).

The levels of *Septoria* on Riband at ADAS Rosemaund reached maxima of 27, 52 and 63% on leaves 1,2 and 3 respectively. On leaf 3, disease severity was found to increase with increasing nitrogen input from 21-62 % between input levels of 0 and 320 kg N/ha (Figure 3.3). However, on leaves 1 & 2 disease severity did not differ between nitrogen treatments except towards the end of the season when approximately 15% more leaf area was expressing symptoms on the three highest N levels (180, 240 & 320 kg N/ha) as compared with the three lowest (0, 80 & 160 kg N/ha). Without further investigation it is not possible to determine whether the nutrient status of the host or differences in canopy micro-climate and architecture were having the greatest influence on the levels of disease severity.

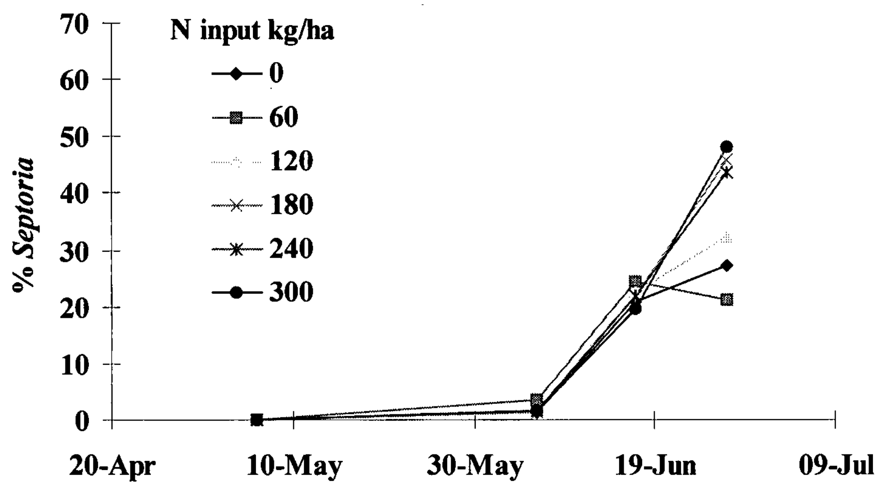



a) Leaf 2

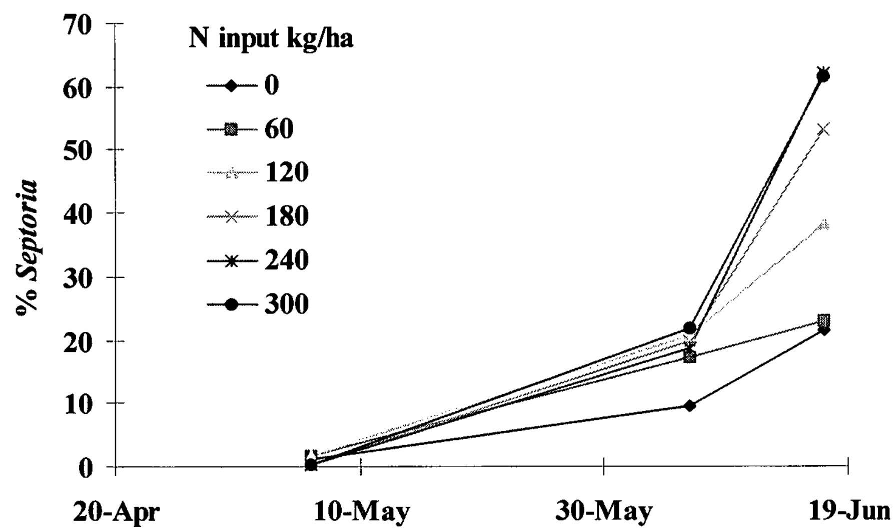



b) Leaf 3

**Figure 3.2.** The effect of host nutrition on the severity of mildew (%) on a) Leaf 2 and b) Leaf 3, on the variety Buster.




a) Leaf 2




b) Leaf 3

**Figure 3.3.** The effect of host nutrition on the severity of *Septoria* (%) on a) Leaf 2 and b) Leaf 3 on the variety Riband.

### Crop growth

In both years, in the fungicide treated plots (2.0 dose), GAI and dry matter accumulation generally increased with increasing N inputs (Figs 3.4 - 3.9). Maximum canopy size occurred at GS 39 with GAI of 4.2, 5.6 and 6.2 in 1997 (Figure 3.4) and 4.5, 6.5 and 7.8 in 1998, following N inputs of 0, 160 and 320 kg N/ha respectively. In 1997 canopy size and total dry matter tended to plateau in N treatments above 160 kg N/ha. In this year some crop lodging occurred in the 160, 240 and 320 kg N/ha treated plots, treated with fungicide and it is likely that this resulted in some reduction in yield and quality at the higher N levels.

In both years, the occurrence of yellow rust had a major effect on both GAI and dry matter accumulation. Loss of GAI generally increased with increasing N input. This was a reflection of the increased disease severity which resulted from increased N inputs. In 1997, GAI was reduced by 0.7, 1.9 and 1.2 (GS39), 1.9, 4.0 and 3.9 (GS61) and 1.5, 3.9 and 3.8 (GS75) GAI units due to disease at 0, 160 and 320 kg N/ha (Figures 3.4, 3.5 & 3.6). The loss of green area due to disease did not have a significant effect on total dry matter at GS39 (Figure 3.7) as would be expected prior to grain filling. However, after anthesis total dry matter was reduced due to disease compared with the treated plots (Figures 3.8 & 3.9). Total dry matter at GS75 was significantly reduced due to disease by 2.2, 3.8 and 4.2 t/ha (Figure 3.9) and 1.2, 4.8 and 5.6 t/ha in the 0, 160 and 320 kg N/ha treated plots in 1997 and 1998 respectively. quality.

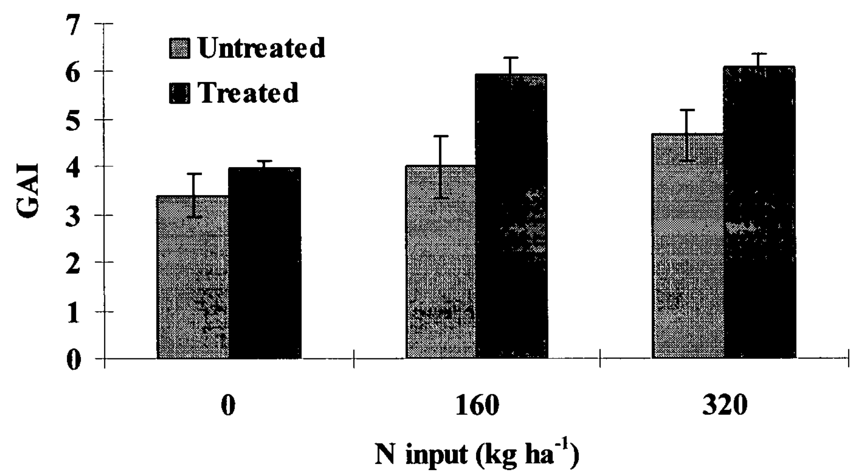



**Figure 3.4.** GAI at GS39 following treatment at three N levels and treated (2.0 dose) and untreated with fungicide

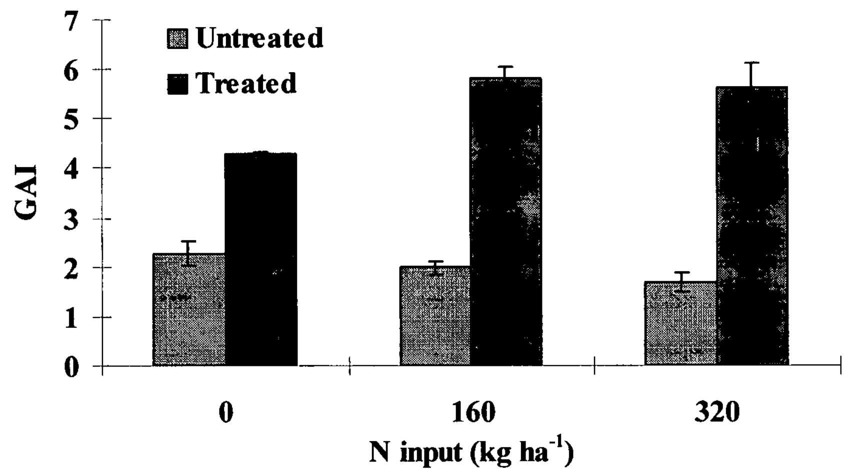



**Figure 3.5.** GAI at GS61 following treatment at three N levels and treated (2.0 dose) and untreated with fungicide

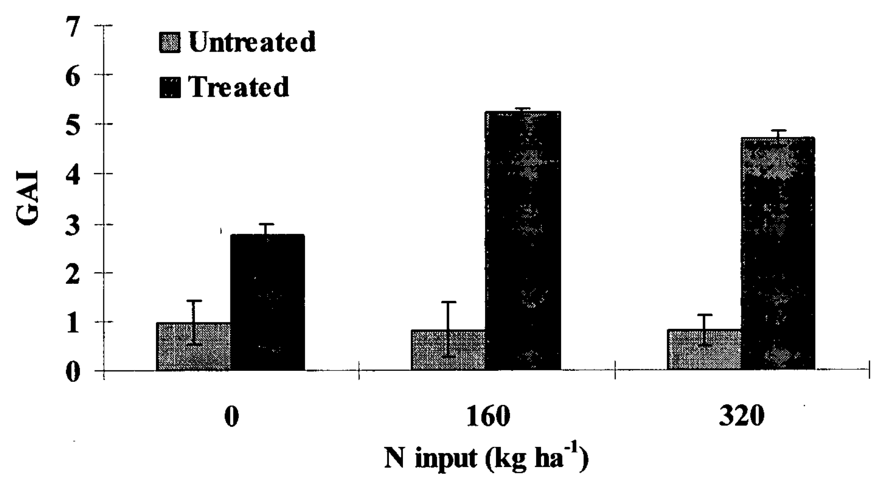



**Figure 3.6.** GAI at GS75 following treatment at three N levels and treated (2.0 dose) and untreated with fungicide

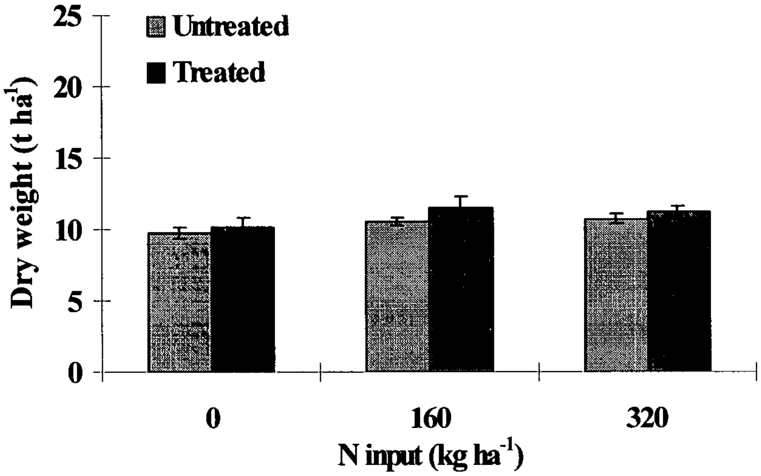



**Figure 3.7.** Total dry weight at GS39 following treatment at three N levels and treated (2.0 dose) and untreated with fungicide.

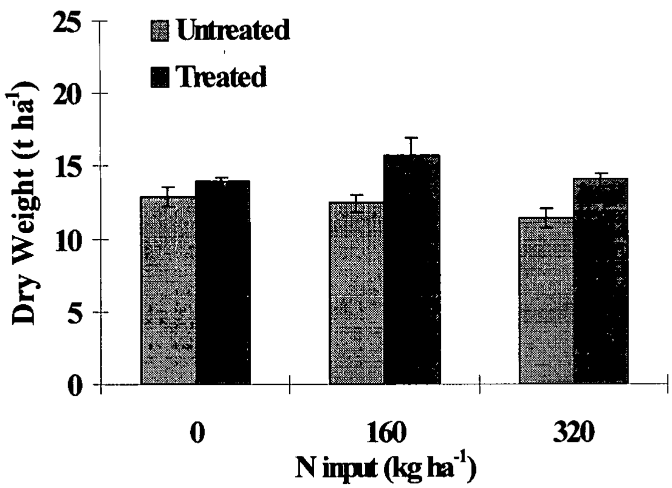



**Figure 3.8.** Total dry weight at GS61 following treatment at three N levels and treated (2.0 dose) and untreated with fungicide

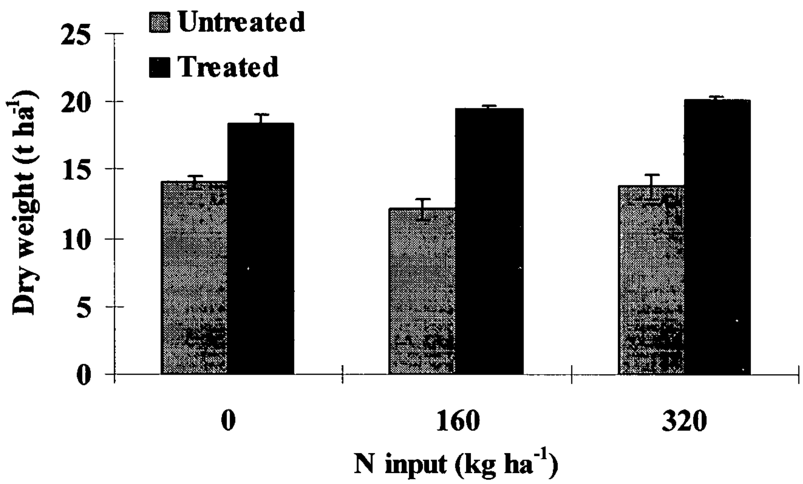



**Figure 3.9.** Total dry weight at GS75 following treatment at three N levels and treated (2.0 dose) and untreated with fungicide

### Grain yield

In 1997 and 1998, grain number per ear was significantly reduced ($P<0.001$) due to disease in the untreated plots as compared with plots treated with any dose of fungicide (Figures 3.10 & 3.11). There was no significant difference in grain number per ear between any of the fungicide treatments. The level of nitrogen input did not significantly effect grain number per ear although in both years there was a slight increase in grain number per ear between the 0 kg N/ha input and all other N input levels, in the fungicide treated plots (Figures 3.10 & 3.11).

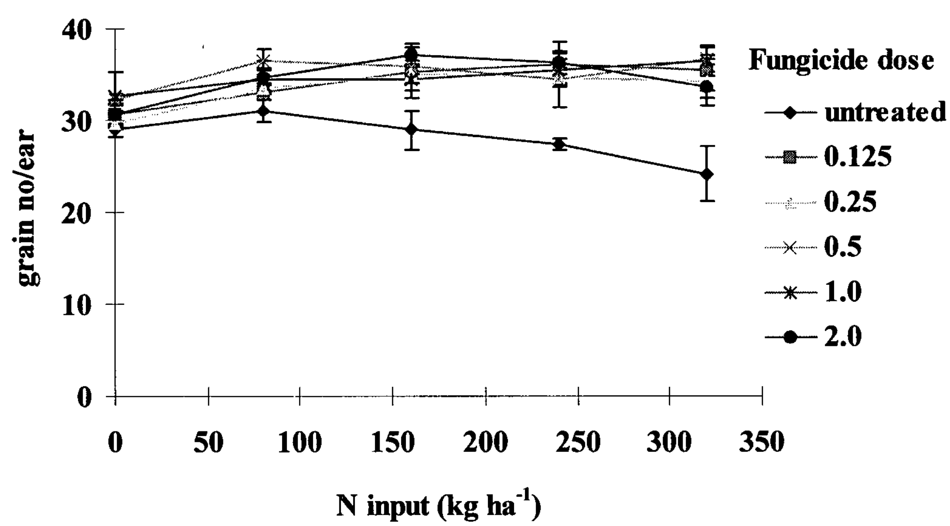



**Figure 3.10.** Grain number per ear at five nitrogen rates treated with six different fungicide doses in 1997.

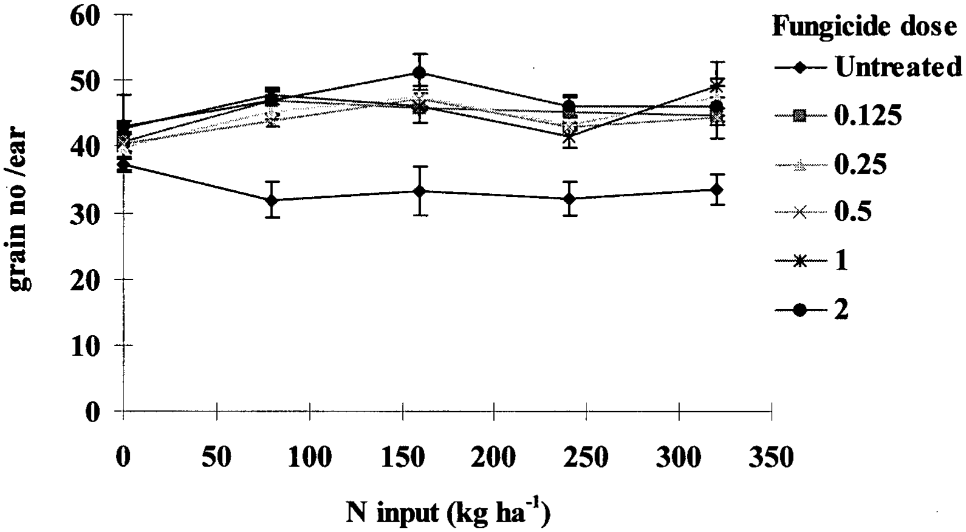



**Figure 3.11.** Grain number per ear at five nitrogen rates treated with six different fungicide doses in 1998.

In 1997 there was no significant difference in thousand grain weight (TGWT) both due to disease, compared with all fungicide doses, and between the five fungicide doses ($P$=0.05) (Figure 3.12). Generally, TGWT decreased with decreasing fungicide dose. Similar results were obtained in 1998 where TGWT was also significantly reduced ($P$=0.05) due to disease (untreated), however, there was no significant difference between fungicide treatments (Figure 3.13). It is interesting to note that TGWT in 1998 was lowest at all N treatments following treatment with 0.125 dose as compared with the other dose levels.

In 1997, TGWT decreased with increasing nitrogen input in contrast to 1998 where no such decrease occurred (Figure 3.12). It is likely that this can be attributed to the crop lodging which occurred in the high N treated plots in 1997.

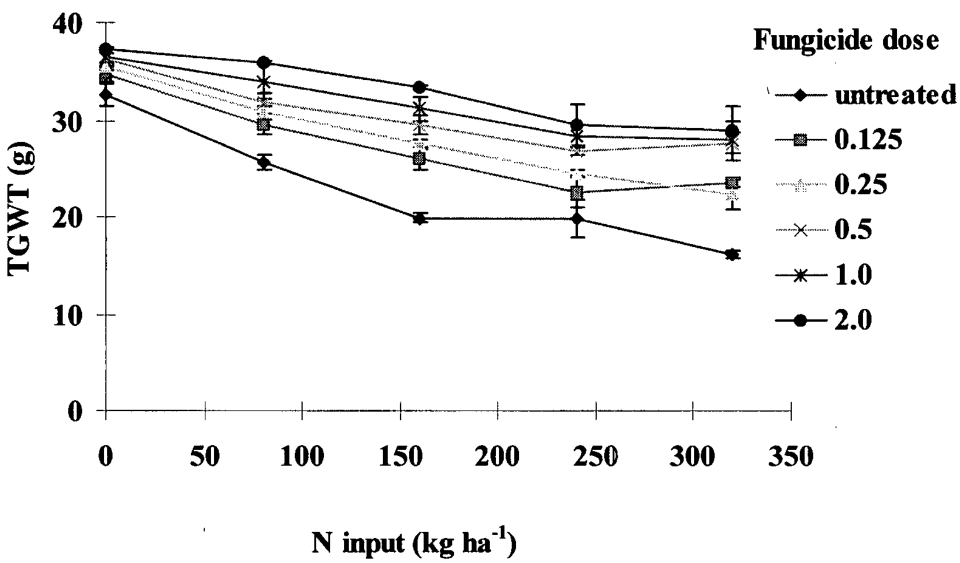



**Figure 3.12.** Thousand grain weight (TGWT) (g) at five nitrogen rates treated with six different fungicide doses in 1997

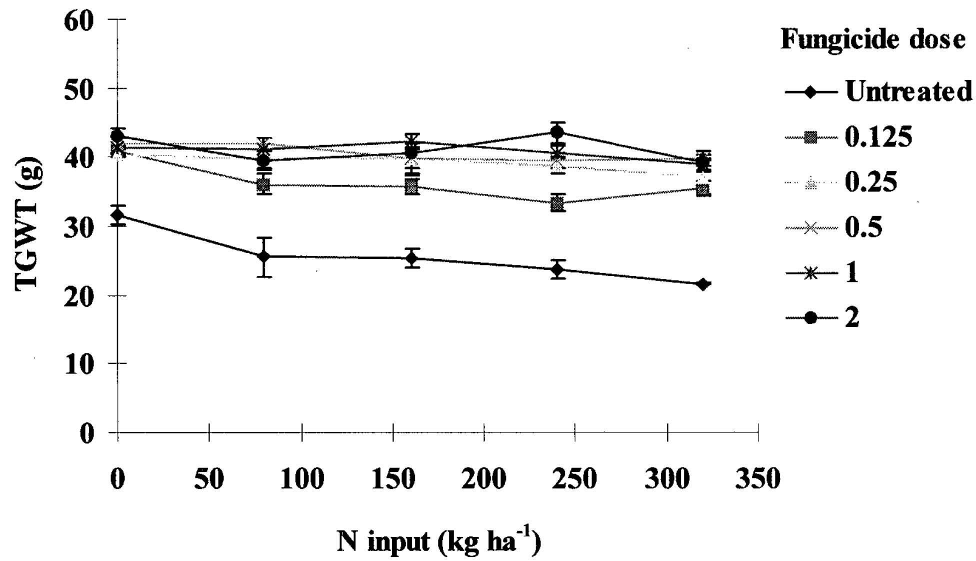



**Figure 3.13.** Thousand grain weight (TGWT) (g) at five nitrogen rates treated with six different fungicide doses in 1998

Yield data in both experimental years was fitted using a linear + exponential (LEXP) curve in the form

$$y = A + B\,(R)^x + Cx$$

The best fit of the data was achieved by keeping R constant and allowing the three remaining parameters, A, B and C, to vary, this approach explained 86.3 % of the variance. The fitted curves for the yield data from 1997 and 1998 are given in Figures 3.14 & 3.15.

In both experimental years the untreated yield decreased with an increase in nitrogen input as a result of the increase in disease severity. Similarly, yield increased with increasing fungicide input, with the highest yield of 7.9 (1997) and 10.4 (1998) t/ha achieved with 2.0 dose of fungicide. In all fungicide treated plots in 1997 and 1998 yield increased to reach an optimum. Although yield then reached a plateau in 1998, yield decreased from the optimum in 1997 probably as a result of the crop lodging already mentioned.

Although optimum yields were achieved with the highest fungicide input, costs will inevitably be increased with an increase in fungicide dose. In order to determine the optimum inputs of both nitrogen and fungicide to achieve maximum profits it was necessary to fit LEXP curves to the profit data. Table 3.4 summarises the optimum nitrogen input (N opt.) for each fungicide dose to achieve maximum profit at that dose.

**Table 3.4.** N Opt. (kg N $ha^{-1}$) and Profit at N Opt. (£) at six fungicide doses in 1997 and 1998.

| | 1997 | | 1998 | |
|---|---|---|---|---|
| Fungicide dose | N Opt. | Profit at N Opt. | N Opt. | Profit at N Opt. |
| Untreated | 17.2 | 323 | 0 | 376.5 |
| 0.125 | 61.3 | 423 | 87 | 567 |
| 0.25 | 72.6 | 438 | 163.5 | 583 |
| 0.5 | 82.0 | 465 | 133.5 | 630 |
| 1.0 | 92.0 | 482 | 161.0 | 650 |
| 2.0 | 92.6 | 461 | 131.0 | 620 |

In both years optimum profit at each fungicide dose was not significantly different although maximum profit was obtained at 1.0 dose in both years. In general, the N Opt. changed according to fungicide dose suggesting that nitrogen input and fungicide dose interact. N Opt. was higher in 1998 than 1997 with maximum profit at 92 and 161 kg N/ha respectively, this is likely to be a result of both differences between varieties and seasonal factors.

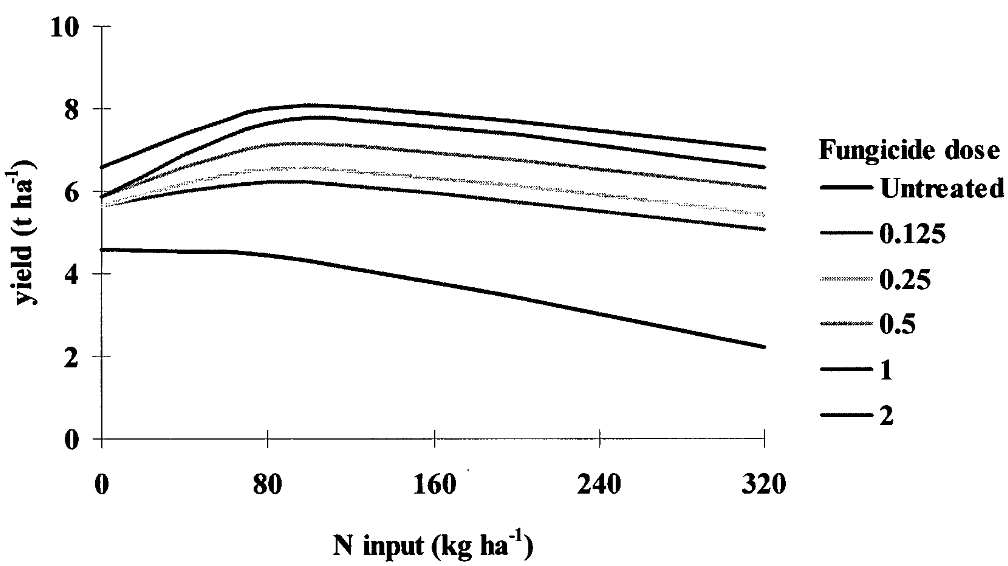



**Figure 3.14.** Yield data (t $ha^{-1}$ @ 85% dry weight) from 1997 fitted with LEXP curves.

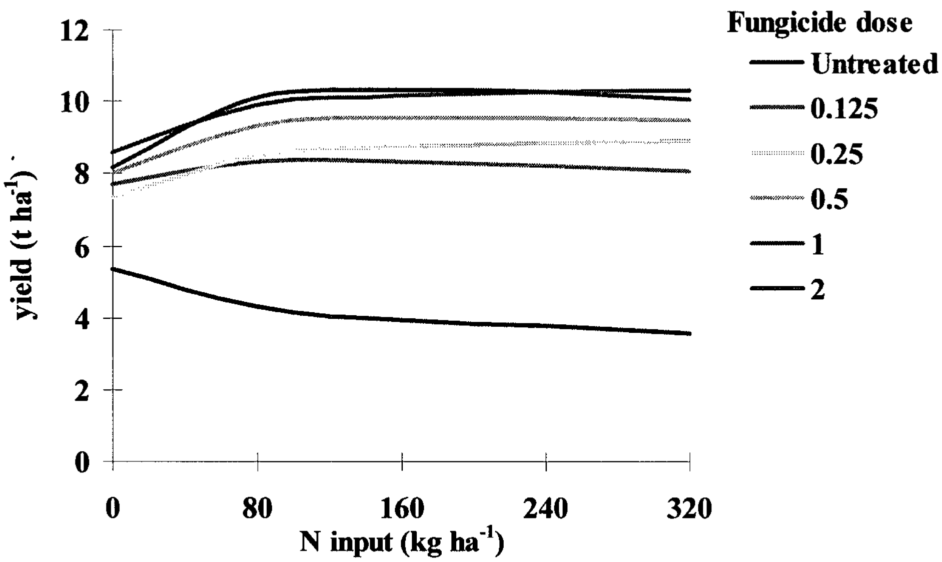



**Figure 3.15.** Yield data (t $ha^{-1}$ @ 85% dry weight) from 1998 fitted with LEXP curves.

**Conclusions**

As in previous studies the severity of yellow rust was found to increase with increasing nitrogen input (Bryson *et al.*, 1997a) (Figure 3.1). Host nutrition also had an influence on mildew severity on an experiment on the winter wheat variety Buster, at ADAS Rosemaund. However, disease levels were generally low and it was not possible to determine whether these differences were significant (Figure 3.2). The effect of host nutrition on the severity of *Septoria* was also investigated on the susceptible variety, Riband. Disease levels reached maxima of 65 and 50 % on leaves 2 and 3. On leaf 3, disease severity was found to increase with increasing nitrogen input although this was not the case on leaf 2 (Figure 3.3). From these data it is not possible to determine whether host nutrition was having a direct effect on mildew or *Septoria* development. It is however possible to hypothesise that host nutrition is more likely to effect the mildew development directly, as it is a biotroph like yellow rust, whereas the structure and microclimate of the canopy (as affected by nitrogen input) is more likely to influence the development of the necrotrophic pathogen, *Septoria.*

In this study, low doses of fungicide were found to provide a good level of disease control against yellow rust. At 0.125 and 0.25 doses disease levels were generally higher in the higher N input treatments on all leaf layers (Figure 3.1) although at dose above 0.5, disease was fully controlled. During the life of this project strains of yellow rust were generally well controlled in most growing situations. However, recent work carried out at NIAB (Rosemary Bayles, Pers. com) has indicated that certain strains of yellow rust are becoming harder to control with conventional fungicide levels. Despite the low levels of *Septoria* present, low fungicide doses were less effective in controlling *Septoria* with symptoms still present on leaves 1, 2 and 3 at doses up to 0.5. *Septoria* symptom levels however did not exceed 5% on any leaf layer following fungicide applications.

In the high fungicide dose treated plots (2.0 dose) canopy increased with increasing nitrogen input with maximum canopy size occurring at GS39. Canopies of GAI 4.2, 5.6 and 6.2 (1997) and 4.5, 6.5 and 7.8 (1998) were recorded following treatment with 0, 160 and 240 kg N/ha respectively. The occurrence of yellow rust in the untreated plots had a major effect on GAI, with this effect increasing with increasing nitrogen input due to the increased levels of severity of the yellow rust symptoms. In

1997, GAI was reduced by 0.7, 1.9 and 1.2 (GS39), 1.9, 4.0 and 3.0 (GS61) and 1.5, 3.9 and 3.8 (GS75) units due to disease at 0, 160 and 320 kg N/ha (Figures 3.4 - 3.6).

Total dry weight in both treated and untreated plots was not significantly different at GS39 but was at GS61 and GS75 (Figures 3.7, 3.8 & 3.9). Differences in total dry matter between 160 and 320 kg N/ha treatments were small, this may have been due to the fact that canopy closure had already been achieved at 160 kg N/ha and further light interception by the 320 kg N/ha canopy had not contributed much more to the total dry matter. Loss in total dry matter at GS75 due to disease increased with increasing N inputs with 2.2, 3.8 and 4.2 t/ha lost in 1997 and 1.2, 4.8 and 5.6 t/ha lost in 1998, in the 0, 160 and 320 kgN/ha treatment respectively (Figure 3.9).

In 1997 and 1998 grain number per ear was significantly reduced due to disease, this is likely to be due to the loss of canopy relatively early in the season resulting in the reduction of sink (grain sites) in the ear. There was no significant difference in grain number per ear in all the fungicide treated plots.

Thousand grain weight (TGWT) in 1997 was significantly different due both to disease and between the five fungicide doses (Figure 3.12). In the presence of disease, and at low fungicide doses the loss of green leaf area is likely to have affected the amount of stored carbohydrate going into the grain during grain filling, hence reducing TGWT. The effect of nitrogen input on TGWT differed between the two experimental years, it was thought likely that the major influence on TGWT in 1997 at the high N rates was due to lodging. In the non- lodged crop of 1998, N input did not have a significant effect on TGWT ( Figures 3.12 & 3.13).

The yield of untreated plots in both 1997 and 1998 reduced as nitrogen inputs increased, this was in line with the increased diseased severity as nitrogen input increased. In order to determine the optimal N input necessary at each fungicide treatment the yield data were fitted using a linear + exponential curve. In 1997, yield curves reached an optimum in the fungicide treated plots and then declined. It is likely that this was due to the lodging that occurred in that year (Figure 3.11). In contrast, in 1998, yield curves reached an optimum and then plateaued (Figure 3.15). In both years yield declined with decreasing fungicide dose. Although disease was not totally controlled at 0.125 and 0.25 dose and severity increased with N input, the percentage of green area affected was not very high. However, in both years maximum canopy size at 160 and 320 kg N/ha was close to the size optimal for light interception with canopies of 5.6 and 6.2 and 6.5 and 7.8 in 1997 and 1998 respectively. It is therefore possible (particularly in 1997) that even relatively small amounts of disease on leaves 1, 2 and 3 would have an effect on final yield. For instance, if the amount of light intercepted by green tissue (Healthy Area Absorption - HAA) in all plots is accumulated from GS39 using Beers law (Bryson *et al.*, 1997b) it is apparent that grain yield is related both to the duration of green tissue as well as the amount of radiation intercepted by it. The regression equation in Figure 3.16 gave an $R^2 = 0.60$. This is not as good a relationship as has been achieved in other studies (Bryson *et al.*, 1997b) however, it must be remembered that the level of lodging in 1997 would have also have effected yield.

In order to determine the economic optimum of both nitrogen input and fungicide dose it was necessary to fit linear + exponential curves to the profit data. Profit was calculated by taking into consideration the cost of nitrogen and fungicide inputs and the value of the grain yield. The data in Table 3.4 show that the nitrogen optimum was higher in 1998 than 1997 with maximum profit at 92 and 161 kg N/ha following 1.0 fungicide dose. It is apparent that despite relatively good disease control at low fungicide doses, in optimal canopy sizes yield is at risk even with low disease levels. Disease control with the application of fungicides is very dependent on product choice, disease occurrence and pressure. However, from this study it is evident that a good disease control strategy is important for good economic returns and that optimal size crop canopies need to be protected in order to achieve their yield potential. The optimal treatment in this situation was 1.0 dose when N was optimum between 92 and 161 kg N/ha.

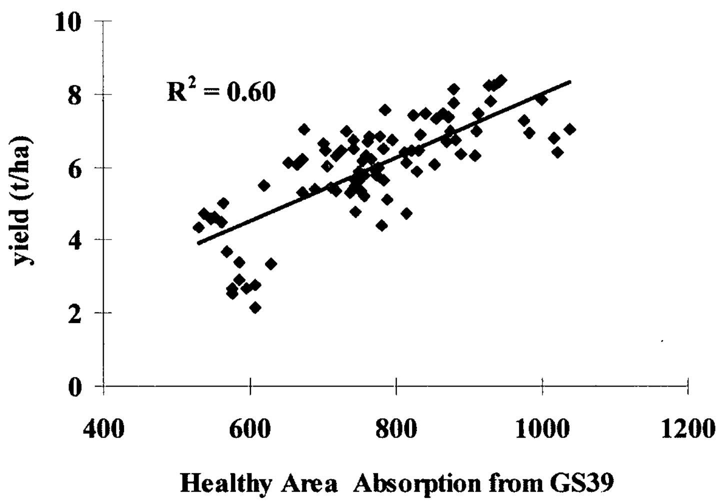



**Figure 3.16.** The relationship of HAA by green tissue (MJ $m^{-2}$) from GS39 with yield (t $ha^{-1}$) in 1997.

## Appendix 4

## REFERENCE CROPS

### INTRODUCTION

One of the principal problems in managing wheat crops is that their growth and development varies considerably between sites and seasons. This has practical consequences as it makes it difficult to predict the timing of agricultural operations, such as application of growth regulators, fungicides and fertilisers. As pressure on costs mounts it becomes more important to time these operations accurately, which in the case of expensive crop treatments can result in more effective application and thus lowered rates of product or the use of less expensive alternatives. This accurate timing is made more difficult by the lack of information on growth and development. Recently, with the publication of the HGCA Wheat Growth Guide and the detailed research reports underlying it there has been a significant advance in the availability of information on the usual timings of growth stages in wheat. The timing information was accompanied by concurrent measurements of the important components of crop growth , thus establishing a system of benchmarks for wheat management. Thus, in strategic planning it is possible to decide the most likely time of farming operations. However, as every farmer knows no two crops are the same and differences in factors such as site, season, sowing date and variety will change the timings required for operations in a particular crop. The acquisition of this information is currently difficult, destructive and labour intensive, but it is expected that on tractor, in field or remote sensing techniques will eventually make this information more readily available on a large scale. However, an important first step will be to see how rapidly provided 'live' information on crop growth and development can better inform on farm decisions, and this is the aim of the current project. A secondary aim was to see how benchmarks may need to be altered to account for variety changes.

### MATERIALS AND METHODS

#### Crop Details

The Reference Crops of Mercia (all years) and Consort (harvest 1997 and 1998) winter wheat were grown with optimal fungicide and fertiliser programmes at Boxworth, Rosemaund and Sutton Bonington. Details of the soil types, previous crops, sowing dates and fertiliser applications are given in Table 4.1 . The only significant factor likely to reduce yield was lodging in the Mercia crop in 1998. Records of crop development, leaf and canopy growth, and dry weights of organs and components of grain yield were collected on each crop starting in mid-February. The methods of data collection described in "How to Run a Reference Crop" (Gay *et al* 1998) were carefully followed in this study. Records were collected much less frequently in Mercia 1997 and 1998.

Table 4.1 Site conditions

| | 1995-6 | | |
|---|---|---|---|
| **Site** | Boxworth | Rosemaund | S. Bonington |
| Altitude (m) | 49 | 75 | 48 |
| Sowing Date | 14 Oct | 9 Oct | 4 Oct |
| Harvest Date | 9 Aug | 19 Aug | 13 Aug |
| Previous Crop | Winter OSR | Winter OSR | Winter Oats |
| Soil Type | Clay loam over chalky boulder clay | Silty clay loam | Strong medium loam to 80 cm over clay |
| % OM | 4.0 | 3.3 | - |
| SMN (0-90 cm, kg/ha) | 90 (Feb) | 150(Feb) | 30 |
| Soil N Supply | 118 | 167 | 61 |
| Total N applied (kg/ha) | 94 | 184 | 185 |
| ***Yield Constraints*** ** | | | |
| Soil pH, P, K, Mg | None | None | None |
| Pest or diseases | None | None | None |
| Weeds | None | None | None |
| Lodging | None | None | None |

| | 1996-7 | | |
|---|---|---|---|
| **Site** | Boxworth | Rosemaund | S. Bonington |
| Altitude (m) | 53 | 92 | 50 |
| Sowing Date | 3 Oct | 30 Sept | 1 Oct |
| Harvest Date | 8 Aug | 19 Aug | 16 Aug |
| Previous Crop | OSR | Winter OSR | Oats |
| Soil Type | Clay loam over chalk | Silty clay loam | Medium loam over sandy loam over clay marl |
| % OM | 3.1 | 2.5 | 5.0 |
| SMN (0-90 cm, kg/ha) | 103 | 75 | 97 |
| Soil N Supply | 108 | 97 | 117 |
| Total N applied (kg/ha) | 168 | 281 | 145 |
| ***Yield Constraints**** | | | |
| Soil pH, P, K, Mg | None | None | None |
| Pests or Diseases | None | None | None |
| Weeds | None | None | None |
| Lodging | None | None | None |

| | 1997-8 | | |
|---|---|---|---|
| **Site** | Boxworth | Rosemaund | S. Bonington |
| Altitude (m) | 53 | 75 | 50 |
| Sowing Date | 5 Oct | 14 Oct | 29 Sept |
| Harvest Date | 18 Aug | 29 Aug | 21 Aug |
| Previous Crop | Winter OSR | Winter Oats | Winter Oats |
| Soil Type | Clay loam over clay, chalk below | Silty clay loam | Sandy clay loam over clay |
| % OM | 4.3 | 2.5 | 4.0 |
| SMN (0-90 cm, kg/ha) | 156 | 91 | 111 |
| Soil N Supply | 207 | 102 | 129 |
| Total N applied (kg/ha) | 100 | 190 | 170 |
| ***Yield Constraints*** | | | |
| Soil pH, P, K, Mg etc | None | P 12mg/l | Early Mn deficiency on Consort |
| Pests or Diseases | Aphids | None | None |
| Weeds | None | None | None |
| Lodging | Severe in Mercia | None | None |

* Yield constraints : Soil analysis: pH<6, P <15 mg/l (Index 0), K <120 mg/l (Index 0), Mg <20 mg/l; Pests, Diseases, Weeds and Lodging judged to have been of sufficient extent to cause a possible yield loss of >5%.

**The Weather**

Here the weather is summarised mainly by comparison with the long term averages for rainfall, temperature and sunshine hours given in Table 4.2 with the comparisons in Tables 4.3, 4.4 and 4.5. However since sunshine hours are no longer recorded at Boxworth solar radiation records are also presented for all sites in Table 4.6. Long term records of solar radiation are available for only one of the sites, so are not used for comparison.

*1995-6*

Total rainfall in the 1995-6 season was lower than average, but September and February had well above average rainfall. Generally, from March to July when main canopy development and growth were occurring there was lower than average rainfall. However, there was noticeably more even distribution of rainfall at Rosemaund. Temperatures in December, February, March and May were below long term averages for all sites but October and November were relatively warm. Sunshine hours for Rosemaund and Sutton Bonington were similar to long term averages. Solar radiation was usually highest at Boxworth and lowest at Rosemaund. At Sutton Bonington solar radiation was usually between that of the other sites except in November and December when it was higher than at Boxworth.

*1996-7*

Rainfall was again below the long term averages, particularly at Boxworth. At all sites there was a noticeably dry September and fairly wet November and February. As in the previous season March and April were dry at all sites. May was dry at Boxworth but average rainfall was received at other sites. June was wet with all sites having about twice their normal rainfall, but July was noticeably dry at Rosemaund and Boxworth. Temperatures in 1996-7 were noticeable for a relatively cold November, December and January, followed by a warmer than usual February and March. In general there were only small deviations from this overall pattern at individual sites. Sunshine hours were lower than average in January and June and high in November , May and July. Overall solar radiation was higher than in the previous season, with higher monthly averages from September to January and again from March to May but lower values from June to August. Again the highest values were achieved at Boxworth and the lowest values at Rosemaund with intermediate values at Sutton Bonington. The only exception to this pattern was in April when solar radiation was higher at Rosemaund than Sutton Bonington.

*1997-8*

In contrast to the previous seasons in this study February was drier than usual, with March April and June all being relatively wet with all sites having a similar pattern of rainfall in relation to their long term averages. Temperatures were well above average from October to March, before returning to average values for the rest of the year, except for a slightly warmer May. Compared with the long term averages sunshine hours at Rosemaund and Sutton Bonington were low in November, March, June and July and higher in February. Solar radiation was generally lower than in the previous two seasons, and with a few exceptions followed the order of Boxworth highest, Sutton Bonington intermediate and Rosemaund Lowest.

Table 4.2. Long term average weather records from the reference sites for 1961-1990

| Site | Boxworth | Rosemaund | Sutton Bonington | Average |
|---|---|---|---|---|
| September | 46 | 58 | 49 | 51 |
| October | 48 | 57 | 48 | 51 |
| November | 51 | 59 | 52 | 54 |
| December | 50 | 66 | 56 | 57 |
| January | 45 | 62 | 50 | 52 |
| February | 35 | 46 | 43 | 41 |
| March | 44 | 52 | 45 | 47 |
| April | 45 | 46 | 46 | 46 |
| May | 50 | 55 | 47 | 51 |
| June | 53 | 51 | 55 | 53 |
| July | 44 | 47 | 48 | 46 |
| August | 56 | 54 | 61 | 57 |
| Total | 567 | 653 | 600 | 607 |

| | Temperature (°C) | | | |
|---|---|---|---|---|
| Site | Boxworth | Rosemaund | Sutton Bonington | |
| September | 14.1 | 13.1 | 13.5 | 13.6 |
| October | 10.9 | 10.1 | 10.4 | 10.5 |
| November | 6.3 | 6.2 | 6.3 | 6.3 |
| December | 4.3 | 4.3 | 4.4 | 4.3 |
| January | 3.3 | 3.5 | 3.6 | 3.5 |
| February | 3.4 | 3.6 | 3.7 | 3.6 |
| March | 5.5 | 5.5 | 5.6 | 5.5 |
| April | 7.7 | 7.7 | 7.8 | 7.7 |
| May | 11.0 | 10.7 | 10.9 | 10.9 |
| June | 14.2 | 13.7 | 14 | 14.0 |
| July | 16.2 | 15.7 | 15.8 | 15.9 |
| August | 16.3 | 15.4 | 15.7 | 15.8 |
| Average | 9.4 | 9.1 | 9.3 | 9.3 |

| | Sunshine (hours) | | | |
|---|---|---|---|---|
| Site | Boxworth | Rosemaund | Sutton Bonington | |
| September | 144 | 132 | 133 | 136.3 |
| October | 108 | 91 | 97 | 98.7 |
| November | 67 | 64 | 60 | 63.7 |
| December | 46 | 45 | 42 | 44.3 |
| January | 54 | 51 | 48 | 51.0 |
| February | 68 | 64 | 62 | 64.7 |
| March | 108 | 107 | 102 | 105.7 |
| April | 142 | 144 | 129 | 138.3 |
| May | 192 | 182 | 178 | 184.0 |
| June | 194 | 184 | 172 | 183.3 |
| July | 184 | 187 | 173 | 181.3 |
| August | 179 | 170 | 169 | 172.7 |
| Total | 1486 | 1422 | 1363 | 1423.7 |

Table 4.3. Rainfall at the reference sites as percentage of long term site mean

| | 1996 | | | | 1997 | | | | 1998 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | BX | RM | SB | **Mean** | BX | RM | SB | **Mean** | BX | RM | SB | **Mean** |
| September | 201 | 139 | 170 | **168** | 1 | 37 | 14 | **19** | 34 | | 24 | **27** |
| October | 41 | 87 | 44 | **59** | 75 | 126 | 96 | **101** | 97 | 13 | 82 | **61** |
| November | 107 | 97 | 101 | **101** | 142 | 100 | 148 | **128** | 70 | 147 | 138 | **120** |
| December | 119 | 110 | 130 | **119** | 64 | 47 | 86 | **64** | 116 | 61 | 80 | **83** |
| January | 97 | 91 | 53 | **81** | 25 | 16 | 37 | **25** | 110 | 144 | 182 | **146** |
| February | 153 | 134 | 106 | **130** | 109 | 157 | 117 | **129** | 13 | 35 | 20 | **24** |
| March | 41 | 133 | 55 | **80** | 16 | 44 | 31 | **31** | 109 | 115 | 129 | **118** |
| April | 26 | 114 | 69 | **70** | 19 | 75 | 46 | **47** | 211 | 310 | 215 | **246** |
| May | 37 | 77 | 43 | **54** | 69 | 109 | 97 | **92** | 31 | 27 | 41 | **33** |
| June | 52 | 44 | 57 | **51** | 284 | 193 | 208 | **228** | 218 | 188 | 231 | **213** |
| July | 91 | 61 | 63 | **71** | 55 | 33 | 90 | **60** | 39 | 47 | 37 | **41** |
| August | 97 | 97 | 95 | **96** | 90 | 196 | 78 | **119** | 30 | 33 | 75 | **47** |
| Total | 87 | 99 | 83 | **90** | 82 | 92 | 89 | **88** | 91 | 0 | 106 | **95** |

Table 4.4. Temperature at the reference sites as a percentage of the long term mean

| | 1996 | | | | 1997 | | | | 1998 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | bx | rm | sb | **av** | bx | rm | sb | **av** | bx | rm | sb | **av** |
| September | 99 | 102 | 100 | **100** | 99 | 104 | 101 | **101** | 109 | | 104 | **108** |
| October | 123 | 124 | 121 | **123** | 108 | 115 | 112 | **112** | 91 | 74 | 93 | **86** |
| November | 121 | 118 | 119 | **119** | 88 | 90 | 89 | **89** | 130 | 133 | 134 | **132** |
| December | 30 | 44 | 43 | **39** | 52 | 65 | 63 | **60** | 119 | 132 | 135 | **129** |
| January | 98 | 120 | 106 | **108** | 40 | 59 | 58 | **53** | 144 | 146 | 146 | **145** |
| February | 60 | 58 | 67 | **62** | 194 | 195 | 190 | **193** | 207 | 199 | 204 | **203** |
| March | 68 | 82 | 72 | **74** | 159 | 152 | 149 | **153** | 145 | 149 | 141 | **145** |
| April | 108 | 110 | 106 | **108** | 116 | 116 | 114 | **115** | 106 | 94 | 100 | **100** |
| May | 80 | 85 | 84 | **83** | 111 | 104 | 102 | **106** | 117 | 122 | 113 | **118** |
| June | 106 | 101 | 101 | **103** | 102 | 102 | 100 | **102** | 102 | 104 | 103 | **103** |
| July | 107 | 106 | 106 | **106** | 103 | 107 | 106 | **105** | 100 | 99 | 99 | **99** |
| August | 107 | 106 | 108 | **107** | 124 | 124 | 122 | **123** | 99 | 102 | 105 | **102** |
| average | 99 | 101 | 100 | **100** | 112 | 111 | 108 | **109** | 112 | 107 | 113 | **111** |

Table 4.5. Sunshine hours at the reference sites as a percentage of the long term mean

| | 1996 | | | | 1997 | | | | 1998 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | bx | rm | sb | **av** | bx | rm | sb | **av** | bx | rm | sb | **av** |
| September | | 69 | 84 | **74** | | 97 | 84 | **88** | | | 113 | **111** |
| October | | 109 | 138 | **118** | | 102 | 123 | **107** | | 74 | 120 | **93** |
| November | | 112 | 115 | **110** | | 124 | 139 | **128** | | 67 | 68 | **66** |
| December | | 89 | 93 | **89** | | 83 | 99 | **89** | | 87 | 94 | **89** |
| January | | 35 | 30 | **31** | | 51 | 73 | **60** | | 79 | 86 | **80** |
| February | | 127 | 121 | **121** | | 89 | 118 | **100** | | 122 | 155 | **135** |
| March | | 49 | 44 | **46** | | 97 | 125 | **109** | | 67 | 76 | **71** |
| April | | 81 | 100 | **89** | | 119 | 106 | **111** | | 82 | 85 | **83** |
| May | | 96 | 87 | **90** | | 119 | 138 | **126** | | 113 | 96 | **103** |
| June | | 124 | 114 | **116** | | 56 | 67 | **59** | | 56 | 67 | **59** |
| July | | 121 | 127 | **123** | | 121 | 118 | **119** | | 70 | 86 | **77** |
| August | | 103 | 101 | **100** | | 97 | 108 | **101** | | 103 | 119 | **109** |
| Total | | 97 | 100 | **96** | | 99 | 108 | **101** | | 76 | 96 | **84** |

Table 4.6. Solar radiation average daily MJ $m^{-2}$ at the reference sites.

| | 1996 | | | | 1997 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | bx | rm | sb | **av** | bx | rm | sb | **av** | bx | rm | sb | **av** |
| September | 9.46 | 7.79 | 8.76 | **8.67** | 9.86 | 9.32 | 9.23 | **9.47** | 11.60 | | 10.22 | **10.91** |
| October | 7.30 | 5.39 | 6.61 | **6.43** | 7.17 | 4.84 | 6.25 | **6.09** | 6.78 | 5.05 | 6.17 | **6.00** |
| November | 3.09 | 2.63 | 3.07 | **2.93** | 3.61 | 2.95 | 3.30 | **3.29** | 2.92 | 2.04 | 2.43 | **2.46** |
| December | 1.68 | 1.22 | 1.71 | **1.53** | 1.98 | 1.51 | 1.86 | **1.78** | 1.73 | 1.22 | 1.75 | **1.57** |
| January | 1.86 | 1.23 | 1.54 | **1.54** | 2.36 | 1.78 | 2.12 | **2.09** | 2.55 | 1.59 | 2.25 | **2.13** |
| February | 4.94 | 4.15 | 4.73 | **4.61** | 4.40 | 3.44 | 4.30 | **4.05** | 6.25 | 4.03 | 5.34 | **5.20** |
| March | 6.77 | 5.36 | 5.72 | **5.95** | 9.91 | 7.62 | 8.69 | **8.74** | 7.45 | 5.95 | 6.97 | **6.79** |
| April | 13.20 | 10.66 | 11.97 | **11.94** | 13.97 | 12.06 | 10.95 | **12.33** | 11.63 | 10.78 | 10.85 | **11.09** |
| May | 16.01 | 15.39 | 14.76 | **15.39** | 19.26 | 15.49 | 18.45 | **17.74** | 17.60 | 17.01 | 16.41 | **17.01** |
| June | 21.12 | 19.41 | 19.92 | **20.15** | 16.12 | 12.10 | 14.10 | **14.11** | 15.39 | 12.75 | 14.01 | **14.05** |
| July | 18.64 | 18.48 | 19.03 | **18.72** | 17.86 | 15.28 | 17.63 | **16.92** | 16.09 | 13.63 | 15.76 | **15.16** |
| August | 14.52 | 14.05 | 14.16 | **14.24** | 15.20 | 11.02 | 14.01 | **13.41** | 16.04 | 15.07 | 15.22 | **15.44** |
| Total | 118.59 | 105.75 | 111.96 | **112.10** | 121.72 | 97.41 | 110.89 | **110.01** | 116.04 | 89.12 | 107.37 | **104.17** |

## RESULTS AND DISCUSSION

### Crop Development

One of the practical problems in managing wheat crops is the difficulty of ensuring timeliness of operations such as application of herbicides, growth regulators and crop protectants that are required at specific growth stages. The publication of benchmark values for these growth stages in the Wheat Growth Guide (Sylvester-Bradley *et al*, 1997) based on previous reference crops is of considerable use in planning the management of crops. However, there is a remaining difficulty that there is significant variation in the dates of growth stages, due to factors affecting individual crops such as varietal, seasonal and weather factors. If the ranges of dates in the previous reference crops are examined they varied by over 60 days for the earlier growth stages, and by up to 30 days for the later growth stages (Table 4.8). This large range is partly due to the inclusion of crops from the more northerly site used previously, but even if only range of the middle the middle 50% of the crops encountered is considered there is a 17 day range (Table 4.8). The practical consequence of this is that future reference crops could provide useful information on how far advanced or retarded crops in a particular season are. The application of this approach was tested here by comparing the dates determined for the growth stages in the 1996-1998 reference crops. At growth stage 30 none of the crops was earlier or later than the previous reference crops. However, if the narrower window from 25 to 75% of the previous reference crops is considered, four of the nine current crops (Sutton Bonington in 1997 and all crops in 1998) reached GS30 earlier than this. By GS31 the number of crops outside this middle window is only two (Sutton Bonington 1997 and Boxworth 1998) and this was reduced to one (Sutton Bonington 1997) by GS39. Thus, the most likely time for finding much earlier growth stages, which will result in missed opportunities for spraying is early in the life of the crop. This is probably a result of the much greater effect of variations in overwinter weather on crop development in this early phase. The robustness of the previous reference crops in establishing the extreme dates for the growth stages was well demonstrated by the 1996-8 crops, since in over 50 growth stage assessments only one date (GS59 for Rosemaund in 1997 which was 5 days earlier) was outside the range encountered in any of the previous crops. Thus the "earliest" dates bin Table 4.8 give latest target dates for the start of growth stage assessments. However it should be borne in mind that for crops sown earlier than those here, or after particularly mild winters earlier assessments may be necessary.

Table 4.7. Dates of growth stages in reference crops at three sites between 1996 and 1998.

| Growth Stage | 1996 Mercia | | | 1997 Consort | | | 1998 Consort | | |
|---|---|---|---|---|---|---|---|---|---|
| | BX | RM | SB | BX | RM | SB | BX | RM | SB |
| **30** | 09-Apr | 09-Apr | 10-Apr | *08-Apr* | 01-Apr | 01-Apr | *28-Mar* | 30-Mar | 30-Mar |
| **31** | 22-Apr | 22-Apr | 22-Apr | 14-Apr | 14-Apr | 07-Apr | 30-Mar | 14-Apr | 20-Apr |
| **39** | 27-May | 25-May | 27-May | 19-May | 18-May | 15-May | 18-May | 19-May | 21-May |
| **59** | **08-Jun** | **06-Jun** | **10-Jun** | **05-Jun** | **28-May** | | **06-Jun** | **08-Jun** | **10-Jun** |
| **61** | **12-Jun** | 16-Jun | **24-Jun** | **10-Jun** | **05-Jun** | 11-Jun | **10-Jun** | **15-Jun** | **16-Jun** |
| **71** | | | | 16-Jun | | 17-Jun | 22-Jun | | 29-Jun |
| **87** | *31-Jul* | *02-Aug* | 29-Jul | *02-Aug* | 28-Jul | *31-Jul* | 27-Jul | 03-Aug | 10-Aug |
| **harvest** | 09-Aug | 19-Aug | 13-Aug | 08-Aug | 19-Aug | 16-Aug | 18-Aug | 29-Aug | 21-Aug |

Notes:

Dates taken from weekly records except before mid April when records were fortnightly, and bold records taken at 2 day intervals. Italic values were estimated.

Table 4.8. Dates of occurrence of growth stages in previous reference crops of Mercia

| Growth stage | Date of Growth stage | | | | | Interval days between | |
|---|---|---|---|---|---|---|---|
| | Earliest | having occurred in given percentage of crops | | | Latest | 25 and 75% of crops reaching growth stage | earliest and latest occurrence of growth stage |
| | | 25% | 50% | 75% | | | |
| 30 | 12-Mar | 05-Apr | 14-Apr | 22-Apr | 09-May | 17 | 58 |
| 31 | 26-Mar | 12-Apr | 22-Apr | 28-Apr | 24-May | 17 | 59 |
| 39 | 08-May | 18-May | 23-May | 28-May | 09-Jun | 10 | 32 |
| 59 | 02-Jun | 06-Jun | 11-Jun | 18-Jun | 03-Jul | 13 | 31 |
| 61 | 03-Jun | 09-Jun | 15-Jun | 18-Jun | 03-Jul | 10 | 30 |
| 71 | 16-Jun | 23-Jun | 26-Jun | 30-Jun | 14-Jul | 7 | 28 |
| 87 | 19-Jul | 24-Jul | 28-Jul | 01-Aug | 22-Aug | 8 | 34 |

## Leaf and Shoot Production

The progress of leaf production is shown in Fig 4.1. Final number of leaves produced varied from 11 to 14 and was in the range found in the previous reference crops. The number of leaves present in mid-February varied from two to eight, the higher number increasing the range from that found in the previous reference crops. This is probably a consequence of better autumn establishment conditions and milder winters than previously.

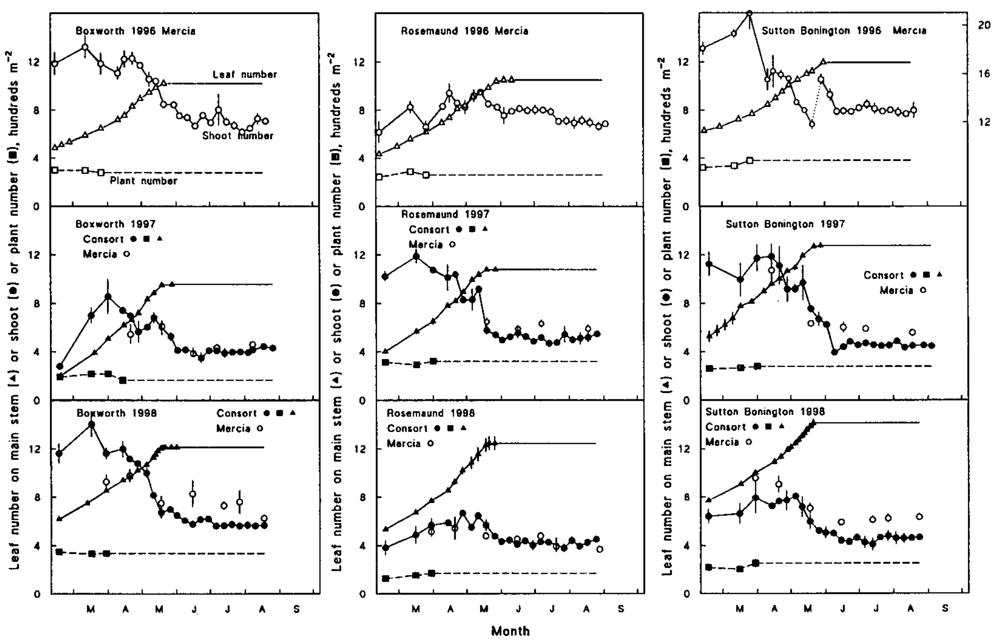



*Fig. 4.1. Time course of leaf number on mainstem (▲) and shoot number per $m^2$ (●) or plant number per $m^2$ (■) for Mercia (open symbols) or Consort (closed symbols) grown at three sites in harvest years 1996, 1997 and 1998. Vertical bars are standard error of mean. The right hand axis scale should be used for shoot number (hundreds $m^{-2}$) Mercia 1996 before the end of May as shown by the dotted line.*

Shoot production again showed the very variable patterns as in the previous reference crops. Particularly noticeable was the very high shoot number in Mercia at Sutton Bonington of about 2100 shoots $m^{-2}$ in 1996 which considerably exceeded previous maxima. of 1400 shoots $m^{-2}$. Again there was often considerable over production of shoots followed by considerable shoot death. However in some crops (Rosemaund and Sutton Bonington in 1998) lower numbers of shoots were produced and thus shoot death was considerably reduced. By the end of the season 400 to 600 shoots $m^{-2}$ survived to produce ears except for the very dense crop at Sutton Bonington where over 750 shoots $m^{-2}$ formed ears. Generally the shoot production patterns in Consort were similar to those of Mercia although there were some differences in detail.

**Nitrogen uptake and Distribution**

As in the previous reference crops, nitrogen uptake by the crop was between 200 and 300 kg ha$^{-1}$ (Fig 4.2) Most of the nitrogen was acquired during vegetative growth with only three of the sites (Boxworth 1997 and Rosemaund 1997 and 1998) seeming to acquire much nitrogen during ear growth. As before high shoot numbers early in the season seemed associated with higher early season nitrogen uptake. The patterns of nitrogen uptake and distribution were similar in Mercia and Consort.

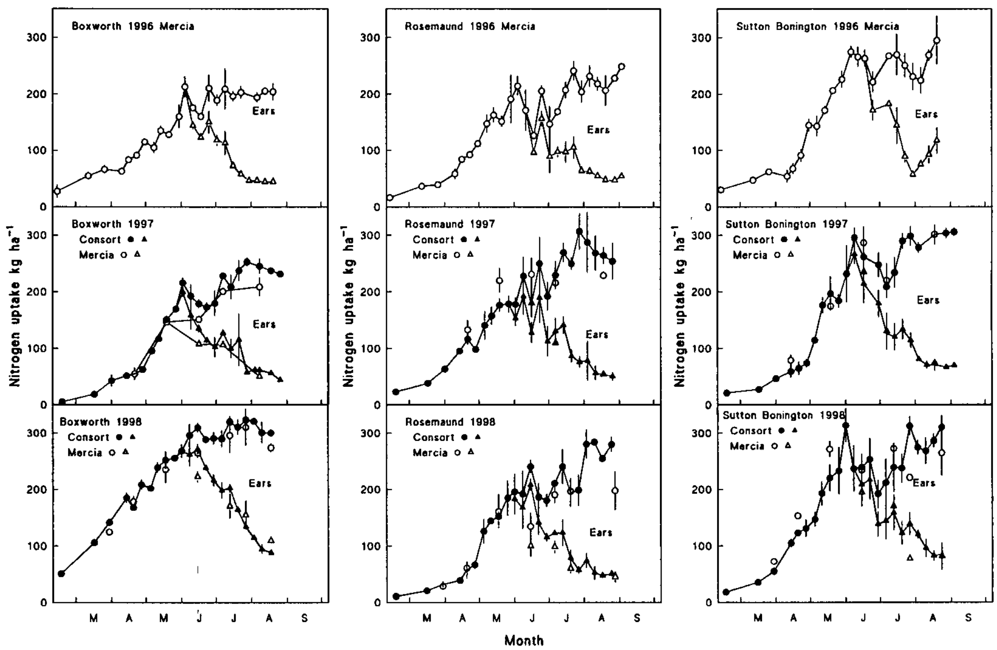



*Fig. 4.2. Time course of nitrogen uptake by whole crop (●) or straw (▲) for Mercia (open symbols) or Consort (closed symbols) grown at three sites in harvest years 1996, 1997 and 1998. Vertical bars are standard errors of mean.*

**Canopy expansion and Senescence**

The progress curves for canopy production and senescence (Fig 4.3) emphasised the similarity of all of the Sutton Bonington Crops to the median. At Boxworth in 1996 canopy production was initially high but maximum canopy size was lower than the median, presumably because of shortage of water restricting leaf growth. Canopy development was slow at Boxworth in 1998 and GAI was low throughout. In contrast at the same site in 1998 a much larger and earlier canopy was produced. This suggests that canopy production at Boxworth was reduced in the two successively drier years of 1997 and 1998 but a wetter year following a mild winter (1998) resulted in a much larger canopy. At Rosemaund in 1996 canopy development was earlier and maximum size was greater than the median and canopy senescence was slow. .In 1997 at Rosemaund the canopy was produced earlier and had a higher maximum value than the median. Canopy production was close to the median but senescence was delayed at Rosemaund in 1998. Overall canopy production was very similar in Mercia and Consort but the impression in 1997 that senescence was earlier in Mercia was confirmed in 1998.

**Dry matter accumulation and distribution**

The time courses of dry weight accumulation with time were generally similar to the median but with a significantly early start and higher values at Boxworth in 1998 and Rosemaund in 1997. These crops which started accumulation of dry weight earlier had reached a GAI of three earlier than the other crops. The point at which GAI reaches three this is usually taken to signify the start of the "grand" growth phase where the growth rate of the crop becomes approximately constant with time. However, in these early crops growth rates were lower than achieved in the later parts of the grand growth phase. Thus it would seem that the benefits of producing a canopy with a GAI greater than three are successively reduced the earlier this point is reached. Crops at Rosemaund also tended to continue dry weight accumulation for longer, an effect also noted at Sutton Bonington in 1998. In general the rates of ear growth were very similar but in higher yielding crops duration of growth was longer.

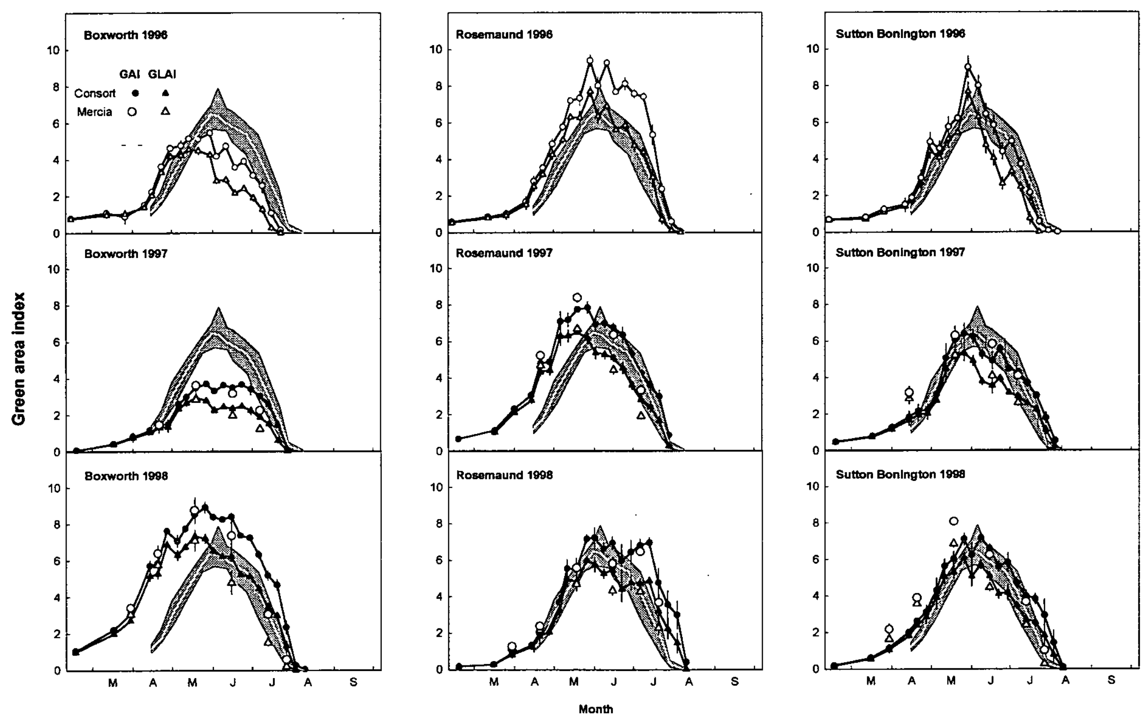



*Fig. 4.3. Time course of green area index (●) or green lamina area index (▲) for Mercia (open symbols) and Consort (closed symbols) grown at three sites in harvest years 1996, 1997 and 1998. The upper and lower limits of the shaded area show upper and lower quartiles and the white line dividing the two areas is the median, from previous reference crops. Vertical bars are standard errors of mean.*

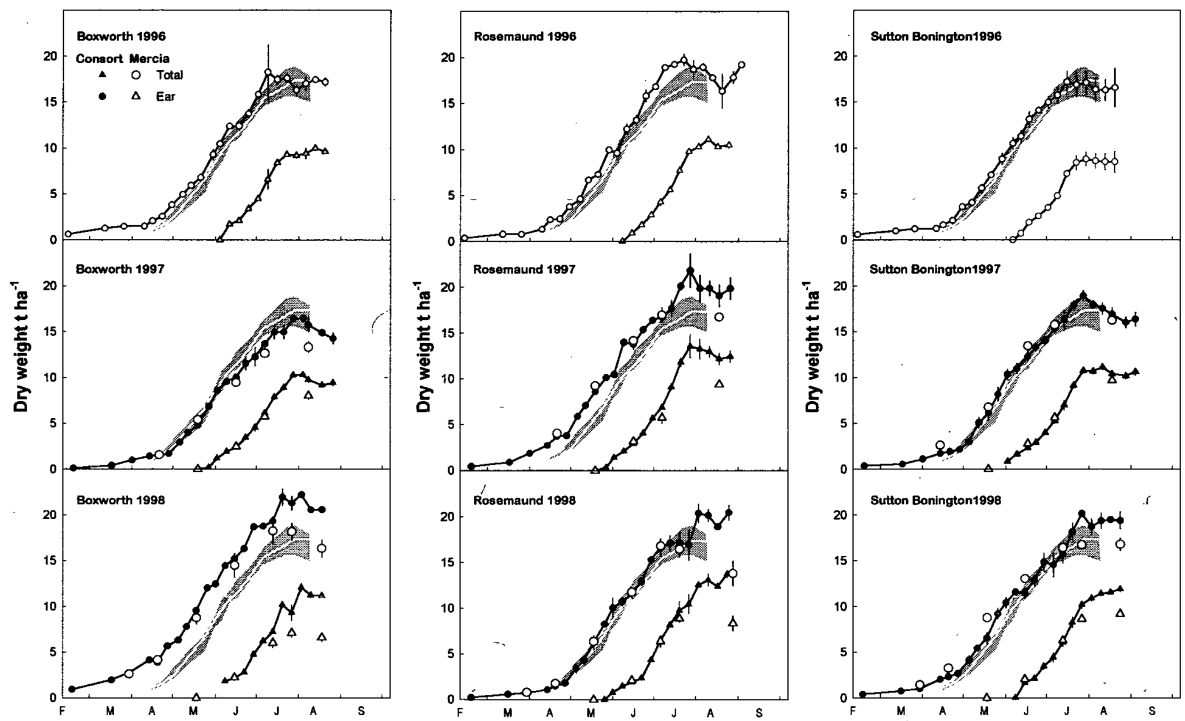



*Fig. 4.4. Time course of total above ground (●) and ear (▲)dry weight for Mercia (open symbols) and Consort (closed symbols) grown at three sites in harvest years 1996, 1997 and 1998. The upper and lower limits of the shaded area show upper and lower quartiles and the white line dividing the two areas is the median, from previous reference crops. Vertical bars are standard errors of mean*

### Grain Filling

The time course of grain filling and moisture content of the central grains on the ear is shown in Fig. 4.5. It appeared that grain filling had finished in most crops by the end of July, which coincided with the end of ear growth (Fig 4.4). In all crops once fresh weight of the grain started to fall no further increase in dry weight occurred. The maximum fresh weight per grain in Mercia was higher at 80mg at Boxworth in 1996 than in the previous reference crops. In Consort all maximum fresh weights per grain were higher than they had been in the current and previous Mercia crops, ranging from 83 to 109 mg. However the range of values of dry weight per grain were very similar in Mercia and Consort at between 40 and 60mg.

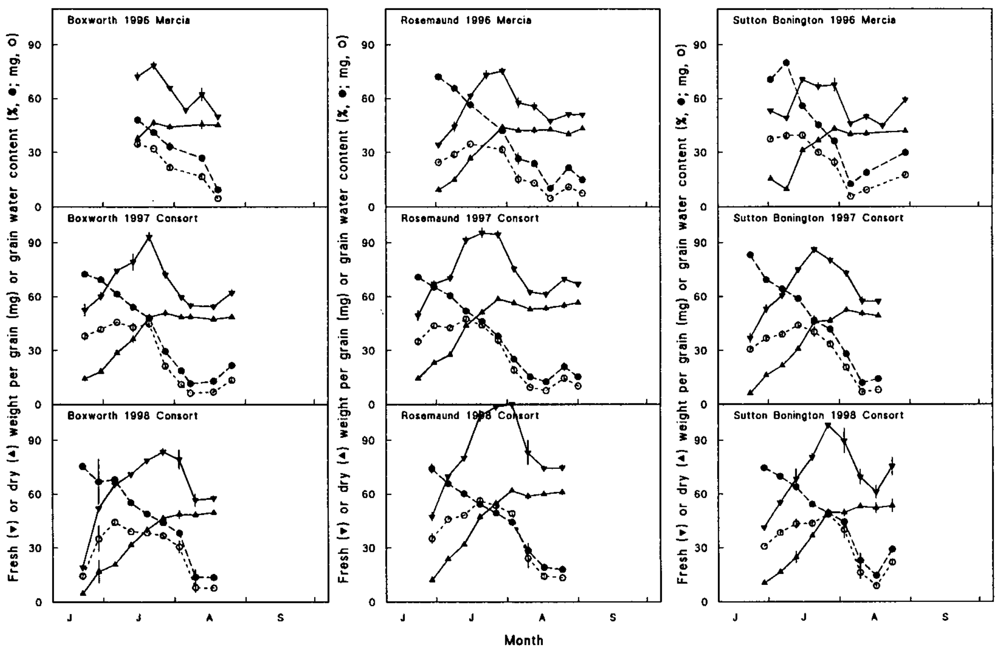



*Fig. 4.5. Time course of filling and drying of central grains in the ear. Water content(%,* ●; mg per grain, O*), dry (▲) and fresh (▼) weight mg per grain for Mercia (1996) or Consort (1997 and 1998) grown at three sites in harvest years 1996, 1997 and 1998. Vertical bars are standard errors of mean.*

## Final Crop Performance

### Grain Yield

The range of values for grain yield of Mercia fall within the range achieved in the previous reference crops except at Boxworth in 1998 when lodging greatly reduced yield (Table 4.9). The yield of Mercia was always less than that of the more recent variety Consort, with an average advantage of 2.5 t ha$^{-1}$. In contrast to the previous reference crops it was noticeable that yields at Rosemaund were higher in all seasons for both varieties. Because of the change in varieties it is difficult to compare between seasons , but there is an indication of lower overall yields in 1997.

As well as the combine harvesting plots were also hand harvested to determine yields on a plot basis (Table 4.10). As was expected there was some variability between the two estimates and the errors tended to be largest when the quadrat harvesting had a large standard error. The overall range of values from quadrat harvests was similar to that achieved in previous reference crops.

Table 4.9. Combine harvested yield (t/ha, 15% moisture) from three sites in three seasons.

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| **Mercia** | | | |
| Boxworth | 9.5 | 7.6 | 6.1**L** |
| Rosemaund | 10.0 | 9.0 | 9.8 |
| Sutton Bonington | 8.3 | 8.0 | 8.6 |
| **Consort** | | | |
| Boxworth | na | 9.5 | 10.3 |
| Rosemaund | na | 11.8 | 12.7 |
| Sutton Bonington | na | 9.7 | 11.9 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 0.06 | 0.13 | 0.17 |
| Rosemaund | 0.13 | 0.06 | 0.13 |
| Sutton Bonington | 0.20 | 0.07 | 0.08 |
| **Consort** | | | |
| Boxworth | na | 0.12 | 0.24 |
| Rosemaund | na | 0.09 | 0.27 |
| Sutton Bonington | na | 0.17 | 0.22 |

Notes: na data not collected

**L** Crop lodged 8 June

Table 4.10. Grain yield for three sites in three seasons from quadrats harvested by hand at the time of combine harvesting.

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| ***Yield tonnes per hectare 100% dry matter*** | | | |
| **Mercia** | | | |
| Boxworth | 8.35 | 6.16 | 5.78**L** |
| Rosemaund | 8.95 | na | 6.69 |
| Sutton Bonington | na | 8.00 | 7.43 |
| **Consort** | | | |
| Boxworth | na | 7.59 | 8.98 |
| Rosemaund | na | 11.73 | 11.40 |
| Sutton Bonington | na | 8.71 | 10.01 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 0.64 | 0.57 | 0.40 |
| Rosemaund | 0.83 | na | 0.89 |
| Sutton Bonington | na | 0.38 | 0.19 |
| **Consort** | | | |
| Boxworth | na | 0.11 | 0.22 |
| Rosemaund | na | 1.34 | 0.30 |
| Sutton Bonington | na | 0.28 | 0.27 |
| ***Hand harvested less combine harvested grain yield tonnes per hectare at 100% dry matter*** | | | |
| **Mercia** | | | |
| Boxworth | 0.28 | -0.30 | na |
| Rosemaund | 0.45 | na | -1.64 |
| Sutton Bonington | na | 1.20 | 0.12 |
| **Consort** | | | |
| Boxworth | na | -0.48 | 0.23 |
| Rosemaund | na | 1.70 | 0.61 |
| Sutton Bonington | na | 0.47 | 0.11 |

Notes: na data not collected

**L** Crop lodged 8 June

**Partitioning**

Total above ground dry matter was lower in Mercia than Consort (Table 4.11) and particularly in Consort in 1998 there were higher values than achieved in previous reference crops. Thus the expected values for total dry matter will need to be modified as varieties with higher dry matter potential are produced. The higher dry matter if combined with a high harvest index for grain gives rise to a high yield potential. Here, harvest indices for Mercia were within the range of those for previous reference crops. Those for Consort were slightly higher, and thus contributed to the higher yield of this variety.

Table 4.11. Total above ground dry matter at harvest for three sites in three seasons

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| ***Total above ground dry matter tonnes per hectare*** | | | |
| **Mercia** | | | |
| Boxworth | 17.4 | 13.3 | 16.3L |
| Rosemaund | 17.8 | 16.8 | 13.8 |
| Sutton Bonington | 16.3 | 16.2 | 16.8 |
| **Consort** | | | |
| Boxworth | na | 15.7 | 20.6 |
| Rosemaund | na | 19.1 | 20.5 |
| Sutton Bonington | na | 16.9 | 19.4 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 0.30 | 0.59 | 0.91 |
| Rosemaund | 0.34 | 0.23 | 1.35 |
| Sutton Bonington | 1.13 | 0.28 | 0.66 |
| **Consort** | | | |
| Boxworth | na | 0.73 | 0.06 |
| Rosemaund | na | 1.20 | 0.82 |
| Sutton Bonington | na | 0.76 | 0.92 |

Notes: na data not collected

**L** Crop lodged 8 June

Table 4.12. Harvest index for grain from three sites in three seasons from hand harvested plots..

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| ***Harvest index %*** | | | |
| **Mercia** | | | |
| Boxworth | 47.8 | 46.1 | 35.4**L** |
| Rosemaund | 50.3 | na | 48.1 |
| Sutton Bonington | 48.2**G** | 49.3 | 44.4 |
| **Consort** | | | |
| Boxworth | na | 48.4 | 43.7 |
| Rosemaund | na | 61.4 | 55.8 |
| Sutton Bonington | na | 51.7 | 51.8 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 2.18 | 2.77 | 0.62 |
| Rosemaund | 3.73 | na | 1.83 |
| Sutton Bonington | 0.71 | 1.96 | 2.06 |
| **Consort** | | | |
| Boxworth | na | 1.84 | 1.15 |
| Rosemaund | na | 4.71 | 0.88 |
| Sutton Bonington | na | 0.86 | 2.19 |

Notes: na data not collected

**L** Crop lodged 8 June

**G** From grab samples

**Components of Grain Yield**

Grain yield can be considered as the product of ears per square metre, grains per ear and weight per grain. Here ears $m^{-2}$ was more variable in Mercia than in the previous reference crops and the previous range of 425 to 696 was extended to 372 to 629 (Table 4.13). The range in Consort in these six crops was 416 to 566 ears $m^{-2}$, smaller than the range in Mercia, but in view of the difficulty of defining the complete range in Mercia with 18 crops this range must be viewed with caution. in five out of the six comparisons shoot numbers were lower in Consort than Mercia. The number of grains per ear (Table 4.14) was within the previous range for Mercia, but was always higher in Consort. This would compensate for the lower number of shoots generally found in Consort. The third component of yield is weight per grain (Table 4.15). The range of weights in Mercia did not extend that of previous reference crops. Generally at a given site and season weights were higher in Consort than Mercia. The value at Rosemaund in 1998 extended the maximum value observed in reference crops from 46.3 to 50.4 mg. It was noticeable at his site that ear growth apparently continued until very close to harvest (Fig. 4.4) although growth of the central grains in the ear had ceased some time previously (Fig 4.5).

Table 4.13. Ears per square metre from three sites in three seasons from hand harvested quadrats.

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| ***Ears per m$^2$*** | | | |
| **Mercia** | | | |
| Boxworth | 731 | 462 | 626**L** |
| Rosemaund | 698 | 592 | 372 |
| Sutton Bonington | 769 | 559 | 634 |
| **Consort** | | | |
| Boxworth | na | 416 | 566 |
| Rosemaund | na | 521 | 451 |
| Sutton Bonington | na | 451 | 466 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 47.3 | 14.4 | 28.1 |
| Rosemaund | 40.3 | 34.9 | 15.7 |
| Sutton Bonington | 25.1 | 9.4 | 17.7 |
| **Consort** | | | |
| Boxworth | na | 14.9 | 9.7 |
| Rosemaund | na | 41.3 | 27.2 |
| Sutton Bonington | na | 27.1 | 22.0 |

Notes: na data not collected;

**L** Crop lodged 8 June

Table 4.14. Grains per ear from three sites in three seasons from hand harvested quadrats.

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| ***Grains per ear*** | | | |
| **Mercia** | | | |
| Boxworth | 30.4 | 35.5 | 27.2**L** |
| Rosemaund | 33.9 | na | 37.8 |
| Sutton Bonington | 26.9**G** | 35.9 | 33.3 |
| **Consort** | | | |
| Boxworth | na | 47.8 | 37.5 |
| Rosemaund | na | 49.1 | 50.4 |
| Sutton Bonington | na | 50.3 | 50.9 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 0.67 | 1.51 | 1.17 |
| Rosemaund | 1.54 | na | 3.21 |
| Sutton Bonington | 0.96 | 1.09 | 0.73 |
| **Consort** | | | |
| Boxworth | na | 0.99 | 1.81 |
| Rosemaund | na | 3.36 | 1.85 |
| Sutton Bonington | na | 1.20 | 0.97 |

Notes: na data not collected;

**L** Crop lodged 8 June;

**G** From grab samples

Table 4.15. Weight per grain mg from three sites in three seasons from hand harvested quadrats.

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| ***Weight per grain mg at 100% dry matter*** | | | |
| **Mercia** | | | |
| Boxworth | 37.5 | 35.4 | 27.9**L** |
| Rosemaund | 37.7 | 43.4**C** | 47.1 |
| Sutton Bonington | 33.9**C** | 34.3 | 35.2 |
| **Consort** | | | |
| Boxworth | na | 36.7 | 42.4 |
| Rosemaund | na | 45.7 | 50.4 |
| Sutton Bonington | na | 38.6 | 42.4 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 0.28 | 0.66 | 1.18 |
| Rosemaund | 0.98 | 0.81 | 0.48 |
| Sutton Bonington | 0.32 | 0.40 | 0.63 |
| **Consort** | | | |
| Boxworth | na | 0.73 | 0.82 |
| Rosemaund | na | 0.35 | 1.53 |
| Sutton Bonington | na | 0.83 | 1.99 |

Notes: na data not collected

**L** Crop lodged 8 June

**C** From combine grain sample

**Grain Quality**

In the previous reference crops of Mercia only about one quarter achieved an adequate protein concentration to reach the target for breadmaking quality (11%). Here, the situation was proportionally a little better(Table 4.16). As expected none of the Consort which is not recommended for breadmaking reached the threshold, even on crops when Mercia had achieved the threshold on the same site.

Table 4.16. Grain protein concentration of combine harvested grain from three sites in three seasons.

| | 1996 | 1997 | 1998 |
|---|---|---|---|
| ***Grain protein at 14% moisture*** | | | |
| **Mercia** | | | |
| Boxworth | 8.9 | 11.5 | 12.0**L** |
| Rosemaund | 9.6 | 10.4 | 10.7 |
| Sutton Bonington | 12.8 | 11.4**Q** | 10.5 |
| **Consort** | | | |
| Boxworth | na | 10.8 | 10.6 |
| Rosemaund | na | 8.2 | 9.2 |
| Sutton Bonington | na | 10.9**Q** | 9.4 |
| ***Standard error*** | | | |
| **Mercia** | | | |
| Boxworth | 0.25 | 0.07 | 0.11 |
| Rosemaund | 0.32 | 0.08 | 0.10 |
| Sutton Bonington | 0.31 | 0.14 | 0.06 |
| **Consort** | | | |
| Boxworth | na | 0.07 | 0.16 |
| Rosemaund | na | 0.09 | 0.10 |
| Sutton Bonington | na | 0.23 | 0.11 |

Notes: na data not collected

**L** Crop lodged 8 June

**Q** From quadrat harvest

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