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EXPLOITATION OF VARIETIES FOR UK CEREAL PRODUCTION (VOLUME I)

GENERAL INTRODUCTION AND EXECUTIVE SUMMARY

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GENERAL INRODUCTION AND EXECUTIVE SUMMARY

by

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Contents

Part 1. GENERAL INTRODUCTION

1. PROJECT OBJECTIVES

The main objectives of the Project were to :

- Improve the utilisation of predictive capability of existing data on varietal performance and to improve the efficiency of future experimentation on cereal varieties.

More specifically, the project should assist :

- Farmers to identify the type of variety to select when particular growing conditions are expected.

- Farmers to confidently resolve the best husbandry for the particular variety sown.

2. MATCHING VARIETIES TO GROWING CONDITIONS

This Project is about 'horses for courses'. Judged by the popularity of cereal varieties as components of trials programmes in their local group activities, growers have an intuition that varieties exist that are better tailored than others to their own conditions. Although examples could be quoted where particular suitabilities of specific varieties had become evident following extensive cultivation (e.g. the unsuitability of Avalon for early sowing and the suitability of Slejpner for early sowing) at the outset of the Project in 1991 it was rare for genotype/environment interactions to be evident at the UK Recommended List (RL) trials testing stage, other than clear-cut features such as disease susceptibilities. Only those varieties which come through the testing system to be added to the RL (where the criterion for inclusion for general use is 'better than or as good as the best on the current Recommended List in all important aspects of performance' (MacLeod, 1993)) are widely available for most farmers to grow. Over the 10-year period 1982-91, the average number of wheat varieties submitted for National List (NL) testing was *c.* 30 per annum. Over the same period, on average only 2 varieties for general use were added per annum to the England and Wales Recommended List (RL). It is possible that over this period some varieties of better performance than current RL varieties in specific farm situations were discarded by testers at an early stage in the evaluation system because of their poorer average performance across all RL sites. With the merging of the testing programmes throughout the UK (National Institute of Agricultural Botany, Department of Agriculture for Northern Ireland, Scottish Agricultural Colleges) in 1988, a considerably wider range of conditions has had to be accommodated in more recent years. The range of environments in which cereals must be grown is increasing as environmental restrictions (e.g. Nitrate Sensitive Areas and Nitrate Vulnerable Zones) and more exacting quality standards introduce additional constraints on the grower. For these reasons, at the outset of the current Project in 1991, it was concluded that more specific recommendations relating to varietal suitabilities and environmental and cultural growing conditions were likely to become more crucial to farmers as their margins tightened in the future.

During the 1990s, generally more than 40% of tilled land was sown each year to wheat in certain eastern counties, for example, Essex, Cambridgeshire, Suffolk, Lincolnshire and Humberside. In other regions, for example, the south west and north west England, the west midlands, Scotland and Northern Ireland, the percentage of tilled land sown to wheat was never significantly greater than 25% in any county, and was mostly 10-15%. In total, *c.* 80% of the UK wheat acreage occurred south of Hull and east of Bristol in these years. Therefore, although there are some advantages in describing potential varietal suitabilities to environment in purely regional terms, a problem with this approach is that the majority of UK wheat crops are grown within a relatively restricted area in the central eastern and southern eastern regions of England. Furthermore, it is difficult to relate regional yield performance to the wide field-to-field variation that still occurs within fields in the same locality. The standard deviation for yield for field-to-field variation between fields on a single farm is about 15%, and between farms in a particular locality 20% (Tinker & Widdowson, 1982).

In the current Project, the objective was to define varietal suitabilities to environment not on the basis of geographical regions, but according to particular growing conditions relating to different aspects of environment or husbandry. Within any defined region, crop performance will be influenced by the soil type: affecting moisture availability, soil N availability, pH, P, K and Mn status, and drainage; the local climate: affecting rainfall, solar radiation and ambient temperature; and the farming system: affecting soil N availability and rotational disease pressures. It is only through a quantitative evaluation of these components of the environment that a satisfactory interpretation of yield performance can ultimately be achieved at the field level. Crop scientists would expect all the environmental components above to affect crop performance to some extent, and so possibly varietal choice. Previous work can be used to indicate the components that will be minor and those likely to be of most importance. The effects of poor soil drainage are perhaps now a minor issue since most tilled land prone to waterlogging is drained; and it has been reported by Letcombe Laboratory that the effects of waterlogging are minimal except when they coincide with crop emergence (Cannel, 1981). Also, through regular use of P, K and lime, nutrient status of soil has improved so that soil acidity or deficiencies in P and K are rare. Manganese deficiency remains a significant problem, but on a minority of cereal land. Soil compaction, weed competition and seedbed conditions may affect yields seriously, but their likely occurrence is not known at the time of variety choice. Straw incorporation has only a small effect on crop performance so that any change due to variety would be undetectable. Other environmental factors, such as incidence of lodging, leaf diseases or damage by frosts, are already dealt with by the UK variety evaluation system which routinely records standing power, disease resistances and winter hardiness. Also, in the case of lodging and leaf diseases, there are parallel HGCA-funded projects 0050/1/92A & 0009/1/90A). Thus it was concluded, in consultation with agronomists, breeders and testers, that the aspects of environment and husbandry most likely to affect selection were as follows:

- **Moisture availability :**
  - ⇒ taking into account the way rainfall, and soil texture and depth affect the amount of moisture that the crop will have available.

- **Place in rotation :**
  - ⇒ taking into account the way the previous crops influence the spectrum of diseases that may affect the roots and stem bases of the crop.

- **Soil N availability :**
  - ⇒ taking into account the way previous cropping and manuring, and also soil organic matter, will alter amounts of N that will be available to the crop, but discounting the effects of P, K and other nutrients.
- **Length of growing season :**
  - ⇒ taking into account the effects of latitude, altitude and sowing date on the temperatures and daylengths which the crop is to experience.

It is these four aspects of environment and husbandry that are therefore targeted in the current Project work.

3. PROJECT ORGANISATION

The Project was under the overall direction of Prof Keith Scott, Division of Agriculture and Horticulture, School of Biological Sciences, University of Nottingham. The four environmental and cultural factors prioritised (Moisture Availability, Rotational Position, Soil N Availability and Length of Growing Season) comprised four distinct Sub-Projects within the overall Project structure. The experimental work, data handling and reporting for each Sub-Project was co-ordinated by a Sub-Group reporting directly to Prof Scott at University of Nottingham. Dr John Foulkes at Division of Agriculture and Horticulture, University of Nottingham took the central role in the Project taking direct responsibility for the Moisture Availability Sub-Project and acting as the technical co-ordinator for the other three Sub-Projects. The four Sub-Groups were organised as below.

- **Moisture Availability** (as affected by soil texture and depth, rainfall, climate change).

Lead centre :	Division of Agriculture and Horticulture, University of Nottingham
Collaborating centre :	ADAS Gleadthorpe
Sub-Project leader :	Prof K Scott (University of Nottingham)
Scientific Staff :	Dr John Foulkes (Univeristy of Nottingham)

- **Rotational Position effects on take-all disease pressure** (as affected by previous crop, cultivations, straw and chaff disposal, soil type).

Lead centre :	ADAS Rosemaund
Collaborating centre :	ADAS Boxworth
Sub-Project leader :	Mr Robert Clare (ADAS Rosemaund)
Scientific staff :	Mr. John Spink (ADAS Rosemaund)

- **Soil Nitrogen Availability** (as affected by soil type, rotation and fertiliser use).

Lead centre :	Queen's University, Belfast
Collaborating centres :	ADAS Boxworth Harper Adams Agricultural College
Sub-Project leader :	Dr Ethel White (Dept of Agriculture for N. Ireland, Crossnacreevy, Belfast)
Scientific staff :	Mr Peter Kettlewell (Harper Adams Collelge) Dr Roger Sylvester-Bradley (ADAS Boxworth)

- **Length of Growing Season** (as affected by latitude, altitude and sowing date, climate change).

Lead centre :	Dept of Agriculture, University of Newcastle upon Tyne
Collaborating partner :	ADAS Rosemaund
Sub-Project leader :	Dr Eric Evans (University of Newcastle)[1]
Scientific staff :	Dr David Frost (ex University of Newcastle)

[1] Dr. Michael Kirby assumed responsibility for reporting the results for this Sub-Project.

For each Sub-Project primary features of growth and development were identified that might correlate with performance with respect to that area of environment/husbandry in HGCA Review No. 18 (Sylvester-Bradley *et al.*, 1990). For each aspect of environment//husbandry targeted, the objective in this Project was to identify physiological traits that might match varieties to environmental suitabilities. For each Sub-Project, field evaluation of varietal performance through experiments which tested extremes, both in terms of environments and varieties, and which tested for associations between varietal characteristics and performance, was undertaken.

For each Sub-Project there were three experimental seasons as follows :

- Moisture Availability (1993-4 to 1995-6)
- Rotational Position (1993-4 to 1995-6)
- Soil N Availability (1993-4 to 1995-6)
- Length of growing season (1991-2 to 1993-4)

In addition to the main four sets of genotype/environment interaction field experiments, two complementary experimental field exercises were undertaken as follows :

- **Variety 'Typing' Trials in 1993-4 and 1994-5**

  Supplementary variety trials were established in four site-seasons : ADAS Rosemaund 1993-4, ADAS Boxworth 1993-4, ADAS Rosemaund 1994-5 and Sutton Bonington 1994-5, specifically for the purpose of characterising large numbers of varieties for target candidate traits. The specific objectives of these 'Typing' Trials were to i) define varietal variation for candidate traits, ii) examine consistency of varietal expression across sites and seasons, iii) gain information on target traits for varieties tested in individual Sub-Projects which was not available at the outset of the Project from existing data sets and iv) test methodologies for feasibility, rapidity and precision when applied to large numbers of testers' field plots.

- **NIAB Additional Character Assessments in 1994-5 and 1995-6**

As part of the field evaluation stage, funding was provided for additional indicative characters to be recorded at selected NIAB RL sites in 1994-5 and 1995-6. These additional assessments would be introduced as a result of on-going work in the four Sub-Projects. It was envisaged that promising candidate physiological traits would be measured in RL trials to i) provide testers with an early opportunity to corroborate the feasibility of proposed methodologies and ii) provide growers with information on new current RL varieties for respective traits.

In addition to the above experimental programmes, as a lead-in to the main phase of the experimental fieldwork from 1993-4 to 1995-6, a two-year research post at NIAB, Cambridge (1991-3) was funded for a Desk-Study to be completed. The objectives of the Desk-Study were to collate existing data on winter wheat from NIAB and research organisations such as ADAS, Universities, Plant Breeding International, Cambridge, fertiliser companies, agro-chemical companies and crop centres. The intention was to : i) examine these for consistency of varietal performance in specific environments, ii) look for pointers to the characters most likely to give rise to differences in performance in specified environments and iii) identify the appropriate spectrum of varieties on which to study the respective environmental and husbandry factors (Foulkes *et al.*, 1994).

4. ANALYSES OF GENOTYPE/ENVIRONMENT INTERACTIONS IN UK RL VARIETY TRIAL SERIES PRE-DATING CURRENT PROJECT

Some interactions between varietal performance and environmental or cultural factors, such as disease incidence, rainfall distribution and major climatic variations, had previously been observed and used in a very generalised way to interpret the results of the UK RL trials. The performance of 12 commercial winter wheat varieties in UK Co-ordinated NL and RL trial series 1988-91 was analysed by Fenwick (1991) in a range of environmental and cultural situations, including season, region of the UK, sowing date, soil type, rotational position, nitrogen application and fungicide application. Of the factors examined, it was concluded that only two, season and disease control, showed consistent interactions with variety. It was concluded that neither geographical location nor soil type had any significant interaction with variety performance, and that relative performance of individual varieties was unaffected by rotational position, time of sowing and N levels. However, the restricted sub-set of varieties examined and the lack of a suitable statistical technique to analyse the data (other than comparison of varietal ranking orders) prevented the assignment of any statistical significances to the varietal responses reported. Fielder (1988) reported an empirical analysis of varietal performance of winter wheat in ADAS/NIAB sowing date trials, 1982-87. Significant varietal responses to sowing date were observed, with slower developing varieties tending to perform relatively better from earlier sowing dates and the converse applying for rapid developing varieties. It was noted that a more intensive monitoring regime for plant characteristics other than yield, e.g. plant, ear and tiller numbers at specific growth stages, was required, to allow a fuller interpretation of varietal yield responses. Our conclusion at the outset of the current Project work was that, to improve regional interpretation and to move towards varietal recommendations for particular combinations of farm and field circumstance, a much better understanding of the interaction between varietal physiological characteristics and environmental effects was required.

5. CHANGES TO RL IN RELATION TO GENOTYPE/ ENVIRONMENT INTERACTIONS SINCE COMMENCEMENT OF CURRENT PROJECT IN 1991

Since the beginning of the current Project, several categories of new information have been introduced in the Cereal Variety Handbook with respect to prediction of winter wheat performance for specific farm situations. In 1993, in addition to the overall fungicide-treated ranking for grain yield, a fungicide-treated ranking was presented for each of five UK regions, namely: north east, north west, central, south east and south west. Regional varietal rankings for grain yield have been provided in all subsequent RL booklets. In 1994, a new category was introduced onto the RL: R (regionally recommended), and in that year the variety Flame was categorised as RPG (regionally provisionally recommended for general use) in the North West. Regionally recommended varieties may be fully or provisionally recommended for general or special use. Regional recommendation has been retained in subsequent RL booklets. In 1995, Soissons was categorised as RPS for central, south east and south west regions and Flame as RPG in the north west. In 1996, Soissons was again categorised as RPS for central, south east and south west regions. In 1997, Soissons was classed as RGS for the central region and Madrigal as RPG for the north east.

Further changes were also initiated in 1994. These comprised two additional tables; the first describing fungicide-treated varietal rankings for grain yield in first wheat and second wheat sites, the second fungicide-treated varietal rankings for grain yield for sites of differing soil type (light, medium and heavy). Varietal rankings according to Rotational Position and Soil Type have subsequently been included in all RL Cereal Variety Handbooks. Two further innovations have occurred more recently. Firstly, in 1995, a table presenting 'site fertility' sensitivity coefficients for varieties was introduced. Varietal coefficients vary from about 0.9 to 1.1, the greater the coefficient the more sensitive the variety is to changes in site yield potential. Secondly, in 1997, as a direct result of worked carried out in the current Project, a table ranking varietal ability to tolerate late-season stress according to accumulation of soluble stem carbohydrate at GS 61+75°Cd (*c.* GS 61 + 5 d) was introduced.

More generally there has been an apparent change in the throughput of entries on the RL. From 1984 to 1993, the number of new entries on the RL never exceeded 4 in any year and averaged 2. However, in 1995 there were 7 new entries, in 1996 there were 2 and in 1997 there were 5. This suggests a tendency for a greater throughput of varieties in recent years, together with a greater total number varieties on the RL and therefore improved scope for growers to select for potential suitabilities. The implications of these recent changes to the testing system are discussed in more detail elsewhere within the Report (see discussion Vol. V, Part 2), but some preliminary points are made here. Firstly, the regionalisation of the RL cannot take account of the wide field-to-field variation within any particular locality. Secondly, for the varietal rankings accorded to first and second wheats in the Cereal Variety Handbook, there is wide year-to-year variation for published rankings. For example, as a percentage of the five-year rolling control mean, Rialto as a second wheat varied from 103 in 1995, to 100 in 1996 to 96 in 1997. Presumably, this was due to a second-order interaction between season and the rotational position/variety. Until these complex second-order interactions are more fully understood, progress with interpretation of relative rankings for first and second wheat in published tables may be limited. However, more generally, it is clear that the need for identifying varietal responses to particular growing conditions for winter wheat to assist growers in variety choice has been recognised by UK variety testers in recent seasons.

6. PROTOCOLS COMMON TO ALL SUB-PROJECTS

6.1. Plot management

All site details for individual field experiments are given in the Methodology sections and Appendix Tables within individual report sections. The standard protocol for plot management followed by all collaborators (other than NIAB) is described below. NIAB RL trials utilized for Additional Character Assessments in 1994-5 and 1995-6 were managed according to the existing 'UNITED KINGDOM CO-ORDINATED RECOMMENDED LIST, PROTOCOL - CEREALS' (NIAB, internal publication).

6.1.1 Plot size, previous cropping, cultivations and soil N,P and K status

Variety sub-plots or sub-sub-plots were of sufficient size to allow for intended destructive sampling plus a combine area of at least 8 x 2 m (excluding wheelings). Apart from the Rotational Position Sub-Project, all experimental wheat crops were at low risk from take-all, i.e. after a break, with minimal grass weed infestation. Cultivations were as normal for the establishment of wheat (ploughing followed by secondary cultivation). Where large residues from the previous crop occurred, they were incorporated before sowing. With the exception of the Soil N Availability Sub-Project, experimental sites were of low to moderate soil nitrogen status. Remedial treatments were taken if pH was < 5.5 or > 7.5. Where pH was > 7.5, an insurance spray against Mn deficiency was applied.

6.1.2. Standard variety, seed rate and crop protection

Each experiment included at least one of two standard varieties. The two standard varieties were Riband and Mercia. With the exception of the Length of Growing Season Sub-Project, the seed rate for each variety was calculated with reference to 1,000 grain weight to sow a standard number of seeds per m^2 for each variety. The standard number of seeds sown was usually 325 per m^2 but was adjusted slightly across sites (for all varieties) according to seed bed conditions to target a spring plant population of 275 plants per m^2. The recommended row-spacing was 12.5 cm. All seed was treated with fungicide (Panoctine 2 ml/kg). An optional insecticide seed dressing (Birlane 3 ml/kg) was recommended. All crops were managed to limit weeds, pests and diseases to very low levels (less than 5% disease infection). In the case of weeds and pests, decisions were taken by the individual site managers concerned, in relation to local information to aid the most suitable control strategy. For diseases a standard prophylactic approach was adopted in all experiments : fenpropidin + prochloraz at GS 31, tebuconazole at GS 39 and tebuconazole + triadimenol at GS 59.

6.1.3. Fertiliser N and PGR

The aim for fertiliser N (other than in the Soil N Availability Sub-Project) was to apply sufficient to achieve optimal economic yield, but no more. N was applied as ammonium nitrate prills. Two applications were recommended, an early dressing in mid-March and a main dressing in mid-to-late April. Thirty to 40 kg/ha N was recommended for the first application and 120 - 180 kg/ha for the main dressing. The final decision on the second application was taken by the individual site managers concerned with a knowledge of local site information. It was typically in the order of 150 – 160 kg N/ha, but an amount as low as 120 – 140 kg/ha N could be applied if, for example, the site was known to be of low yield potential or had a particular history of lodging. Growth regulators were applied at all sites (with the exception the Length of Growing Season Sub-Project in 1991-2) to minimise the risk of lodging. The standard prophylactic programme was a split rate of Chlormequat (2/3 at end of tillering + 1/3 at GS 31) followed by, depending on conditions, a half to three-quarters rate Terpal at GS 37.

6.2. Crop and environmental measurements

Unless specifically stated otherwise (see individual Methodology sections for Sub-Projects (Vols II - IV), Typing Trials (Vol. V) and NIAB Additional Character Assessments (Vol. V)), all measurements listed below were taken as outlined in 'How to run a reference crop', Vol. II (of III), Project Report No. 151, 'Predictive information on plant development in relation to eventual yield and quality' (HGCA, 1998).

- **Crop measurements**

  ⇒ Definitions of plant development
  ⇒ Definitions of main shoots and shoots
  ⇒ Leaf emergence records on tagged main shoots to estimate
    ◊ phyllochron,
    ◊ final leaf number per main shoot and
    ◊ crop height
  ⇒ Crop sampling, sub-sampling, growth analysis and chemical analysis methods to estimate
    ◊ shoot numbers per m^2
    ◊ green area index (GAI)
    ◊ crop dry mass per m^2
    ◊ stem water soluble carbohydrate content
    ◊ crop N content
    ◊ grain yield (at harvest) and
    ◊ grain yield components (at harvest)

⇒ Combine harvesting of plots to estimate

◊ combine grain yield

◊ combine thousand grain weight.

- **Environmental measurements**

⇒ Sampling of soil cores and sub-sampling for chemical analysis to estimate

◊ Total soil mineral N (NH_4^+ and $N0_3^-$) (kg N/ha) with soil depth

⇒ Collection of meteorological data.

Part 2. EXECUTIVE SUMMARY

1. VARIETAL RESPONSES TO DROUGHT

BACKGROUND AND OBJECTIVES

- In years with rainfall appreciably below average, serious yield-limiting deficits will occur in a significant percentage of UK wheat fields. In these dry years, varieties suited to drought-prone soils will be of value to a significant number of growers.

- In order to assist wheat growers and their supporting organisations in the selection of varieties for specific environments, the intention was to :

  ⇒ suggest ways in which varietal traits may confer resistance to drought, and
  ⇒ test varieties, possessing combinations of either desirable or undesirable traits, for their field performance in irrigated and unirrigated conditions.

- The following traits were identified as those which might be used to indicate resistance to drought :

  ⇒ Maximum rooting depth (deeper rooting conferring drought resistance)
  ⇒ Water use efficiency (higher water use efficiency conferring drought resistance)
  ⇒ Flowering date (earlier flowering conferring drought resistance through drought avoidance)
  ⇒ Green canopy area production (restricted maximum canopy size conferring drought resistance through conservation of water pre-anthesis for use during grain filling)
  ⇒ Soluble stem carbohydrate (greater stem soluble carbohydrate accumulation conferring drought resistance through greater potential for grain filling buffering from stored reserves).

EXPERIMENTAL PROGRAMME

- There was one experiment of identical split-plot design in each of three seasons : 1993-4, 1994-5 and 1995-6. Each experiment was located on the loamy medium sand at ADAS Gleadthorpe. There were two irrigation treatments (unirrigated and fully irrigated) randomised on main plots, and six varieties (Haven, Maris Huntsman, Mercia, Rialto, Riband and Soissons) randomised on sub-plots. The six varieties examined were selected to provide the greatest possible contrast for traits from within mostly commercial, current varieties. The rationale for variety choice at the outset of experimental programme is shown in the table below.

Rationale for variety selection according to trait expression from existing evidence at outset of programme

	Leafiness	Root depth	Flowering	Stem reserves	Water Use efficiency
Haven[1]	Intermediate	n/a	Late	High	n/a
M. huntsman	High	n/a	Intermediate-late	Low	n/a
Mercia	High	n/a	Early-intermediate	n/a	n/a
Rialto[1]	Low-Intermediate	n/a	Intermediate-late	n/a	n/a
Riband[1]	Low	n/a	Intermediate	Intermediate	n/a
Soissons[1]	Low-intermediate	n/a	Early	n/a	n/a

[1] = Semi-dwarf variety possessing Rht1 or Rht2 gene.
n/a = information not available at outset of experimental programme.

RESULTS

Rainfall patterns and soil moisture deficits

- AWC measured to 1.65 m (depth of soil water measurements) was 151 mm. The soil returned to field capacity overwinter in each season.

  ⇒ The season of 93-4 was characterised by no early drought, but onset of late drought broadly coinciding with flowering in mid-June.
  ⇒ Rainfall pattern in the season of 94-5 resulted in the onset of pre-anthesis drought in early May which was subsequently sustained throughout the grain filling period.
  ⇒ Rainfall pattern in the season of 95-6 resulted in the onset of pre-anthesis drought in mid-to-late May which, as in 1995, continued through grain filling.

Effect of drought on grain yield

- Combine grain yield was significantly reduced by drought in all seasons :

  ⇒ by 1.83 t/ha in 93-4,
  ⇒ by 3.06 t/ha in 94-5 and
  ⇒ by 4.55 t/ha in 95-6.

- The larger reductions occurred in the two seasons where stress occurred earlier and therefore lasted longer.
- Averaged across seasons, irrigated yield of varieties broadly reflected their performance on the Recommended List. Thus :

  ⇒ the high yield potential varieties, Haven, Riband and Rialto yielded 10.9, 10.4 and 10.3 t/ha, respectively,
  ⇒ the low yield potential, older M. Huntsman and the bread-making variety Mercia yielded 9.2 and 9.3 t/ha, respectively, and
  ⇒ the mid-range yield potential French-bred, milling variety Soissons showed intermediate yield at 9.6 t/ha.

- Overall, the six varieties responded differently to drought and the irrigation/variety interaction was significant :

  ⇒ Rialto and Mercia only lost about 2.7 t/ha grain under drought,
  ⇒ Haven and Riband lost about 3.5 t/ha and
  ⇒ Soissons and M. Huntsman showed intermediate yield losses.

- Haven showed drought resistance to late drought in 93-4, but maintained yield no better than other varieties in response to early onset of drought in 94-5 and 95-6. Rialto showed consistent drought resistance in all seasons in response to both early and late onsets of drought.

Effect of drought on components of yield

- Compared to irrigated controls, averaged over seasons drought reduced:

  ⇒ Grains per ear by 13% from 41.2 to 35.7,
  ⇒ Thousand grain weight by 12% from 43.1 to 38.0 and
  ⇒ Ears per m^2 by 8% from 501 to 460.

- With post-anthesis drought in 93-4, the irrigation/variety interaction was only significant for grain weight, where Rialto maintained grain weight better under drought than other varieties.
- With pre-and post anthesis drought in 94-5, the interaction was significant for grains/ear and grain weight. Rialto and Riband maintained grains/ear better than other varieties. Rialto, Mercia and Soissons maintained grain weight better than other varieties.
- In 95-6, with pre-and post anthesis drought similar to 94-5, there was a significant interaction for grain weight only, due to proportionately greater reduction for Mercia and Soissons compared to other genotypes, particularly Riband.
- In summary, the consistently better maintenance of yield under drought for Rialto compared to other varieties was explained by maintaining grains/ear markedly better than other varieties, by maintaining grain weight better than most varieties, but by maintaining ear number no better than other varieties examined.

Flowering date versus yield response to drought

- It was hypothesised that early flowering might confer drought resistance due to reduced water use in the vegetative phase conserving water for grain filling.
- The range of GS 61 amongst the five UK-bred varieties examined was six days, but the French-bred Soissons was on average five days earlier than the earliest UK-bred variety, Mercia.
- Under drought, the varietal range for water uptake from mid-April to end of grain fill was 227 - 250 mm. Rialto had consistently greater uptake than the shorter life cycle length varieties, Soissons and Mercia.
- The early flowering varieties generally used about 25 mm less water from mid-April to GS 61 than the late flowering types. As expected, the early flowering genotypes then used more water during grain filling, but varietal differences for water uptake during

grain filling were not as large (in the range *c.* 60 - 75 mm) as for differences in water uptake up to flowering (in the range *c.* 150 – 175 mm).

- In general, early flowering conferred only a marginal advantage in increased water uptake during grain filling. There was no consistent evidence for varieties of early flowering date to maintain grain yield better under drought compared to those of intermediate date of flowering. Late flowering, as exemplified by Haven, however, did show some evidence for conferring poorer maintenance of yield compared to either early or intermediate flowering date for the varieties currently examined in the early drought seasons 94-5 and 95-6.

Maximum rooting depth versus yield response to drought

- In general, varietal differences detected in total seasonal water use related to greater extraction at all depths within the soil profile rather than to deeper depth of maximum extraction. For only one variety, Soissons, was there a suggestion for poorer extraction at depth below about 1.2 m, but even here the absolute difference in uptake at depth was small and never approached statistical significance.
- Thus, there was no strong evidence for differences in maximum depth of water extraction, and, by inference, differences in maximum rooting depth.
- It follows that results failed to show an association between varietal yield response to drought and maximum rooting depth.

Water use efficiency versus yield response to drought

- Results, in general, failed to show differences in water use efficiency (above-ground dry mass production per unit water evapotranspiration) amongst varieties under drought. Averaged across seasons and irrigation treatments, the varietal range was 4.79 - 5.13 $g/m^2/mm$ and non-significant.
- It follows that there was no evidence for an association between varietal yield response to drought and water use efficiency.

Leafiness versus yield response to drought

- The original hypothesis was that normal investment in leaves may be excessive in UK drought situations, and that varieties with restricted maximum canopy area could conserve water during vegetative growth for more profitable use during grain filling.
- Under drought, varietal differences in maximum green area were relatively small, in the range 3.5 to 4.8 GAI units, and were not well correlated with water use in the pre-flowering period. The original hypothesis that reduced investment in leaves may be advantageous in UK drought situations was therefore not supported from current results.

Stem carbohydrate reserves versus yield response to drought

- The original hypothesis was that varieties with the ability to amass and relocate larger amounts of stem reserves would be more tolerant of effects of premature canopy senescence under drought.
- There were significant varietal differences in all seasons for amounts of soluble stem carbohydrate at GS 61+75°Cd (*c.* GS 61 + 5 d). Averaged across seasons in the unirrigated treatment, Rialto and Haven had greatest reserves at 3.00 and 2.90 t/ha, respectively, compared with Mercia (2.20 t/ha), M. Huntsman (2.46 t/ha), Riband

(2.48 t/ha) and Soissons (2.52 t/ha). The irrigation/variety interaction was non-significant in all cases reflecting a similar ranking for varieties in irrigated and unirrigated conditions.

- Amounts were unaffected by late drought in 93-4, but were 0.36 t/ha less and 0.21 t/ha less under drought in 94-5 and 95-6, respectively.
- At harvest, in all seasons amounts of stem soluble carbohydrate remaining were low (< 0.25 t/ha for all varieties).
- In each of the three seasons there was a good relationship between varietal ability to amass stem reserves at the end of flowering and maintenance of yield under drought. In 93-4, better yield performance of Rialto and Haven compared with Riband under drought correlated well with their greater reserves compared to Riband. With early droughts in 94-5 and 95-6, Rialto yielded best associated with its having highest stem reserves. The large reserves of Haven in these seasons, however, did not translate into greater yield under drought compared to other genotypes. Thus, high stem reserves on its own may not be sufficient to confer drought resistance in all varietal backgrounds in early drought seasons. More generally, however, the hypothesis that stem reserves differ meaningfully amongst UK varieties and these differences confer differential tolerance of drought was strongly supported by the evidence of current experiments.

Harvest crop dry mass versus yield response to drought

- Although not a candidate trait at the outset of Project work harvest above-ground dry matter is included in this summary, as significant varietal differences were found in all seasons for it and these differences seemed to bear some relationship with drought performance.
- When analysed across the three seasons, there were statistically significant varietal differences with values in the range 12.3 to 13.7 t/ha (unirrigated) and 16.2 to 17.2 t/ha (irrigated). Harvest dry mass was greater for Rialto compared to all other varieties, both with and without irrigation, and particularly compared to Mercia.
- Varieties ranked similarly in irrigated and unirrigated conditions.
- Rialto, the most drought resistant variety, had greater above-ground dry mass compared to other genotypes, both with and without irrigation. Interpretation of the mechanisms underpinning Rialto's greater propensity for growth is still at a preliminary stage. However, it appears this capacity may have related, in part, to a greater radiation use efficiency. Evidence suggested greater harvest biomass may comprise a part of the desirable varietal ideotype for conferring resistance to both early and late onset of UK drought. Possibly more above-ground growth may have been associated with greater below-ground investment in roots, a feature likely to have been accentuated in Rialto by an extended period from GS31 to GS61, the developmental period during which greatest proliferation and growth of crown roots occurs.

OVERALL CONCLUSIONS

- Overall, the cross-year analysis of variance showed a significant irrigation/variety interaction for grain yield ($P< 0.05$). Rialto and Mercia only lost about 2.7 t/ha grain under drought compared with Haven and Riband which lost about 3.5 t/ha with Soissons and Maris Huntsman showing intermediate yield losses.

- For both absolute yield under drought and relative performance under drought compared to irrigated controls, Rialto consistently performed better than two other contemporary varieties of similar yield potential, Riband and Haven.
- For the six varieties examined, there was evidence for greater varietal drought resistance to be associated with :

  ⇒ An ability to amass larger amounts of stem soluble carbohydrate reserves.
  ⇒ A greater capacity for growth *per se* as indicated by harvest above-ground biomass.

- There was no consistent evidence for drought resistance to be associated with varietal differences in :

  ⇒ Maximum rooting depth
  ⇒ Maximum canopy green area
  ⇒ Water use efficiency.

- There was evidence that late flowering conferred drought susceptibiliy in early drought seasons, as exemplified by Haven. However, the advantage conferred by early flowering varieties over those with intermediate flowering dates appeared to be only marginal.
- There was no evidence for drought resistance to be associated with the tall, non-semi-dwarf growth habit as exemplified by the variety M. Huntsman. This contradicted some of the 'folklore' for taller varieties to be more drought resistant types, current at the commencement of Project work.

FUTURE WORK

UK variety evaluation

- As a result of Project work, the two most recent NIAB Cereal Variety Handbooks have published a table giving quantitative varietal rankings for late-season stress tolerance according to stem soluble carbohydrate at flowering. In addition to stem soluble carbohydrate, the main candidates for inclusion as routinely recorded characters in RL trials to give indication of drought resistance at an early stage of a variety's national usage would seem to be :

  ⇒ Flowering date
  ⇒ Harvest index (thereby allowing the calculation of harvest dry mass).

- Differential responses to drought have been shown amongst current UK RL varieties in Project work. This would seem to justify the inclusion of a restricted number of drought-prone sites of lower AWC in the UK RL trial series.

Breeding for drought prone soil types

- Current work has highlighted the importance of the accumulation of stem reserves in buffering drought performance. The consistency of the variety ranking order across irrigation treatments and seasons indicated that this trait may be highly heritable. If the major genes controlling this trait could be identified in collaborative work involving wheat geneticists, then in the medium-to-longer term molecular marker tags could be provided to wheat breeders allowing them to develop more focused breeding programmes in which varieties could be designed specifically for use on drought-prone soil types.

2. VARIETAL RESPONSES TO ROTATIONAL POSITION

BACKGROUND AND OBJECTIVES

- A significant proportion of UK wheat is grown following another cereal crop. The exact proportion varies between seasons and is affected by changes in agricultural policy such as the introduction of set-aside. Over the period 1989 to 1996 non-first wheats have accounted for between 36 and 59 % of the UK crop.
- Lower yield of non-first wheats is caused by i) lower soil N availability than following a high residue break crop, ii) increased stem-base disease and iii) increased take-all. The impact of i) and ii) can be minimised by adjusting fertiliser N amounts and controlling stem-base disease through varietal resistance and early season fungicide application. The situation with iii) is different, as there is no evidence for varietal resistance to take-all and no really effective, commercially means of chemical control currently available.
- Although there are no reports in the literature of consistent varietal differences in take-all resistance, the capacity of varieties to tolerate take-all root loss may not be the same. It is on this basis that an explanation was sought for interactions between variety and rotational position in current work, over and above those attributable directly to nutrition and above-ground disease or pest effects.
- Therefore this Sub-Project examined the potential for identifying varietal physiological traits that may confer tolerance of take-all root loss in second or successive wheats.
- At the outset of the experimental programme the candidate varietal traits identified were :

  ⇒ Economy of tillering (excessive production of tillers, which are subsequently lost, effectively wastes water resources, which may be deleterious where water uptake is restricted due to take-all root loss).

  ⇒ Flowering date (earlier flowering reduces the probability of total grain loss due to severe take-all pre-flowering (GS 61) and with later epidemics the onset of severe take-all is more likely to occur later in the grain filling period with less yield loss).

  ⇒ Stem carbohydrate reserves (capacity to amass large amounts of stem reserves can buffer loss of assimilate supply associated with accelerated canopy senescence in second or subsequent wheats).

EXPERIMENTAL PROGRAMME

- In each of three seasons (1993-4, 1994-5 and 1995-6), an experiment was conducted at two sites with rotational position as the main plot treatment in a randomised split-split-plot design. The sites were chosen, on past evidence, as prone to either relatively high (ADAS Rosemaund) or relatively low (ADAS Boxworth) levels of take-all infection. In 93-4 and 94-5, there were two rotational position treatments per main plot (first wheat and second wheat) and in 95-6 there were three (first wheat, second wheat and third wheat).
- Immediately prior to the establishment of the first test year of the experiment it appeared likely that a chemical means of controlling the take-all fungus would become commercially available in the foreseeable future. In order to assess the likely implications of this for varietal selection with rotational position, two seed treatments

(standard seed treatment, and standard seed treatment plus the experimental product) were randomised on sub-plots.

- Eight varieties of winter wheat - some selected on the basis of reported different varietal yield responses to rotational position and others to have a combination of desirable or undesirable candidate traits for conferring tolerance of take-all root loss - were randomised on sub-sub-plots within each sub-plot.

Rationale for selection of varieties at outset of experimental programme

Brigadier	Shown in preliminary analysis to perform well as a non-first wheat in ADAS federated variety trial series in 1991-2.
Cadenza	Rapid development with good early vigour and 'solid' stems (potentially associated with large stem reserves) indicated potential tolerance of take-all root loss.
Lynx	Shown in preliminary analysis to perform poorly as a second wheat in Cambridge Plant Breeders' trials 1991-2.
Rialto	New variety with both high yield potential and grain quality. Allowed a 'cross-over' to examine counteracting effects of rotational position on dry matter yield and grain N%.
Riband	Shown in preliminary analysis to have relatively better performance as a non-first wheat in NIAB RL trials 1987-91.
Soissons	Early flowering and shy tillering (good economy of tillering) indicative of potential tolerance to take-all root loss.
Spark	Shown in preliminary analysis to perform poorly as a second wheat in ADAS federated variety trial series 1991-2.
Zentos	Very late flowering German bread wheat and tall (potentially associated with poor stem reserves) indicative of potential low tolerance of second wheat.

- The aim was to exclude differential residual N amounts from the comparison of rotational positions. To this end fertilizer N inputs to break crops preceding each first wheat were targeted to leave a similar residues to that in the second and third wheat main plot treatments in the experiments.

RESULTS

Take-all epidemics

- Boxworth, chosen as the low take-all risk site, consistently showed low take-all levels, the final take-all index on second or third wheats exceeded 10% only in 93-4 at 12%. At these low levels, no difference was discernible in incidence on first and second or third wheats.
- Although final disease levels were always higher at Rosemaund, none of the seasons could be classed as a high take-all season. Incidence of significant take-all predominantly occurred later after GS 39 in all seasons. In 94-5, where lack of spring rain retarded disease development, non-first wheats had significantly more disease than first wheats (10.2 vs 16.7). In 95-6, where a trickle irrigation system was installed in order to avoid the problems of the previous year, unseasonably cold conditions prevailed for much of the spring and early summer. Differences were again significant in first (9.9) and third (23.0) wheats. Differences between rotational position treatments were not significant in 93-4.

Yield responses

Effect of rotational position

- At three of the six site-seasons (Rosemaund 93-4, Boxworth 94-5 and Boxworth 95-6) yield reduction due to a non-first wheat position was small < 0.2 t/ha.
- For Boxworth 93-4, Rosemaund 94-5 and Rosemaund 95-6, the yield loss was greater at 0.30 t/ha, 0.50 t/ha and 0.85 t/ha, respectively, and it is here that suitability of varieties for growing as second or subsequent wheats is investigated.
- The lack of statistical significance of the rotational position effect in these latter three site-seasons probably concealed a real effect. There was a lack of precision at the main-plot level associated with low degrees of freedom apportioned to rotational position in the split-split-plot design. This design was, however, necessary to provide large enough main-plot areas to minimize the risk of spread of take-all inoculum from one to the other.

Varietal responses to rotational position

- At Boxworth 93-4, average yield loss of second compared to first wheats was relatively small at 0.3 t/ha. Despite the small overall yield loss, there were indications that varieties responded differently to rotational position. Soissons yielded slightly better as a second wheat; whilst at the other end of the range Spark lost 0.67 t/ha as a second wheat, with intermediate yield losses for other varieties.
- At Rosemaund 94-5, the relatively small yield loss overall of second wheats masked a significant range amongst varieties. Riband and Rialto lost the least yield (0.20 and 0.25 t/ha respectively) and Brigadier the most 1.06 t/ha. Yield loss amongst the remainder of the varieties ranged from 0.40 t/ha for Cadenza to 0.65 t/ha for Lynx.
- At Rosemaund 95-6, yield loss in second wheats was smaller than in either of the other two seasons. However, the greater disease pressure in the third wheats resulted in an average loss of 0.85 t/ha. Varieties ranked similarly for absolute third wheat yield to that for second wheats in the previous season. Rialto was clearly the highest yielding followed by Lynx and Soissons (Rialto producing 0.62 t/ha more than Soissons at 9.00 t/ha) with Zentos and Riband at the other end of the yield range.
- Averaging over the three site-seasons, there were trends for varieties to respond differently to rotational position. As a non-first wheat, Soissons lost only about 0.40 t/ha grain yield compared with Spark and Brigadier which lost about 0.75 t/ha yield. However, amongst the group of varieties showing intermediate responses it was difficult to detect consistent differences in their responses across site-seasons.

Varietal traits

- Assessments of development rate, shoot number, green canopy area and biomass were only undertaken routinely at ADAS Rosemaund. Unless otherwise stated effects described below for facets of growth and development are for the Rosemaund site.

Rate of development

- There was no discernible effect of rotational position on date of reaching respective development stages in any season.
- The varietal range for GS 31 was 20 d and for GS 61 was 12 d.

- Soissons was the earliest variety and Spark and Zentos invariably the latest at all growth stages in all seasons.

Shoot production

- There was generally no statistically significant effect of rotational position on shoot numbers per m^2.
- The slower developing varieties, Brigadier, Lynx, Riband, Spark and Zentos, had higher maximum shoot number at GS 31 than the more rapidly developing varieties, Cadenza, Soissons and Rialto.
- For economy of tillering (dry matter lost in aborted shoots), Brigadier was the least efficient and contained 2.62 t/ha in non-yield producing shoots at GS 39 compared to Soissons, the most efficient, at 0.86 t/ha.

Green canopy area production

- Maximum green area index in 94-5 (4.5) was smaller than would normally be expected. In contrast, in 95-6 it was above the norm (7.5).
- Due to the build-up of the take-all epidemics later in the season, after the canopy production phase, rotational position effects on maximal GAI were small and not statistically significant in 94-5 and 95-6.
- GAI differences amongst varieties were generally small, with maximal values in the range 4.2 - 4.7 in 94-5 and 7.0 - 8.5 in 95-6. Rialto was amongst the varieties with lowest GAI in both seasons consistent with findings in the Moisture Availability Sub-Project.
- At no stage in any season was there a significant interaction between rotational position and variety for GAI.

Above-ground crop dry mass

- There was a trend for lower harvest biomass in non-first wheats by 0.97 t/ha at Boxworth 93-4 and 0.81 t/ha at Rosemaund 95-6.
- The effect of greater maximum dry mass for Rialto compared to other varieties was clearly evident in the experiments at Rosemaund, corroborating findings in the Moisture Availability Sub-Project
- There was no evidence that the varieties responded differently to rotational position (i.e. ranked differently as first and non-first wheats), in terms of harvest dry mass produced.

Harvest crop N offtake

- The rotational position effect was only significant at Rosemaund 95-6, where it was greater at 234 kg N/ha in the first wheats than in third wheats at 211 kg/ha.
- Varietal differences in total N uptake were significant at Rosemaund 95-6 and nearly significant at Rosemaund in 94-5. There was a tendency for varieties performing poorly as non-first wheats in terms of grain yield (e.g. Spark) to exhibit poorer N offtake.

Stem soluble carbohydrate reserves

- There was no consistent effect of rotational position on amount of stem carbohydrate reserves at end of flowering.
- In all site-seasons (BX 93-4, RM 94-5 and RM 95-6) there was a statistically significant effect of variety on reserves at the end of flowering ($P < 0.06$), with values in the range 2.34 to 3.35 t/ha overall. Varietal rankings at the extremes of the range were consistent across site-seasons. Lynx or Rialto consistently had highest amounts, whilst Spark consistently had amongst the lowest amounts.

Varietal traits versus yield response to rotational position

Economy of tillering

- At Rosemaund 95-6 (the only site-season with precise estimates of dry matter lost in aborted shoots), there was a broadly consistent relationship between economy of tillering and the relative performance of a variety as a third wheat.
- Performance for most varieties supported the original hypothesis, in that those losing least dry matter in aborted shoots performed relatively better as third wheats. Thus,

⇒ Soissons with least dry matter in aborted shoots performed relatively well as a third wheat.

⇒ Conversely, Brigadier, with most dry mass in shoots destined to die, performed relatively poorly as a third wheat.

Flowering date

- There were consistent and relatively large differences amongst varieties. The range for GS 61 was 5 d for the British varieties (Cadenza 14 June to Spark 19 June), increasing to 12 d through the inclusion of the continental varieties Soissons (8 June) and Zentos (20 June).
- Although Soissons (early) and Spark (late) performed relatively better and worse, respectively, as non-first wheats, overall flowering date did not consistently predict relative performance with rotational position. The lack of an unambiguous correlation between earlier flowering and better resistance to late-season stress corroborated findings in the Moisture Availability Sub-Project. The balance of evidence pointed to earlier flowering contributing to the varietal type conferring maximum tolerance of take-all, but at a lower order of priority than that originally envisaged.

Stem soluble carbohydrate reserves

- Of the varietal characteristics recorded, amount of soluble carbohydrate reserves in the stem at the end of anthesis had the greatest and most consistent effect on non-first wheat performance.
- In second wheats (at BX 93-4, RM 94-5 and RM 95-6), for every 1 t/ha increase in stem reserves there was about a 1 t/ha increase in second wheat yield.
- The overall varietal range was from 3.38 (Rialto) and 3.31 (Lynx) to 2.36 (Zentos) and 2.42 (Spark), and variety ranking was consistent across site-seasons.

- It is concluded that the ability to accumulate soluble stem carbohydrate is an important component of the varietal type best suited to maintaining yield performance in conditions with high take-all root loss.

OVERALL CONCLUSIONS

Varietal susceptibility to take-all

- The take-all results, expressed as an index accounting for both incidence and severity, consistently showed no effect of variety on take-all level. Given the number of individual assessments, it can be confidently stated that varietal resistance to the disease was not a factor in the results of current work.

Desirable combinations of traits for tolerance of take-all

- Averaged across the three site-seasons (BX 93-4, RM 94-5 and RM 95-6), non-first yield loss for the eight varieties varied between 0.42 (Soissons) and 0.74 (Brigadier) t/ha. At the extremes, there was some evidence for scope for identifying suitabilities. For example, the extremes were exemplified by Soissons (take-all tolerant) and Spark and Brigadier (take-all intolerant).

⇒ Soissons	good economy of tillering high stem reserves
⇒ Spark and Brigadier	poor economy of tillering low stem reserves

- The varietal traits discussed above, however, are most probably not of equal importance. In this work soluble carbohydrate reserves appear to have had the largest influence on variety performance
- Currently, it could only be stated with confidence that the indicative traits outlined here are capable of highlighting the varietal extremes in tolerance of take-all root loss from within current commercial varieties.

Future work

- As a result of Project work, the most recent NIAB booklets have provided a table giving quantitative varietal rankings for late-season stress tolerance according to stem reserves. The main candidates for inclusion as further routine assessments in RL trials to give indication of suitabilities to non-first wheats at an early stage of a variety's national usage would seem to be :

⇒ Economy of tillering.
⇒ Flowering date.

- Present results showed that for the group of varieties with intermediate yield responses to rotational position their non-first wheat performance was inconsistent from site-season to site-season. Introducing an explicit treatment structure into the RL trials system so that first and second wheat sites represent balanced contrasts across sites of light and heavy soil types might aid the provision of a data set more amenable to interrogation for the detection of these complex interactions.

- If chemical means of controlling the take-all fungus with a seed treatment become available in the near future, the consequences for management of non-first wheats, including variety choice, would need to be quantified. HGCA-funded Project (0035/01/97) has recently been commissioned to investigate the potential effects of chemical control of the take-all fungus on husbandry decisions (sowing date, variety, fertilizer N and seed rate) in non-first wheats.

3. VARIETAL RESPONSES TO SOIL N AND FERTILIZER N

BACKGROUND AND OBJECTIVES

Variation in soil nitrogen and performance

- About 10% of UK winter wheat is grown where the soil can provide more than two-thirds of N needed for optimal growth (*c.* 300 kg N/ha), about 30% is grown where the soil can provide between one and two thirds of this supply and the remaining 60% where the soil provides less than one-third of the optimum supply.
- The effect of soil N supply on crop processes is likely to be more significant prior to application of fertilizer N in the spring.
- The following traits were identified as potentially playing a role in conferring suitability to different soil mineral N environments:

  ⇒ Crop N offtake (without fertiliser this is equivalent to N recovered from soil N)
  ⇒ Recovery of fertiliser N (varies with site and weather conditions; average recovery is about 65%)
  ⇒ Green area index
  ⇒ Canopy N requirement (g/m^2) : (calculated by dividing the N in the canopy by its GAI)
  ⇒ Shoot number per m^2
  ⇒ Nitrogen harvest index
  ⇒ Grain N%
  ⇒ Harvest index and
  ⇒ Resistance to lodging.

Empirical evidence for varietal responses to soil N and fertilizer N supply

- As part of Sub-Project work prior to the commencement of the field experimental programme in 1993-4, an analysis of data provided by Levington Agriculture for a variety/fertilizer N trial series 1982-92 suggested certain findings. Effects due to introduction of variety from 1980 to 1989 were :

  ⇒ Grain yields increased by 0.96 t/ha (i.e. about 0.1 t/ha per year)
  ⇒ Grain N concentration (at 2.26%) did not change, so
  ⇒ N in the grain increased by 21 kg/ha,
  ⇒ N recovered from the soil decreased by 7.7 kg/ha, so
  ⇒ N required from fertilizer increased by 29 kg/ha.
  ⇒ Recovery of fertilizer N increased from 44 to 53%, so
  ⇒ N supplied as fertilizer increased by 56 kg/ha.

- The analysis indicated that at nil fertilizer N more modern varieties had poorer N offtake than older varieties, indicative of lower ability to acquire soil N. Also more modern varieties required more fertilizer N, were better at recovering it, and had higher N optima than older varieties.

Objectives

- To test whether there are varietal differences in crop N uptake and efficiency of utilization conferring differential relative performances under low and high soil N conditions.
- To examine the association between varietal traits, hypothesised to provide suitabilities to low and high soil N, and observed performance under conditions of contrasting soil N availability.

EXPERIMENTAL PROGRAMME

- Experiments were conducted at each of three sites (Boxworth, Cambridgeshire, Crossnacreevy, Belfast and Harper Adams, Shropshire) in three seasons (1993-4, 1994-5, 1995-6). Each experiment used a randomised factorial split-plot design. Nine or six residual soil N x fertilizer N treatment combinations were randomised on main plots: i.e. three soil N amounts (established in the set-up season (R0 (low), R1 (intermediate), R2 (high)) x three or two amounts of fertilizer N (F0 (nil) , F1 (40 kg N/ha), F2 (optimum fertilizer N). Ten varieties were randomised on sub-plots: Apollo, Avalon, Cadenza, Haven, Hereward, Hunter, Longbow, Mercia, Riband and Rialto. The varieties selected included bread and feed types and covered a range in ability to acquire soil N (based on results of Levington Agriculture data set analysis).

RESULTS

Soil mineral N residues established

- At Boxworth, R2 residues were generally greater than at the other sites, ranging from *c.* 260 kg N/ha in autumn 1993 to > 500 kg N/ha in autumn 1995. At Crossnacreevy, R2 residues were generally much lower than at Boxworth, with a maximum of from 103 kg to 54 kg N/ha. At Harper Adams, R2 residues were normally intermediate between those at Boxworth and Crossnacreevy.

Grain yield responses

Site effect

- Across all three seasons, F2 (optimum fertilizer N) grain yields for Boxworth were close to the norm for East Anglia. F2 yields at Crossnacreevy, in all three years, were slightly higher than the norm for this site. For Harper Adams, F2 yields were, as at Boxworth, close to the site norm.

Soil N residue effect

- Averaged across fertilizer N treatments, increasing residual soil N amounts caused an increase in yield for all site-seasons, except Harper Adams 94-5, but differences were only statistically significant at Boxworth (all seasons) and Crossnacreevy 95-6. In the presence of adequate application of fertilizer N in the spring (i.e. at F2), the overall effect of soil N residue treatment on yield performance was minimal, with means of 8.49 t/ha (R0), 8.33 t/ha (R1) and 8.48 (R2) t/ha. In the absence of fertilizer N (i.e. at F0), there were larger effects, with overall values of 4.76 (R0), 5.61 (R1) and 6.79 (R2) t/ha.

Variety effect

- Averaged over all nine site-seasons and soil N treatments:

  ⇒ At F2, yield varied between 7.9 t/ha in Avalon and 8.9 t/ha in Rialto. With the exception of Rialto (the most modern of the bread wheats) the bread-making varieties, as expected, were lower-yielding.

  ⇒ At nil N (F0), grain yield was 2.7 t/ha lower than at F2. Avalon was again the lowest yielding variety with 5.4 t/ha and Rialto the highest with 6.1 t/ha. Most varieties ranked similarly at both nil N (F0) and optimum N (F2).

Varietal responses to soil N

- The soil N/variety interaction was non-significant in seven out of the nine site-seasons, varieties generally ranking similarly with differing residual soil N amounts.
- For the two site-seasons where the interaction was statistically significant, Boxworth 95-6 and Harper Adams 94-5, the individual variety responses were not consistent :

  ⇒ At Boxworth 95-6, Avalon, Longbow and Mercia yielded relatively better at low soil N than at high soil N compared to Apollo and Rialto.

  ⇒ At Harper Adams 94-5, Apollo, Hunter, and Rialto yielded relatively better at lower soil N than at high soil N compared to other varieties.

Varietal traits

Shoot number

- At nil fertilizer N, there were more shoots for R2 (high soil N) compared to R0 (low soil N) in the spring for seven out of the nine site-seasons. The overall mean for R2 was *c.* 1000 shoots per m^2 compared with *c.* 850 shoots per m^2 at R1 and R0.
- At harvest, there were on average 119 (F0) and 57 (F2) more ears per m^2 in R2 (high soil N) plots than R0 (low soil N) plots, although differences were not statistically significant in eight out of nine site-seasons.
- Generally varieties responded similarly to differing soil N amounts. The soil N/variety interaction at harvest was only statistically significant in two out of nine site-seasons.

Crop N uptake

- At nil N, N offtake at harvest was 86 kg/ha at R0 (low soil N) compared with 158 kg/ha at R2 (high soil N). At F2 (optimum N), the respective means were 206 kg N/ha at R0 and 227 kg N/ha at R2.
- Averaged over site-seasons and soil N treatments, at nil N Rialto had higher N uptakes than other varieties consistently throughout the growing season.
- The variety/soil N interaction at harvest was non-significant in seven out of eight site-seasons where N offtakes were measured. Generally varieties responded similarly to differing soil N amounts in terms of their crop N uptake.

Green area index

- At nil N (F0), on average GAI at flowering increased from 2.6 at R0 (low soil N) to 5.1 at R2 (high soil N). At F2, the respective increase was only from 5.3 to 5.8.

- Averaged over soil N treatments, GAI at flowering varied between 4.9 in Cadenza and 6.4 in Hunter at F2. At nil N (F0), Cadenza had the lowest value of 3.3 and Hunter and Mercia the highest of 3.9.
- The Soil N/variety interaction was only statistically significant at two out of eight site-seasons where GAI was measured. At the two site-seasons where there was an interaction, the varietal responses observed were not consistent.

Canopy N requirement (ratio of shoot N uptake : green canopy area)

- At nil N (F0), CNR at flowering was similar at R0 (2.5 g/m^2) and R2 (2.7 g/m^2). At F2, CNR was again similar in R0 (3.9 g/m^2) and R2 (3.8 g/m^2).
- Averaged over all sites-seasons and soil N treatments, CNR at flowering ranged from 2.1 g/m^2 for Hunter to 3.0 g/m^2 for Cadenza at F0. At F2, it varied from 3.5 g/m^2 for Hunter to 4.4 g/m^2 for Cadenza.
- Only at one site-season out of eight where CNR was measured was there a statistically significant soil N/variety interaction. Generally the evidence was for a consistency of varietal ranking for CNR with differing soil N amounts.

Harvest above-ground crop dry mass

- At F0, harvest biomass increased from 10.1 t/ha at R0 (low soil N) to 14.4 t/ha at R2 (high soil N). At F2, the respective biomass increase was from 15.1 t/ha to 16.4 t/ha. The soil N effect was significant in four out of nine site-seasons.
- Variety differences were statistically significant in two of nine site-seasons, at Crosssnacreevey 94-5 and 95-6. There was some consistency in varietal rankings. At F2 , Rialto was the second highest ranking variety in each of the two site-seasons, whereas Avalon was in one case the lowest and in the other the third lowest ranking variety.
- The Soil N/variety interaction was only significant in two out of the nine site-seasons at Boxworth in 95-6 and Crossnacreevey in 95-6. At these two site-seasons, there was a consistent effect for Rialto to have relatively greater dry mass at R2 (high soil N) compared to R0 (low soil N).

Grain N%

- The soil N effect was statistically significant in eight out of nine site-seasons. At F0, it was 1.51% at R0 (low soil N) and 1.85% at R2 (high soil N). At F2, the increase was smaller, from 2.16% to 2.21%.
- Varietal differences were statistically significant at six out of nine site-seasons. At F0, Avalon and Hereward had high N% at most sites, and the converse for Haven, Longbow and Riband. At F2, Avalon and Hereward again had high N% and again conversely Haven, Longbow and Riband low N%.
- Although the soil N/variety interaction was statistically significant in three of the nine site-seasons, no consistent varietal responses to differing amounts of soil N were observed.

Overall summary for varietal traits

Extent of detectable soil N/variety interactions

- Summarizing across all varietal traits measured :

- ⇒ In early spring, statistically significant interactions did not occur on any of the 25 occasions when such interactions could have arisen.
- ⇒ At GS 31, two interactions out of a possible 36 were obtained.
- ⇒ At GS 65, five interactions out of a possible 40 were obtained, and
- ⇒ At harvest, ten out a possible 51 interactions were obtained.

- Thus, in general, there were few interactions between soil N residue levels and variety for characteristics potentially affecting crop N uptake and utilization.
- For no trait were different varietal responses to soil N consistently expressed across the nine site-seasons.

OVERALL CONCLUSIONS

Soil N and fertilizer N effects

- Although at nil fertilizer N, average grain yield increased from 4.8 t/ha at R0 (low soil N) to 6.8 t/ha at R2 (high soil N), in the presence of subsequent fertilizer application (i.e. at F2) the effect of soil N residues was minimal, with values in the range 8.3 to 8.5 t/ha.
- Savings in fertiliser costs may potentially be achieved where soil N is high. For example, 100 kg/ha soil N, 60% of which is recovered by the crop, would lead to savings of £40/ha in fertiliser N. From current experiments, it can probably be concluded that recovery of large amounts of soil N only has a significant detrimental effect on yield in the presence of fertiliser N when the crop has been grossly over-fertilised.

Varietal responses to soil and fertilizer N

- Overall the lack of consistent differences between varieties in their response to soil N suggested soil N residue status does not greatly affect relative varietal rankings for yield.
- Within the set of varieties examined, a few varieties stood out in having high/low expressions of traits. For example, Rialto had high N uptake and high biomass at all growth stages and Longbow generally low N uptake and low biomass. However, for a number of the traits most varieties fell into intermediate categories in their trait expressions of traits. The lack of consistent differences amongst varieties for traits hypothesised to affect crop N uptake and utilization was, therefore, consistent with the lack of observed soil N/variety interactions for grain yield.

Levington Agriculture data set analysis

- Despite the absence of evidence to corroborate the original hypothesis that varietal suitabilities to differing soil N backgrounds exist for currently commercial varieties, significant findings were produced from Sub-Project work through the analysis of the Levington Agriculture Fertilizer N/variety trial series showing :

    - ⇒ More modern varieties had lower N offtakes at nil N than older varieties, indicative of poorer ability to acquire soil N, and
    - ⇒ More modern varieties also required more fertilizer N, were better at acquiring it, and had higher N optima than their predecessors.

- Survey evidence indicates since 1985 national fertilizer N usage on winter wheat has remained broadly stable at *c.* 185 kg/ha N kg/ha. The inference from the Levington Agriculture data set analysis is that current usage may be underestimating the requirement for N now, or alternatively the requirement for N may have been overestimated in previous years.
- It seems breeders may have been selecting for varieties during the last 15 or so years better adapted to exploiting large amounts of fertilizer N. The corollary is that breeders may have inadvertently selected for modern varieties poorly adapted at acquiring soil N.
- It follows that in the future there may be scope for the testing agencies to keep a watch for cultivars prone to inefficient recovery of soil N or those with higher fertilizer N requirement than the norm.

4. VARIETAL RESPONSES TO LENGTH OF GROWING SEASON

HYPOTHESIS

- The hypothesis under test stated that there are consistent varietal differences in sensitivity to sowing date; that this depends on pattern of development and length of life cycle and that the physiological mechanisms affecting these characteristics can be identified and quantified. The particular plant characteristics selected for measurement were winter hardiness, vernalization, rates of development, green area growth, standing ability and length of life cycle.

EXPERIMENTAL PROGRAMME

- There were ten main experiments done over the period 1989-90 to 1993-4 at the ADAS Rosemaund and Arthur Rickwood Research Centres and at Cockle Park Experimental Farm, University of Newcastle-upon-Tyne. In all experiments a number of varieties with contrasting patterns of development and lengths of life cycle were sown over a range of dates from early in September to the middle of November. At ADAS Rosemaund and Arthur Rickwood eight sowings were made, about ten days apart, and in addition to routine crop monitoring, apex development and dry mass growth were measured. At Cockle Park, there were only two or three sowing dates, but a more complete set of growth and development observations were made.

GRAIN YIELD, HARVEST INDEX AND YIELD COMPONENTS

Grain Yield

- At ADAS Rosemaund and Arthur Rickwood, maximum yields were attained by October sowings. The trends at Cockle Park were less clear but maximum yields were often obtained from sowing 2 (early-to-mid October) or 3 (early-to-mid November).
- The most marked differences in response to sowing date were between early maturing spring varieties and mid-to-late season winter varieties. Examples are Rascal vs. Riband at Rosemaund 91-2 and 92-3, Arthur Rickwood 92-3 and Cockle Park 92-3.
- However, even when there were significant V x S interactions, variety rankings (absolute yield) were consistent across all instances with greatest yield over all sowing dates coming from mid-to-late season varieties, e.g. Riband and Beaver and the least from spring and early, quality varieties, e.g. Avalon.

Curve fitting for grain yield data

- At ADAS Arthur Rickwood and Rosemaund both the quadratic and the linear plus exponential functions were fitted to grain yield data vs. sowing date for individual varieties and fitted more or less equally well. In all cases estimates of effective optimum sowing date for maximum yield (S_{opt}) were later for the quadratic than the linear plus exponential function.
- Inspection of the estimates of S_{opt} did not indicate any systematic difference between varieties.
- There was no clear indication from the estimates of S_{opt} that varieties consistently gave their highest yields from sowing at particular periods during the season.

Yield components

- Variety was the only treatment which had a consistent effect on thousand grain weight. Where sowing date effects or the sowing date x variety interaction were significant, differences appeared to be due to lodging.
- For number of ears per m² (Cockle Park only), the only consistent effect was due to variety. The sowing date effects were confounded with differences in seed rate and the S x V interactions were probably due to differential lodging, e.g., Cadenza and Tonic which responded most strongly to sowing date had the greatest lodging scores.

Harvest index

- The only consistent factor to affect harvest index was variety. Neither sowing date nor the sowing date x variety interaction affected harvest index uniformly in all cases.

Conclusions

⇒ Harvest index is strongly affected by variety but not by sowing date.

⇒ Yield components are strongly affected by variety, but there was no consistent sowing date effect or sowing date x variety interaction.

⇒ Maximum yields were obtained from sowings made in October. However, the majority of experiments were affected by either lodging or the effects of dry seed beds, affecting early sowings detrimentally. Thus, there was nothing in the experimental data to contradict the hypothesis that greatest potential grain yield is obtained from mid-September rather than mid-October sowing dates.

⇒ Spring varieties and non-vernalization requiring winter varieties suffered the greatest yield loss from early sowing; this was probably due to their greater tendency to lodge.

⇒ High yield potential varieties such as Riband give the greatest yield at all sowing dates.

DEVELOPMENT

Overall development response to sowing date

- Developmental differences enable selection of varieties which match growth to the optimum environment and, or avoid stress. All development stages responded to sowing date with the earliest stages showing the strongest response. There were differences among varieties in the degree of response. These differences may be significant in crop management as the timing of developmental stages may affect yield potential.

Double ridge stage (DR)

- Effect of vernalization was evident in the contrast between winter and spring varieties at ADAS Rosemaund and Arthur Rickwood 91-2 and Cockle Park 92-3. Rascal, a spring wheat with low or nil vernalization response, developed rapidly when sown in September in relatively high temperatures and long days, but Avalon and Riband did not as their vernalization requirement was not fulfilled. In contrast, from October or November sowings, spring (Rascal) and winter (Avalon and Riband) varieties responded similarly. These plants were exposed to low, vernalization-effective temperature during the seedling stage and were fully vernalized soon after emergence.

- The role of photoperiod in determining date of DR was illustrated by the French winter wheat, Soissons at Cockle Park in 91-2 and 92-3. Its relatively late date of DR from early sowings indicated a strong vernalization requirement. When sown late it was the earliest to DR, indicating that its development was not restrained by short days of winter, once its vernalization requirement was satisfied. Thus Soissons appeared to have a strong response to vernalization and a weak response to daylength. The converse combination of attributes was shown by Spark. This behaviour may be explained by assuming that Spark has a particularly strong response to daylength.

Ear emergence or anthesis

- Differences among varieties in response to sowing date were similar to those observed for double ridges and similar control in relation to daylength and low temperature was evident.
- Differences in response to photoperiod post double-ridge (vernalization is considered to be complete by this stage) clearly reinforced and modified the differences observed at the double ridge stage. Soissons, though medium-to-late for date of the double ridge in the early sowings, was the earliest to ear emergence or anthesis in both early and late sowings, possibly indicating a weak response to daylength in the double-ridge to ear emergence or anthesis phase.

Phyllochron

- In all varieties the rate of leaf emergence was faster in the late than in early sowings but the change in rate of leaf emergence differed among varieties. The greatest change in response to sowing date was found in spring varieties such as Rascal, and the least in Hereward and Beaver.
- Varietal differences in phyllochron are significant in relation to rate of tillering as this is dependent on rate of leaf emergence. It is also an important component in some models which predict growth and/or development (Weir *et al.* 1984, Kirby and Weightman, 1997).

Conclusions

- To advance any technique to categorise varietal suitability for particular situations, (date of sowing or region) or to predict development, it will be necessary to characterise responses more fully than at present. Tests to provide such additional information should probably form part of a general testing system, and as far as possible be field based. For example, with some extra observations, the NIAB 'latest safe date' (for sowing) might form the basis of a metrical characterisation of vernalization response. While testing for photoperiod response under conditions of complete environmental control are out of the question, daylight extension in the field during the short days of winter could be possible using relatively cheap tungsten filament bulbs on an outdoor wiring rig.

GROWTH

Plant establishment

- Over the ten experiments, there was no clear evidence that factors such as declining temperature, wetter soils, and more difficult sowing conditions affected plant establishment in the later sowings. Rather, the dry seed beds which occurred in the early sowings appeared to be the main factor affecting number of plants. Plant mortality through the season did not appear to differ systematically with sowing date.

Lodging

- In the ten experiments, large observed differences in lodging among varieties in response to sowing date were consistent with their reported 'standing power' in the NIAB recommended lists (NIAB, 1989 et seq.). This supports the observations by Fielder (1988) that lodging in September sown crops was more severe in varieties with poor standing power. Some of the observed differences in the progress of lodging were also due to differences in development stage. Avalon and Rascal, which were generally the first to lodge, were also the earliest to the ear-emergence and anthesis stages.
- Lodging of early sown crops occurred in years when there was high dry mass at the ear-emergence or anthesis stages compared with later sowings. Any association between lodging, straw length and date of sowing was inconclusive.

Green canopy production

- Trends for green area index in the early part of the season (October to April samples) were consistent with the predictions by the ARCWheat model, that is, early sowing leads to earlier expansion of the canopy, greater GAI and greater green area duration than late sowing.

Crop dry mass

Dry mass pre-flag leaf emergence

- Two types of response could be distinguished. In one, exemplified by Arthur Rickwood 92-3 and Cockle Park 92-3, dry mass declined with later sowing. In the other type, illustrated by Arthur Rickwood 90-1 and 91-2, the response curve was 'hump backed', that is dry mass increased from the first sowing to some intermediate sowing and then declined with later sowings.
- The hump-backed responses were associated with years in which rainfall amounts were low over the first three to four sowing dates leading to erratic seedling emergence. In real time though, seedlings emerged first from sowing 1, second from sowing 2 and so on. Therefore reduced dry mass was not due to a shorter growing period and it appears that water shortage and protracted emergence inflicted some permanent damage on the seedling.

Post anthesis dry mass

- There were seven instances in which the relations between dry mass at about anthesis and at final harvest were compared; in three (Rosemaund 90-1, Arthur Rickwood 91-2 and Cockle Park 92-3) there was a positive correlation. In three of the other cases there was a negative correlation attributable to lodging.

Conclusions

- An important objective of this Sub-Project was to examine the hypothesis that physiological differences among varieties may adapt them to perform best from a particular part of the sowing season. Because of the intervention of purely agronomic factors (seedbed conditions and lodging) the effect of any physiological factors was often obscured. In the cases where effects were not obscured, differences in developmental physiology among the varieties did affect growth. The conclusions drawn are that :

  ⇒ Dry seed beds in early sown crops delay seedling emergence and may permanently affect plant growth and reduce dry mass.
  ⇒ Early sown crops are most susceptible to lodging and this may affect subsequent grain growth, and negate the possible advantages of early sowing.
  ⇒ In the absence of agronomic hazards crop growth conforms to the general prediction that early sowing makes available greater resources for growth and the dry mass response to sowing date was consistent with crop model predictions.
  ⇒ There was some evidence that physiological differences, such as rate of early development or long life cycle, adapted varieties to particular sowing dates.

Grain dry mass growth

- The duration of grain growth at Cockle Park 92-3 was uniform across varieties and sowing dates and the mean overall value was 716°Cd, which is similar to estimates obtained by Loss *et al.* (1989).

GENERAL CONCLUSIONS

Differences from hypothesis and model yield

- Yield responses were different from that expounded in the initial hypothesis and that simulated by the ARCWheat model. While the model predicted the highest yield from the earliest sowing (1 September) and a continuous decline as sowing is delayed thereafter, observed yields usually peaked at an October sowing. At Cockle Park, with only two or three sowing dates, maximum yield was observed mostly in the second or third sowing (October or November).

Yield vs. growth and final biomass

- In the absence of response of harvest index to sowing date, yield differences were a consequence of differences in biomass. In 1990-1 and 1991-2, dry seed beds depressed biomass in the early sowings. In 1992-3, when seedling emergence was normal, severe lodging in the early sowings severely affected post anthesis growth, so that the maximum final biomass occurred in the later sowings. In 1992-3, where growth patterns were not affected until lodging commenced at the post ear-emergence stage, the observed response of dry mass to date of sowing at this stage was consonant with the model predictions. Therefore, although maximum yield was generally not obtained from early sowings, the results did not totally negate the hypothesis that growth and yield potential would in general be greatest from early sowing.

Development, growth and yield

- Only where poor seed bed conditions or lodging were absent could the effect on yield of varietal differences in development be assessed with confidence. Only for Rascal at Cockle Park was there a clear illustration of an interrelation between growth and development. This example indicated that rapid development in response to early sowing resulted in frost damage which detrimentally affected dry mass and leaf area growth.

Sowing date and variety selection

- The experiments described in this report generally reinforce and extend the understanding of yield formation and plant development in relation to sowing date. Although the highest yields were not attained by the earliest sowings the physiological analysis indicated that, in the absence of hazards, early sown crops (i.e. early in September) have the greatest yield potential. Certain varietal characteristics are necessary to exploit the superior resources provided by early sowing. In adapted varieties either suitable levels of vernalization response, as exemplified by Riband, or photoperiod response, as exemplified by Spark, regulate development so that the vulnerable stages do not occur until risk of winter damage is past. With later sowing, slow development may delay anthesis so that conditions for grain filling are sub-optimal and harvesting may be difficult because of deteriorating weather conditions. Therefore varieties with lower vernalization and photoperiod response are more suitable for late sowing.

FUTURE WORK

Characterisation of varieties

- Development patterns adapt varieties for particular management practices, and are determined by difference in response to low temperature (vernalization), daylength, and differences in inherent earliness or basic development rate. For most British commercial varieties little is known about the detail of these responses other than anecdotal generalisations. To advance any technique to categorise varietal suitability for particular situations, (date of sowing or region) or to predict development, it will be necessary to characterise responses more fully than at present. With some extra observations, the NIAB 'latest safe date' (for sowing) might form the basis of a metrical characterisation of vernalization response. Tests based on existing NIAB 'latest safe date' data and weather records and on daylight extension in pilot small plot trials could be investigated to assess feasibility. In parallel with such tests, a radical review of the methods of recording and analysis is necessary. Present methods are based on the observation of cardinal stages (double ridge, terminal spikelet, etc.) which are of doubtful physiological or agronomic significance. Analysis then seeks to assess the affect of the environment on development of phases defined by these stages. This produces a scheme of great complexity, with probably more than 15 parameters needed fully to describe development. Consideration should be given to a technique based on rate of leaf emergence and final number of leaves. This describes development more realistically, with fewer parameters and is no more time consuming, substituting apex dissection with leaf counting.

- It is impossible experimentally to test variety response to all combinations of environmental variation due to sowing date, site and season. In conjunction with the development of techniques to characterise vernalization and photoperiod response, parallel development of a model, suitable for computer simulation of plant phenology might be envisaged. Such a model would form a tool to assess the utility of varietal tests, to predict development in average and extreme conditions and to monitor crop development on a (near) real time basis.

Lodging

- This study, like many others, has confirmed the relation between lodging, standing ability and early sowing (Fielder, 1988). The H-GCA Project 0050/01/92 provides a schedule of observations with which an analysis of the effect of sowing date on plant morphology could be analysed.

Dry seed bed effect

- If the long-term effects of delayed seedling emergence on growth are confirmed then they are of considerable significance. Further research on two aspects of dry seed beds is indicated. First, more information is needed on the effect of dry seed bed on plant development and morphology. Characters which might be measured are pattern of pre-emergence seedling growth and, post-emergence, root and tiller formation. Second, the effect of such factors as water use by volunteers from the previous crop and cultivation methods on seed bed water content warrants further study. Such information might establish quantitative criteria about the distribution and concentration of soil water necessary for satisfactory seedling growth.

Resource capture

- The use of a modelling method in this report to amplify the general hypothesis of the response of yield to sowing date focused attention on resource capture and growth. Any future work might further concentrate on canopy growth, radiation interception and dry mass production. The different rates of change in the radiation and temperature levels during the grain growth period is clearly important in relation to phenology and merits further analysis.

5. VARIETY TYPING TRALS

OBJECTIVES

- Variety 'Typing Trials' were established in four site-seasons : at ADAS Rosemaund 1993-4, ADAS Boxworth 1993-4, ADAS Rosemaund 1994-5 and Sutton Bonington 1994-5. The objectives were :

  ⇒ To define varietal variation for prioritised physiological traits over a wide range of genotypes.
  ⇒ To examine consistency of varietal rankings for traits across different sites and seasons.
  ⇒ To measure characteristics for the 18 varieties selected for testing in individual Sub-Project experiments concurrently in the same experiment.
  ⇒ To gain information on varieties under test in the individual Sub-Project experiments not available at the outset of the Project from existing data sets.
  ⇒ To test field methodologies with regard to precision and rapidity.

EXPERIMENTAL PROGRAMME

- Varieties were chosen so as to include all 18 tested in individual Sub-Project experiments, plus additional varieties to extend the range with respect to i) developmental rate (by including continental varieties) and ii) date of variety introduction (by including older, taller genotypes, e.g. Maris Huntsman - introduced *c.* 1970).

- The following traits were measured :

  ⇒ Extinction coefficient,
  ⇒ Date of GS 31 and GS 61,
  ⇒ Fertile shoots per m^2 at GS 31 and GS 61,
  ⇒ Canopy N requirement (g shoot N per m^2 green canopy area) at GS 39 and 59,
  ⇒ Soluble stem carbohydrate (g/m^2) at GS 61 +75°Cd and harvest,
  ⇒ Harvest above-ground dry mass (g/m^2) and harvest index,
  ⇒ Harvest above-ground crop N offtake kg/ha and N harvest index,
  ⇒ Grains per ear, and
  ⇒ Thousand grain weight.

VARIETAL VARIATION FOR TRAITS

- The varietal ranges for the 18 or 17 common varieties for which measurements were undertaken across 3 or 4 site-seasons are shown in the table below :

Varietal ranges, means and statistical significances for physiological traits for the 18/17 common varieties measured in Variety Typing Trials in 1993-4 and 1994-5.

Physiological trait	Site-seasons	Varieties	Var. Range	Var. mean	Statistical significance Variety	Site-season	V./S-s'son
Date of GS 31	3	18	20 d				
Date of GS 61	3	18	15 d				
K_{PAR}	3	18	0.44 - 0.66	0.56	<0.05	<0.01	<0.01
Max shoots/ m^2	3	18	873 – 1281	1052	<0.001	<0.001	<0.001
Final shoots/m^2	4	18	390 – 625	480	<0.001	0.013	<0.001
CNR g/m^2	3	18	2.29 - 3.62	2.83	<0.001	<0.001	<0.05
Stem CHO (GS 61+75°Cd g/m^2)	3	17	2.54 - 4.47	3.21	<0.001	<0.01	NS
Harvest biomass g/m^2	4	18	1386 – 1574	14.6	<0.001	0.01	<0.001
HI	4	18	0.48 - 0.52	0.50	<0.001	NS	<0.001
Harvest crop N offtake kg/ha	4	18	184 – 208	197	<0.01	<0.001	<0.05
Nitrogen harvest index	4	18	0.76 - 0.79	0.77	<0.001	<0.05	NS
Grain yield g/m^2	4	18	745 – 929	848	<0.001	<0.01	<0.001
Grains per ear	4	18	33.4 - 44.5	39.7	<0.001	<0.01	<0.001
Thousand grain weight g	4	18	36.0 - 51.5	45.7	<0.001	<0.001	<0.001

- For all traits, there were statistically significant differences amongst varieties (P< 0.05), with differences between at least some of the varieties being consistently expressed across environments.

Date of GS 31 and GS 61

- The range for date of GS 31 was 15 d for UK-bred varieties, extending to 20 d including the continental varieties examined. For GS 61, the corresponding ranges were 6 and 17 d, respectively. The varietal ranking orders for GS 31 and GS 61 were generally consistently expressed across all site-seasons.

Economy of tillering

- The varietal range for tiller economy (as indicated by the difference between the maximum and final shoot number) was 393 - 789 per m^2. This range corresponded to differences in dry mass lost in aborted shoots of between *c.* 1.5 - 2.5 t/ha (see Vol. II, Part 2, Varietal responses to rotational position). More work is needed to define the relationship between the umber of shoots lost and dry matter contained in these lost shoots more precisely.

Canopy N requirement

- Canopy N requirement varied amongst varieties from 2.3 - 3.6 g/m^2, implying that the amount of N required to generate optimal maximum canopy size of *c.* GAI 5 may vary amongst varieties.

Soluble stem carbohydrate

- The amount of soluble stem carbohydrate at GS 61+75°Cd (*c.* GS 61 + 5 d) differed amongst varieties in the range 2.5 - 4.5 t/ha. Differences were large enough to affect yield performance meaningfully in late-season stress environments, i.e. with drought or severe take-all. In such environments, the ability to amass more stem reserves confers tolerance of accelerated loss of green canopy and/or photosynthetic efficiency. Varietal differences were consistently expressed across site-seasons.

Total above-ground harvest dry mass

- More modern varieties showed a trend for greater dry mass at harvest in the overall range 13.9 - 15.7 t/ha. This trend appeared to be associated with the possession of the 1B/1R rye chromosome translocation , which has been cited by breeders as conferring a 'stay green' effect on the lower canopy during senescence (Blackman, personal communication). There was little evidence for differences in water use efficiency amongst varieties in the Drought Sub-Project (see Vol. II, Part 1). Therefore, greater biomass for some varieties may be indicative of a greater capacity for water uptake and possibly with investment in a more extensive rooting system.

FEASIBILITY OF ASSESSMENT METHODOLOGIES

- In terms of labour requirement and rapidity of assessments, current work showed there is scope for introducing measurements of :

  ⇒ date of GS 31 and GS 61,
  ⇒ fertile shoot numbers per m^2 at GS 31 and GS 61,
  ⇒ amount of stem reserves per m^2 at GS 61+75°Cd , and
  ⇒ above-ground harvest dry mass (g/m^2)

  into field experimental programmes testing large numbers of varieties.

- The current methodology for measuring canopy N requirement would, however, need to be improved to reduce the time involved in estimating green areas before it could be applied routinely to programmes testing large numbers of varieties.

FUTURE WORK

- Future work could concentrate on :

  ⇒ Introducing assessments of some traits on a permanent basis into a sub-set of RL trial sites (see Vol. V, Part 2, discussion). The most obvious candidates would appear to be :

  ◊ date of GS 61... indicating suitability to drought-prone soil types and second or subsequent wheats
  ◊ shoot numbers per m^2 at GS 31 and GS 61, allowing estimates of economy of tillering ... indicating suitability to second and subsequent wheats
  ◊ amount of stem reserves accumulated at GS61+75°Cd per m^2 ... indicating suitability to drought-prone soil types and second or subsequent wheats.

6. NIAB ADDITIONAL CHARACTER ASSESSMENTS

OBJECTIVES

- The objective was to provide NIAB testers with the opportunity to test candidate traits developed in Project work at an early stage in their own RL trials. This would allow examination of the feasibility of proposed methodologies in large numbers of testers' plots. Some promising indicative characters were already known at the mid-term stage of the Project and were put forward as of immediate potential use to variety testers, namely :

  ⇒ Date of GS 31 ... indicative of suitability to sowing date,
  ⇒ Date of GS 61 ... indicative suitability to sowing date, drought and second wheat environments and
  ⇒ Amount of stem soluble carbohydrate reserves at GS 61+75°Cd ... indicative of suitabilities to drought and second wheat environments.

- In addition to the main objective, subsidiary objectives of the NIAB Additional Character Assessments were to :

  ⇒ Corroborate varietal ranges for traits established in Typing Trials and individual Sub-Project experiments.

  ⇒ Characterise newest candidate varieties in RL trials for important indicative traits.

EXPERIMENTAL PROGRAMME

- Additional Character Assessments were measured in two fungicide-treated replicates of winter wheat RL trials at five sites in 1994-5 :

  ⇒ Bridgets
  ⇒ Rosemaund
  ⇒ Harper Adams
  ⇒ Headley Hall
  ⇒ Cockle Park

  and three sites in 1995-6 :

  ⇒ Rosemaund
  ⇒ Harper Adams
  ⇒ Headley Hall.

- The additional characters assessed in 1994-5 were :

  ⇒ Date of GS 31,
  ⇒ Date of GS 61,
  ⇒ Harvest index (allowing for the calculation of above-ground harvest biomass) and

⇒ N Harvest index (allowing for the calculation of total harvest N offtake).

Those in 1995-6 were :

⇒ Date of GS 31,
⇒ Date of GS 61,
⇒ Fertile shoot number per m^2 at GS 31 and GS 61 and
⇒ Stem soluble carbohydrate dry mass at GS 61+75°Cd and harvest.

VARIETAL RANGES AND FEASIBILITY OF ASSESSMENT METHODOLGIES

Date of GS 31 and GS 61

- The varietal range for date of GS 31 was 25 (94-5) and 17 d (95-6), and for GS 61 17 (94-5) and 13 d (95-6). The feasibility of assessing these stages in NIAB RL trials was demonstrated. For varieties common to NIAB Additional Character Assessments and Typing Trials assessments, variety ranking orders were broadly consistent for dates of both development stages.

Tiller production and survival

- The NIAB assessments in 95-6 generally corroborated varietal differences in tiller production and tiller survival determined in the Variety Typing Trials (see Vol. V) and the Drought and Rotational Position Sub-Projects (see Vol. II, Parts 1 and 2). The overall range was 955 - 1602 fertile shoots per m^2 at GS 31 and 521 - 852 per m^2 at GS 61+75°Cd. The feasibility of assessing fertile shoot number in NIAB RL trials was demonstrated.

Soluble stem carbohydrate

- The overall varietal range in 95-6 was *c.* 2 - 4 t/ha. This corroborated findings in Variety Typing Trials (see Vol. V) and the Drought and Rotational Position Sub-Projects (see Vol. II, Parts 1 and 2). The feasibility of assessing stem reserves in RL trials was shown. There was a tendency for the higher yield potential, modern varieties to have greater amounts of stem reserves. There was close correspondence between varietal rank orders in the NIAB Additional Character Assessments and Typing Trial data sets for common varieties.

Harvest above-ground dry mass

- Varietal differences for harvest above-ground dry mass in 94-5 were statistically significant ($P< 0.05$) when analysed across sites, with values in the range 12.7 - 15.0 t/ha. The feasibility of measuring harvest dry mass in RL trials was demonstrated. As in the Variety Typing Trials, there was a tendency for the more modern varieties to have greater dry mass compared to their predecessors.

Harvest crop N offtake

- There were statistically significant variety differences for crop N offtake at harvest within the range 149 -171 kg/ha N ($P< 0.001$) from the cross-site analysis for assessments in 95-6. The feasibility of measuring this character will be essentially the same as that for harvest dry mass; however, there is an additional cost of *c.* £5 per plot for the chemical analysis.There was a tendency for greater N offtakes for the more recently introduced varieties compared to older varieties, corroborating findings in the soil N availability Sub-Project (see Vol. III).

FUTURE WORK AND GENERAL CONCLUSIONS

- Ultimately, it is desirable that the industry fully exploits any consistent interactions between variety and growing conditions, such as have been shown in this Project. However, this cannot happen without it first being shown that it is feasible to characterise indicative traits for large numbers of plots in NIAB NL and RL trials. The feasibility of assessing target physiological traits over larger numbers of testers' plots was demonstrated for all traits examined in NIAB trials in 1994-5 and 1995-6. Given that it was shown to be practical, routine measurements of traits at a restricted sub-set of sites, if introduced, will involve additional effort and costs. These additional efforts and costs have been quantified in the work of the current Project (see Vol. V, Part 2).

- The prime means for communication of specific varietal information within the industry has been the RL published by NIAB, and associated organisations; the most recent published tables not only give ratings for resistance to diseases, standing power, and latest safe sowing dates, but also show average amounts of stem WSC, and these are accompanied by preliminary attempts at classifying varieties for suitabilities to different levels of site fertility and rotational position, as well as soil type (NIAB, 1997).

- Undoubtedly there is scope to increase and improve the provision of such information through further research and development, but this raises questions concerning : the extent to which measurements of traits can be applied to numerous candidate varieties, i.e.

  ⇒ the extent to which variety classification can depend on indicative traits,
  ⇒ the feasibility of measuring numerous traits in testers' trials,
  ⇒ the extent to which NL and RL trials should include special sites or treatments which specifically vary growing conditions, e.g. levels of fertility, drought or sowing date,
  ⇒ whether it will be economic to breed varieties and supply seed for resultant niche markets, and
  ⇒ whether growers and their supporting industries are willing to pay greater attention to detail to accommodate the increasing complexity that will affect their management decisions.

- The extent to which these extra costs will be accepted must depend on the extent of the benefit which results. The size of the interactions shown in the current Project, particularly in relation to varietal responses to drought and rotational position, would undoubtedly be sufficient to support some changes in the industry's practices.

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