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EXPLOITATION OF VARIETIES FOR UK CEREAL PRODUCTION (VOLUME IV)

VARIETAL RESPONSES TO LENGTH OF GROWING SEASON

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(VOLUME IV)

VARIETAL RESPONSES TO LENGTH OF GROWING SEASON

by

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Summary

The hypothesis under test stated that there are consistent varietal differences in sensitivity to sowing date and that this depends on pattern of development and length of life cycle. There were ten main experiments 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 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. Maximum yields were usually obtained from October sowings. However, the majority of experiments were affected by either lodging or dry seed beds, affecting early sowings detrimentally. Thus, there was nothing in the data to contradict the hypothesis that greatest potential grain yield is obtained from mid-September rather than mid-October sowing dates. The most marked differences in response to sowing date were between early maturing spring varieties and mid-to-late season winter varieties, e.g. Rascal vs. Riband. 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. With regard to developmental responses, the effect of vernalization on date of double ridge stage was evident in the contrast between winter and spring varieties. Rascal, a spring wheat with low or nil vernalization response, developed rapidly when sown in September in relatively high temperatures and long days, whereas Avalon and Riband did not as their vernalization requirement was not fulfilled. Soissons appeared to have a strong response to vernalization and a weak response to daylength. The converse combination of attributes was shown by Spark. An important objective of the work 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. The main conclusions drawn are that : i) dry seed beds in early-sown crops delay seedling emergence and may permanently affect plant growth and reduce dry mass, ii) early-sown crops are most susceptible to lodging and this may affect subsequent grain growth, and negate the possible advantages of early sowing and iii) 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. 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, regulated development so that the vulnerable stages did not occur until risk of winter damage was 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. From currently reported work there was some evidence that physiological differences, such as rate of early development or long life cycle, adapted varieties to particular sowing dates. It is concluded that to advance any categorisation of varietal suitability for particular situations, (date of sowing or region), it will be necessary to establish methods for undertaking metrical characterisation of vernalization and photoperiod varietal responses in the UK variety evaluation system.

CONTENTS

1. INTRODUCTION

In Britain, wheat is sown over a wide range of dates, starting early in September and continuing, at least in a few cases, until January or February, the 'latest safe date' (NIAB, e.g.1994). The majority of crops are sown during October but a substantial proportion of the total area of winter wheat is sown earlier (19%) or later (16%) (Polley & Slough, 1993; Foulkes, *et al.*, 1994).

Highest yields are, on average, achieved by crops sown in the second half of September and then there is a continuous decline with later sowing until February when it is no longer possible to sow winter varieties (Bingham *et al.*, 1983; Green and Ivins, 1985; Fielder, 1988; Fenwick, 1991). A similar response to date of sowing has been established for yield of winter barley (Green *et al.*, 1985) and for spring barley (Bell and Kirby, 1966). The superiority of early sowing can be explained by earlier canopy closure, enabling the crop to intercept more radiation and, therefore, to accumulate a greater biomass. Also the longer growing season leads to a greater maximum green area and the grain filling period occurs when temperature and radiation levels are optimal.

Recently there has been a desire by some farmers to exploit the perceived high-yield potential of early sowing. Sowing, as reported in the farming press, may be as early as the second half of August. This calls for considerable management skills, including the selection of varieties best adapted for early sowing. On the other hand, sowing may be delayed until sugar beet or potatoes have been lifted. Selection of variety is again important and different characteristics may be necessary to obtain optimum results.

There is evidence that varieties differ in their response to date of sowing (Bingham *et al.* 1983; Fielder, 1988). For example Bingham *et al.*, showed that although Longbow and Norman out-yielded Avalon from sowing dates early in September, yields of later sown crops were similar.

Clearly it is important to confirm that varietal differences in response to date of sowing occur in most situations and that they are consistent from year to year and amongst sites. If differences do occur, then it is worthwhile to identify those varieties which have the highest yield or greatest economic return when sown at a particular part of the season.

Classification of varieties suitable for early or late sowing involves extensive sowing date experiments conducted over several years, e.g. ADAS-NIAB trials 1982-87 (Fielder, 1988). During this time the spectrum of varieties can change, as some varieties do not come up to expectation. An alternative approach may be to identify physiological characters which determine yield response to sowing date. Screening varieties for such characters may provide the basis for a more efficient method of classifying varietal response to sowing date.

Attempts to explain variation among varieties of yield response to sowing date have identified two broad categories which affect response to the environment throughout the life cycle. One line of research has concentrated on the avoidance of stress (mainly temperature or water stress) at critical times in the life cycle. Most examples come from countries with climates more extreme than Britain; for example, in Australia, date of sowing and length of life cycle are paramount considerations for the avoidance of the extreme high temperature and drought at the end of the growing season (Hay & Kirby, 1991).

The other approach is to examine the effect of date of sowing on the relationship between a particular phase of the life cycle and the environment to identify optimum conditions for maximum yield. For example, the conditions prevailing during the grain filling period, when relatively low temperature and adequate water supply are necessary for optimum grain filling. The two approaches are similar, but one attempts to identify catastrophes (e.g. severe frost or high temperature) while the other identifies optimum conditions for growth, as far as they are known. A corollary of these considerations is that length of life cycle is an important characteristic in determining response to date of sowing.

1.1. Projects to examine variety adaptation to sowing date

One of the conclusions from the ADAS/NIAB sowing date/variety trial series reported by Fielder (1988) was that improved monitoring of individual experiments would permit better comparison of data between sites and seasons, and allow a more detailed interpretation of the results from each site. It was suggested that regular assessments of plants per m^2, tillers per m^2, ears per m^2 (post GS 55) and total above-ground dry weight should be undertaken. The target dates of December, early March, GS 31, GS 39 and GS65 and leaf area index = 0, and pre-harvest were proposed. Another recommendation from this work was that more than two sowing dates should be included in experiments to detect with greater precision the response of varieties to sowing date. In part, in response to such previous work, ADAS initiated a series of experiments at ADAS Rosemaund and ADAS Arthur Rickwood 1990-94 where four varieties were tested at eight sowing dates and plots were intensively monitored for patterns of shoot production and survival and dry mass production. The current project work located at Cockle Park Experimental Farm, University of Newcastle-upon-Tyne aimed to study suitabilities of varieties to particular sowing date windows in a broadly similar way, although the crop growth measurements were more strategically aimed at particular features of physiology and included, for example, assessments of green canopy surface area throughout the season which were not assessed in the ADAS Rosemaund/Arthur Rickwood exercise.

1.2. Hypothesis

The hypothesis which the projects set out to test was explained in the application for the project 'Exploitation of varieties for UK cereal production' (1991), 'A study of the effect of the length of growing season on cultivar performance in autumn sown wheat. Proposed experimental protocol' by E.J. Evans and D.P. Murphy (1991) and 'Minutes of a meeting held at Rothampsted initiated by H-GCA to explore possible funding for sowing date experiments' (undated).

In summary the hypothesis states 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 plant characteristics selected for measurement were winter hardiness, vernalization, rates of development, standing ability and maturity date (Proposal document). Also identified were green area growth, rooting, tillering and yield formation (Minutes).

1.3. Experiments

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-on-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 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.

1.4. Report structure

In previous paragraphs, variety adaptation was rationalised with reference to a pattern of growth and development most suited for the environment generated by a sowing date. That is, a well defined trend in growth and yield in response to sowing date was anticipated, based on hypothetical considerations and previous experimental work. Departure from this trend by one variety relative to another might then be explained by such factors as differences in development rate rendering the varieties differentially able to exploit the environment.

A first glance at the yield, section 5, reveals that the yield responses were not consistent with the hypothesis and varied among sites, seasons and varieties. Because of this some prominence is given to an examination of the sowing date response, *per se*, as well as differences in variety response to sowing date. In particular the factors affecting growth are studied in detail in section 4 before the significance of any differences in development among varieties is summarised in the general discussion section 6.

2. MATERIAL AND METHODS

2.1. Sites

The experiments were sited at ADAS Research Centres at Rosemaund and Arthur Rickwood and at Cockle Park, University of Newcastle-on-Tyne (Table 2.1).

Table 2.1. *Site details*

Site	Code	Map reference	Latitude
ADAS Research Centre, Rosemaund	RM	SO565480	52.1° N
ADAS Research Centre, Arthur Rickwood	AR	TL434816	52.25° N
University of Newcastle, Cockle Park	CP	NZ195914	55.1° N

2.2. Sowing dates

Eight sowings were made during each season at RM and AR from 1989-90 to 1992-3. The sowings were planned at ten day intervals from 1 September onwards. The sowings are sometimes referred to in the text as 'sowing 1 ...' rather than by date; e.g. 'RM 92-3, sowing 8' refers to the sowing made on 13-November 1992 at Rosemaund in the 1992-3 season (Table 2.2a).

Two or three sowings per season were made at CP. The sequential numbering of the sowings is shown in Table 2.2b.

Table 2.2. *Sowing date and number for a) Rosemaund and Arthur Rickwood and b) Cockle Park.*

a)

	RM 89-90	RM 90-1	AR 90-1	RM 91-2	AR 91-2	RM 92-3	AR 92-3
Sowing	Sowing date						
1	9-Sep	1-Sep	1-Sep	1-Sep	3-Sep	4-Sep	2-Sep
2	21-Sep	11-Sep	11-Sep	11-Sep	11-Sep	13-Sep	11-Sep
3	29-Sep	21-Sep	22-Sep	21-Sep	21-Sep	24-Sep	22-Sep
4	9-Oct	1-Oct	1-Oct	1-Oct	1-Oct	5-Oct	1-Oct
5	18-Oct	11-Oct	11-Oct	11-Oct	11-Oct	13-Oct	12-Oct
6	30-Oct	21-Oct	22-Oct	20-Oct	21-Oct	23-Oct	22-Oct
7	7-Nov	31-Oct	1-Nov	29-Oct	1-Nov	2-Nov	3-Nov
8	16-Nov	8-Nov	13-Nov	11-Nov	11-Nov	13-Nov	12-Nov

b)

	CP 91-2	CP 92-3 A	CP 92-3 B	CP 93-4
Sowing	Sowing date			
1	5-Sep	4-Sep	4-Sep	13-Sep
2	15-Nov	1-Oct	13-Nov	11-Oct
3		13-Nov		2-Nov

2.3. Varieties

Four varieties were selected for study in each year at RM and AR and in the growth analysis experiments at CP (CP 91-2 and CP 92-3, experiment A),(Table 2.3).

In addition, at CP a larger number of varieties were studied less extensively (1991-2 and experiment B, 1992-3); these are listed in Appendix table 3. Six varieties were selected at CP in 1993-4.

Table 2.3. *List of varieties.*

Site	Varieties
RM 89-90	Apollo, Avalon, Riband, Pastiche
RM, AR 90-1	Apollo, Avalon, Riband, Pastiche
RM, AR 91-2	Avalon, Beaver, Rascal, Riband
CP 91-2	Avalon, Riband, Slejpner, Tonic
RM, AR, CP 92-3	Avalon, Beaver, Rascal, Riband
CP 93-4	Avalon, Avital, Beaver, Rascal, Riband, Zentos

Avalon and Riband were common to all experiments; both are winter varieties, but on the basis of previous studies Riband was expected to be more suitable for early, September sowing, whereas Avalon achieved its best yield from later, October sowing. The other winter varieties were chosen on the basis of their maturity rating, e.g. it was postulated that the late variety Beaver would perform best from early sowing.

In 1991-2 to 1993-4, the spring varieties Rascal and Tonic were also included in all sowings of the main experiments and other spring and non-vernalization requiring varieties were included in the experiments at CP (1991-2 and experiment B, 1992-3, Appendix table 3). These are clearly unsuited to early sowing, but provide a contrast of physiological responses which may adapt variety to sowing date.

2.4. Weather

Maximum and minimum temperatures and rainfall were obtained from Agro-met weather stations near to the experiment sites. At RM radiation data were obtained from on-site solarimeter records and at CP from Close House Weather Station. A summary of monthly values for mean daily temperature, cumulated rainfall and daily mean radiation is given in Appendix table 1.

2.5. Plot management

Cultivation and fertiliser application were based on local practice and details are given in Appendix table 2, together with notes of soil type and analysis and previous cropping. Seed rates varied within and among site x year instances (Table 2.4).

Table 2.4. *a).Seed rates at RM and AR (kg/ha, 1989-90, seeds/m² otherwise) b) seed rates at CP (seeds/m²)*

	RM 89-90	RM 90-1	AR 90-1	RM 91-2	AR 91-2	RM 92-3	AR 92-3
				Seed rate			
	170	375	375	375	375	375	375

b)

	CP 91-2	CP 92-3 A	CP 92-3 B	CP 93-4
Sowing		Seed rate		
1	400	400	400	400
2	600	400	600	400
3		600		400

Generally, plots were managed to exclude the effects of fungal disease, pests and weeds on growth and yield. Growth regulators (straw shorteners) were applied at Rosemaund and Arthur Rickwood. The details of the agro-chemicals and their time of application are given in Appendix table 2.

2.6. Experimental design and statistical analysis

At all sites and in all years a split plot experimental design was used, with sowing date main plots and variety sub-plots. There were either two or four replicates. Separate plots were used for sampling for growth and development and for combine yield. The whole area of one plot was harvested for final combine yield and random quadrat samples from pre-determined positions were taken from the other plot for growth analysis measurements (Table 2.5).

Table 2.5. Plot size and quadrat size.

Site	Plot size	Quadrat size
RM 89-90	24 x 2.05m	4 x 0.25m²
RM 90-1	24 x 2.05m	4 x 0.25m²; 3 x 1m of row*
AR 90-1	16 x 2.05m	4 x 0.25m²
RM 91-2	24 x 2.05m	4 x 0.25m²; 3 x 1m of row*
AR 91-2	16m x 2.05m	4 x 0.25m²
CP 91-2	20m x 1.88m	2 x 0.5m rows (0.26m²)
RM 92-3	24 x 2.05m	4 x 0.25m²
AR 92-3	16m x 2.05m	4 x 0.25m²
CP 92-3	20m x 1.88m	8 x 0.5m rows (0.52m²)
CP 93-4	20m x 1.88m	

*Post GS59

The significance of the response to sowing date (S) and variety (V) and of any interaction between them (S x V) of the characters measured was tested by analysis of variance (ANOVA), using GENSTAT (GENSTAT 5 Reference Manual). Other types of statistical analysis are referred to in the sections where they were employed.

2.7. Sampling

In the 1990-1, 1991-2 and the 1992-3 series of experiments samples were made through the growing period to measure growth and development characters. The basis upon which the sequential samples were made varied; in some cases samples were taken on a date basis, i.e. all treatments were sampled on the same day. Another strategy was to sample on the basis of stage of development, i.e. plots were sampled when the plants had achieved, for example, the double ridge stage and therefore over a range of dates. In other experiments samples were taken when a defined period of thermal time from sowing had elapsed, for example, 800°Cd; in this case all varieties within a sowing were sampled on the same date, but sampling date varied amongst sowings.

Details of the sampling method employed are given in the relevant sub-sections, but as this introduced complications in analysis and data presentation, the reader should be wary for differences in technique.

2.8. Measurements

In all instances yield and some yield components were measured. In the 1991-2 to 1992-3 seasons, some growth and development analyses were also done. Measurements were generally done using standard methodologies described in the Common Protocol (Vol. I, Part1, Section 6). Where they differed among sites, details are given in the relevant section (i.e. 3.Development, 4.Growth or 5.Yield).

3. DEVELOPMENT

3.1. Introduction

One facet of the selection of suitable varieties for a particular sowing date is matching the life cycle of the plant to the changes in the environment which occur through the season. Ideally, growth and development phases should take place when the environment is most favourable or should avoid environmental conditions which may damage the plant.

While winter is clearly a stressful period for plant growth and survival, recent seasons have not tested the difference in frost resistance among winter varieties. The sowing of spring varieties in the autumn has, however, shown how more rapid development may increase the risk of damage by low temperature. Rapid development of the shoot apex and earlier ear initiation, marked by the double ridge stage, are associated with physiological changes in the plant, including the beginning of stem elongation. The elevation of the apex above soil level, removing it from the insulating effects of the soil, renders the young ear more susceptible to sub-zero temperatures.

Frost, in the form of radiation frosts, may also damage the developing ear at around the time of ear emergence, killing the flowers or young grains. While this is common in the earlier flowering winter barley, it is less well known in wheat. With the advent of early continental varieties such as Soissons, care may be needed in the management of such variety types to avoid the hazard of radiation frosts which may occur until the end of May in some areas.

To maximise yield, grain filling must occur when the environment allows a long period of growth and adequate radiation for photosynthesis. It must also be early enough so that harvesting operations are not hampered by poor drying conditions.

Drought, though less of a hazard than in countries like Australia, may reduce yield in some areas of Great Britain. Drought avoidance is an important mechanism to maximise yield in drought conditions, using varieties with life cycle lengths which allow adequate growth, but in which the grain filling period occurs before severe water deficit stops growth.

In the experiments described in this report, a number of development stages were observed and their response to a wide range of sowing dates and their relation to environmental conditions were studied. Some spring and early maturing varieties were included; while such varieties would not normally be sown early in the season, their inclusion extended the range of response and clarified trends of behaviour which would not normally be seen with orthodox management.

3.2. Methods

Frequent samples were taken from November onwards to estimate the date when the double ridge and terminal spikelet stages occurred. At RM and AR, 5 plants per replicate were removed from two replicates; at CP observations were made on six plants taken from the first replication. At each sampling the main shoot was dissected and a stage was recorded when most plants were at or beyond the stage in question.

Flag leaf emergence, ear emergence and anthesis were scored when 50 percent or more of all shoots in the plot were at or beyond the stage under observation. A summary of the stages observed in each site x year instance are shown in Table 3.1.

Table 3.1. Summary of development stages observed in each site x year.

	Double ridge	Terminal spikelet	Flag leaf emergence	Ear emergence	Anthesis
RM 89-90	√	√			
RM 90-1	√	√			
AR 90-1			data incomplete		
RM 91-2	√		√	√	
AR 91-2	√	√			
CP 91-2	√	√	√	√	
RM 92-3	√	√	√	√	
AR 92-3	√	√			
CP 92-3	√	√	√	√	√

At CP 92-3 number of leaves on the main shoot and number of tillers were counted at intervals throughout the season. Counts were made on ten marked plants in permanent sub-plots established in replicate 1 of the growth analysis plots. The number of tillers in two adjacent 0.5 m lengths of row was counted in 3 replicates at RM and AR once or twice during life cycle at about the time of maximum number of tillers.

3.3. Results

Details of all observed dates of development are shown in Appendix table 3.

3.3.1. Overall development response to sowing date

Typical responses to sowing date are shown for Avalon in Fig. 3.1. For stages other than the double ridge stage the overall span of time for the occurrence of a stage was less than the span over which the sowings were made. Thus, in the case of anthesis at CP 92-3 the variation in the date of anthesis was 8 days compared with 70 days from first to last sowing. At RM 92-3, ear emergence occurred over a period of 21 days, compared with a sowing period of 71 days.

At CP 92-3 there were 82 days from the earliest to the latest occurrence of the double ridge stage compared with the 70 day span of sowing dates. The period over which the double ridge stage occurred at RM 92-3 was 119 days compared with the 71 day sowing period. The delay in the of occurrence of a stage for each days delay in sowing is summarised in Table 3.2.

Table 3.2. Delay (days) in the occurrence of a stage for a days delay in sowing. Estimates from linear regression of date of development stage vs. sowing date.

	Double ridge	Terminal spikelet	Flag leaf emergence	Ear emergence	Anthesis
CP 92-3	1.1	0.6	0.3	0.1	0.1
RM 92-3	1.8	0.7	0.2	0.3	

Therefore, in the case of Avalon, with the exception of the double ridge stage the effect of sowing date on date of attainment of a development stage becomes less with advancing stage and by anthesis the difference in days may be only about one tenth of the range in days of the sowing dates.

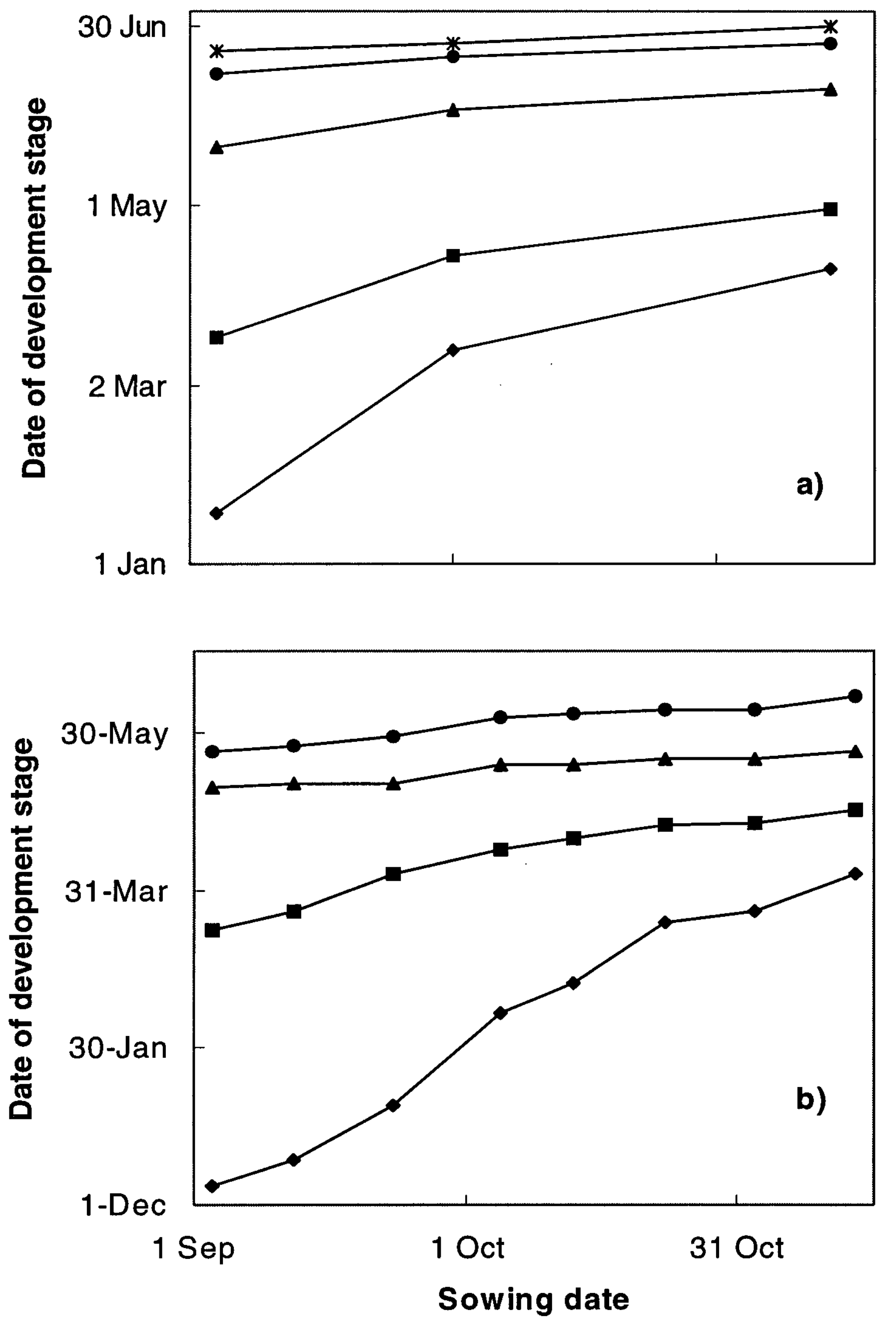


Fig. 3.1. Date of development stages for Avalon. a) Cockle Park 1992-3; b) Rosemaund 1992-3. The symbols are ◆, double ridge stage; ■, terminal spikelet stage; ▲, flag leaf emergence; ●, ear emergence and -x-, anthesis

3.3.2. Variety differences in response to sowing date.

As shown in the previous section, the greatest response to sowing date was found for the double ridge stage and the least for later stages of development such as ear emergence or anthesis. Because these stages are of particular significance for both the agronomy and physiology of the crop, they are used to illustrate varietal response to sowing date.

3.3.3. Rosemaund and Arthur Rickwood

3.3.3.1. Double ridge stage

At both sites and in all years there were differences in response to sowing date among varieties. This was most clearly shown at RM 92-3, where the full ranges of sowing dates was sampled for all varieties except Beaver (Fig. 3.2). From the first sowing in 1992-93, Rascal attained the double ridge stage on 16 October, 53 days before Avalon (8 December) which was 10 days earlier than Riband (18 December).The differences at each subsequent sowing after this tended to become smaller and from the October and November sowings the difference among varieties was more or less constant (Fig. 3.2). On average, over this period of sowing, Rascal was 13 day days earlier than Avalon which was 4 days earlier than Riband. Similar responses were found at RM 91-2, AR 91-2 and AR 92-3, although there were fewer data (Appendix table 3).

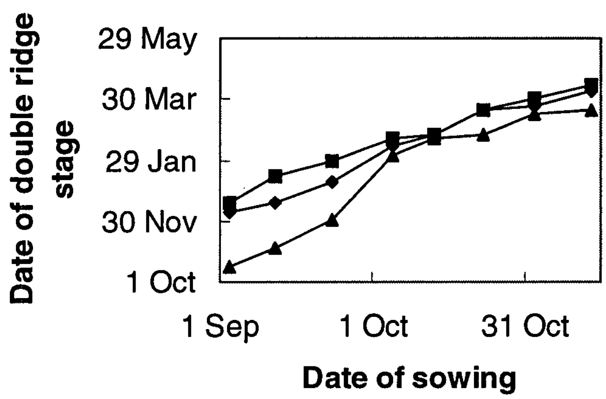


Fig. 3.2 Rosemaund 1992-3. Date of double ridge stage vs. date of sowing. The symbols are: ◆, Avalon; ■, Riband and ▲, Rascal

At Rosemaund in 1989-90 the dates when the double ridge stage was detected were generally the same in all varieties. In 1990-91, when Avalon and Apollo were observed, no systematic difference in response to sowing date was apparent. On average the double ridge stage occurred 6 days earlier in Avalon.

3.3.3.2. Ear emergence

Ear emergence was measured only in RM 91-2 and RM 92-3. The most complete data were for RM 92-3 (Fig. 3.3). In this year the greatest response was seen in Avalon and Rascal where the difference between the first and last sowing was 21 and 23 days respectively. Riband and Beaver had weaker response to sowing date, the latest sowing delaying ear emergence by 11 and 10 days. The difference between Beaver, the latest, and Rascal, the earliest, variety declined from 21 days in the first sowing to eight days in the last sowing.

In RM 91-2 a similar response was observed, but there was a restricted set of observations for Riband and Rascal (Appendix table 3).

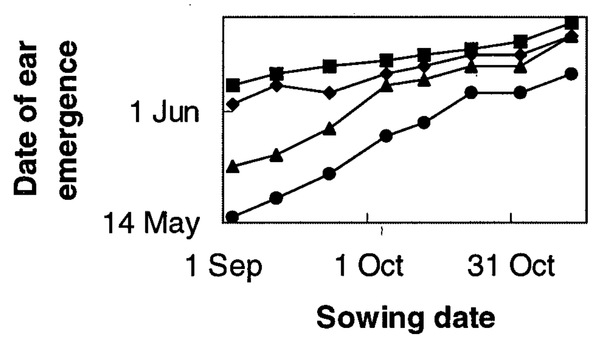


Fig. 3.3. Rosemaund 1992-3. Date of ear emergence vs. date of sowing. The symbols are :▲, Avalon; ■, Beaver; ●, Rascal and ◆, Riband.

3.3.4. Cockle Park

At CP 91-2 twenty four varieties were sown at two dates (Table 3.3) and were scored for the double ridge and terminal spikelet stages, and flag-leaf and ear emergence. In the following year, CP 92-3, Avalon, Beaver Rascal and Riband were sown at three dates and a further 18 varieties were sown on two dates (Table 3.3). Anthesis was scored in addition to the stages scored in CP 91-2.

3.3.4.1. CP 92-3, Avalon, Beaver Rascal and Riband

The responses of the double ridge stage and anthesis to date of sowing were similar to those described for these varieties at Rosemaund and Arthur Rickwood (Fig. 3.4).At all sites in 1992-3, a proportion of the dissected shoot apices of Rascal were dead, killed by frost.

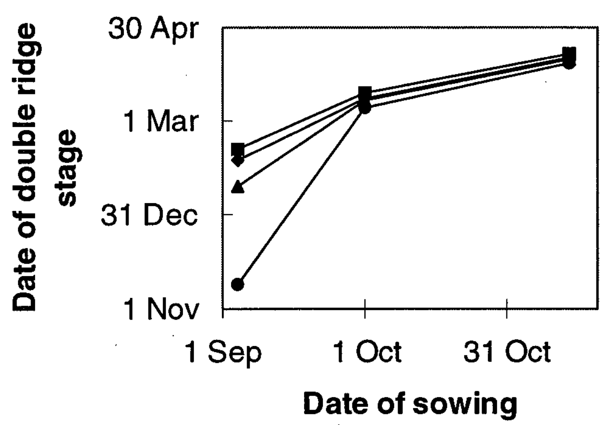


Fig. 3.4. Cockle Park, 1992-3. Date of the double ridge stage vs. date of sowing. The symbols are: The symbols are :▲, Avalon; ■, Beaver; ●, Rascal and ◆, Riband.

3.3.4.2.1. Double ridge stage

In Fig. 3.5 the date of the double ridge stage in the early sowing is plotted versus that in the late sowing for both seasons (91-92 and 92-93). For those varieties which were included in both years, their relative positions on the graph are similar.

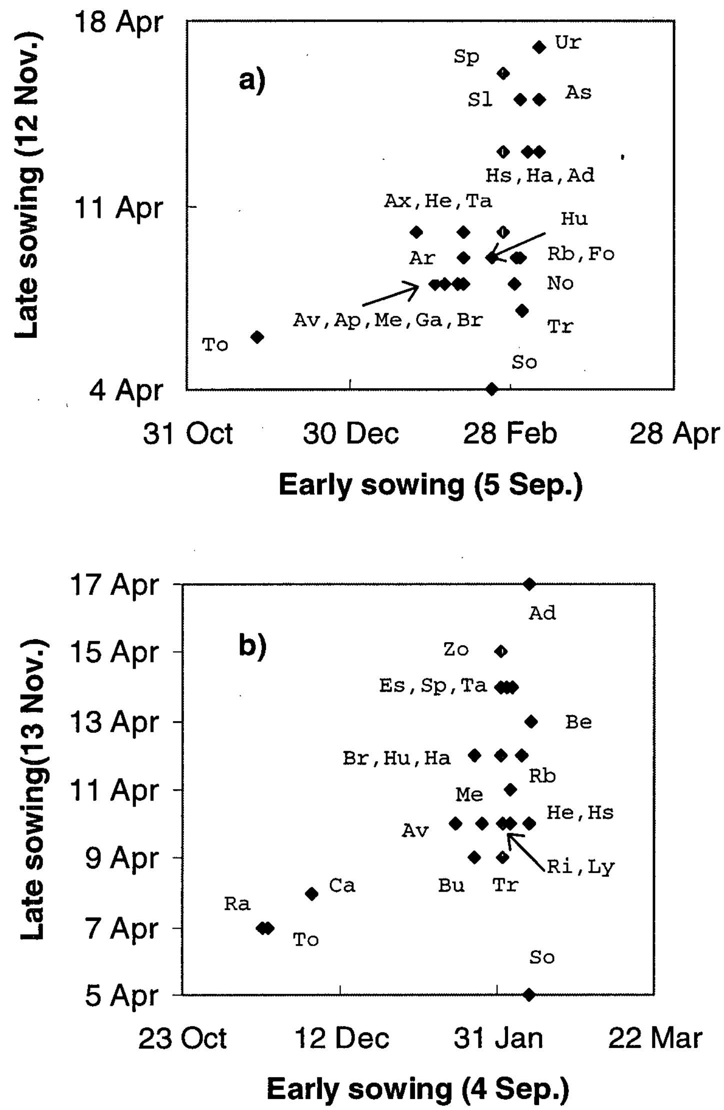


Fig. 3.5. Cockle Park. Date of double ridge stage for the early sowing vs. that for the late sowing. a) 1991-2; b) 1992-3. The code for the variety name are shown adjacent to each point. The codes are the first two letters of the name except for Apostle, As; Hussar, Hs; Riband, Rb and Torfrida, Tr.

Over the two years three spring varieties (*sensu* the NIAB cereal variety hand book) were observed. Rascal and Tonic both formed double ridges before the New Year in the first sowing and were first to the double ridge stage in the late sowing. Axona (91-92 Fig. 3.5a) behaved more like a winter variety. From the late sowing it occupied a middle position in the ranking of date to double ridge stage and when sown early it was similar to Avalon.

Cadenza, though classified as a Winter variety (NIAB), resembled a spring variety forming the double ridge stage early in December. Thus its development pattern was more or less intermediate between that of its parents, Tonic and Axona.

Amongst the winter varieties, some were consistently relatively late or early, irrespective of sowing date. Examples are Avalon (early) and Spark or Admiral (late). Other varieties, particularly Soissons showed a different relation between the early and late sowings. In both years it was the first to form double ridges from the late sowing, but was medium to late from the early sowing. The relative dates of the double ridge stage from the two sowings are partly due to differences in response to sowing date. Thus for varieties in which the stage occurred on the same date in the early sowing (e.g. Admiral, Hereward, Hussar and Soissons, 92-3, Fig. 3.4b), differences in the late sowing were due to differences in response to sowing date (Table 3.3).

Table 3.3. *Response (days/day difference in sowing date) of the double ridge stage and ear emergence or anthesis. The response to sowing date was calculated as* $(S_l-S_e)/(D_l-D_e)$, *where* S_e *and* S_l *are the dates of occurrence of a particular development stage and* D_e *and* D_l *are the sowing dates for the early and late sowings respectively.*

	CP 91-2		**CP 92-3**	
	Double ridge	Ear emergence	Double ridge	Anthesis
Admiral	0.51	0.09	0.94	0.10
Apollo	0.96	0.09		
Apostle	0.54	0.09		
Aristocrat	0.87	0.09		
Avalon	1.00	0.13	1.17	0.23
Axona	1.13	0.10		
Beaver			0.87	0.27
Brigadier	0.85	0.10	1.11	0.16
Buster			1.07	0.16
Cadenza			1.80	0.17
Estica			1.03	0.16
Fortress	0.56	0.09		
Galahad	0.85	0.10		
Haven	0.57	0.12	0.90	0.19
Hereward	0.88	0.07	0.84	0.13
Hunter	0.71	0.13	1.00	0.16
Hussar	0.71	0.09	0.84	0.11
Lynx			0.93	0.11
Mercia	0.88	0.09	1.06	0.14
Norman	0.57	0.09		
Rascal			2.01	0.31
Rialto			0.96	0.13
Riband	0.57	0.10	0.94	0.21
Sleipner	0.65	0.12		
Soissons	0.63	0.10	0.77	0.16
Spark	0.75	0.09	1.00	0.16
Tara	0.66	0.12	0.97	0.11
Tonic	1.94	0.16	1.99	0.16
Torfrida	0.51	0.09	0.94	0.13
Zodiac			1.04	0.10
Urban	0.57	0.07		

The greatest response to sowing date was seen in the spring varieties, Tonic, Rascal and Axona and in Cadenza. Among the true winter varieties Avalon had the greatest response and the later maturing varieties such as Hussar, Hereward and Torfrida had the lower responses. Soissons although early maturing also had a low response to sowing dates.

3.3.4.2.2. Ear emergence or anthesis

The plots of early vs. late sowing for ear emergence (CP 91-2) or anthesis (CP 92-3) show that in general there was a stronger relation between the early and late sowings than for the double ridge stage (Fig. 3.6). For example Soissons was the earliest variety from both sowing dates in both years, in contrast to the relative dates of the double ridge stage. There were differences of response among varieties which attained the double ridge stage on the same date in the early sowing e.g. Zodiac, Hunter and Haven, CP 92-3 (Fig. 3.6, Table 3.3). However this was not altogether consistent for the varieties common to both years e.g. Hunter and Haven changed ranking from 91-2 to 92-3.

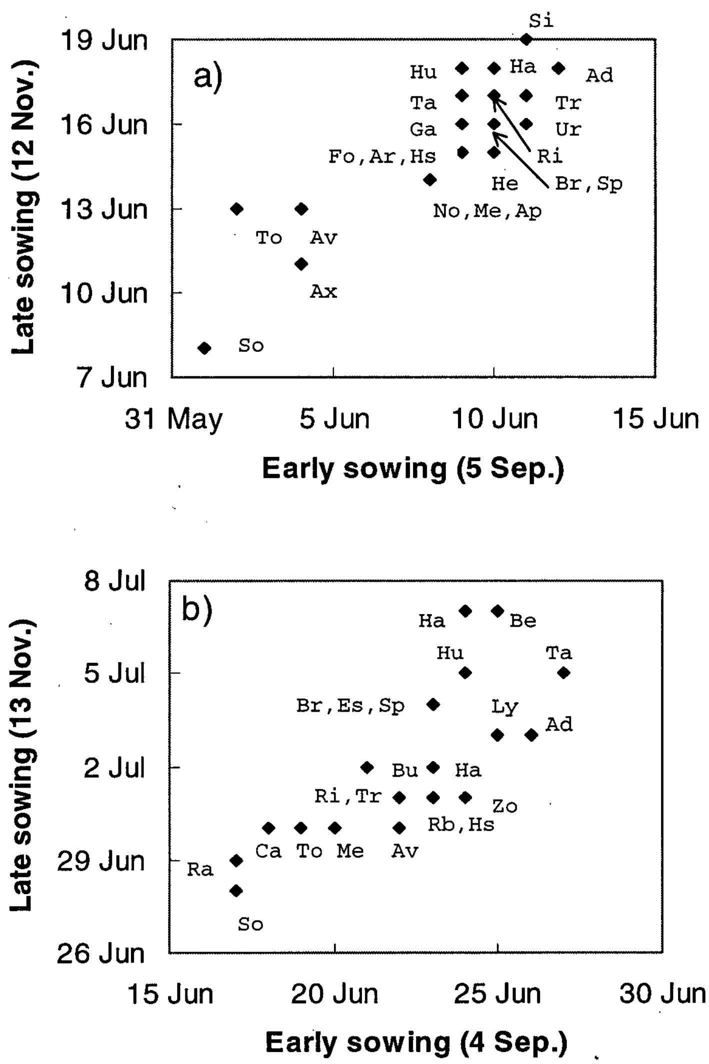


Fig. 3.6. Cockle Park. Early sowing vs. late sowing for a) date of ear emergence, 1991-2 and b) date of anthesis, 1992-3. Coding of the points as in Fig. 3.5

3.3.5. Difference in response among years

3.3.5.1. Double ridge stage

There was variation between years in the date of the double ridge stage from sowings made at comparable dates, illustrated by Avalon at Rosemaund, which had the most complete set of results (Appendix table 3). The greatest difference, 45 days, was between the first sowing in 1992-93 (8 Dec.) and 1990-91 (22 Jan). The difference reduced with later sowing and for the last sowing the greatest difference was 10 days, (between the same years) but note that 1992-3 was the latest observed date (Fig. 3.7).

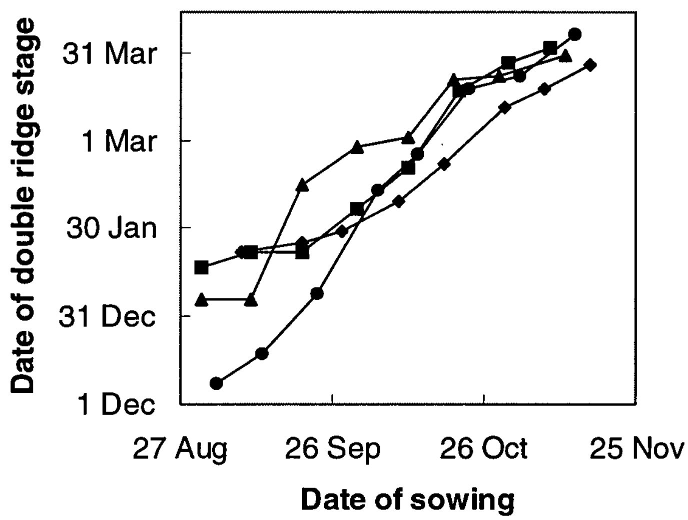


Fig. 3.7 Rosemaund. Date of double ridge stage vs. date of sowing Avalon, ◆, 1989-90; ■, 1990-1; ▲, 1991-2; and ● 1992-3.

This results from the large differences in response to sowing date among years. The strongest response was observed in the 1992-3 and the weakest in 1989-90 so that the double ridge stage was earliest over the first three sowing in 1992-3 and in 1989-90 over the five remaining sowings (Fig. 3.7). At Cockle Park the double ridge stage for Avalon in the early sowing was 13 days earlier compared with two days later in the late sowing in 1992-3 than 1991-2 (Appendix table 3). This again reflected a difference in response to sowing date between the two years (Table 3.3).

3.3.5.2. Ear emergence

Ear emergence data to inspect the effect of season on response to sowing date were available for RM 91-2 and RM 92-3. For Avalon, the response was such that ear emergence was one day earlier at the first sowing in 1992-3, but ten days later at the last sowing (Fig 3.8). The response of the other varieties was similar.

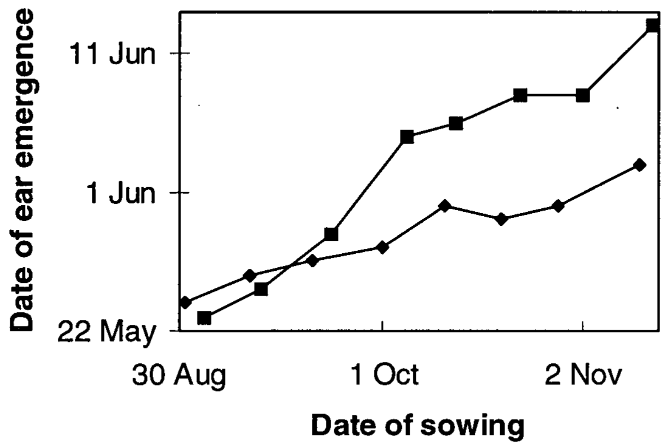


Fig. 3.8. Rosemaund. Date of ear emergence vs. date of sowing for Avalon; 1991-2, ◆; 1992-3, ■.

3.3.6. Difference in response among sites

The double ridge stage in Avalon at CP 92-3, first sowing was 41 days later than at RM 92-3 (Fig. 3.9). As sowing became later the dates at the two sites converged and from the last sowing the difference was only 4 days. A similar pattern of development was seen for Rascal with the quickest development at Rosemaund and the slowest at Cockle Park (Fig. 3.9).

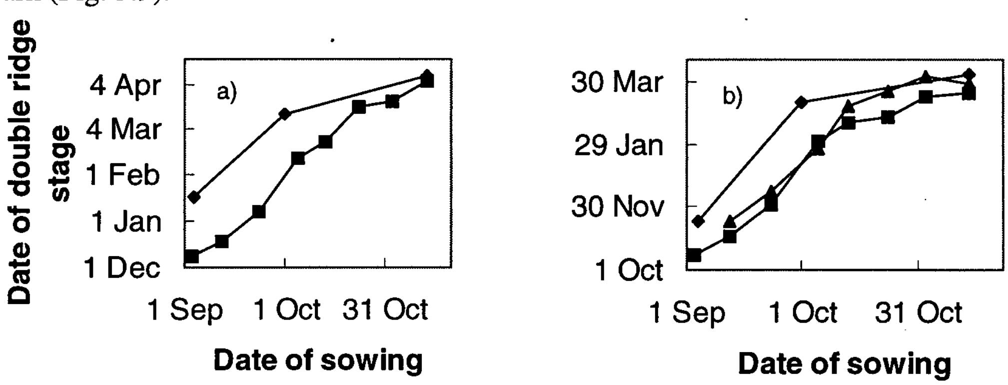


Fig. 3.9. Double ridge stage vs. date of sowing. a) Avalon; b) Rascal. The symbols are:■, RM; ▲, AR and ◆, CP

3.3.7. Phyllochron and final number of leaves

The final number of leaves, the rate of leaf emergence and phyllochron were determined at Cockle Park for 23 varieties in 1991-2 and for four varieties (Avalon, Beaver, Rascal and Riband) in 1992-3. In both years there was a very highly significant linear relation between number of leaves and thermal time (base temperature 0°C) and generally the R^2 coefficient was over 99 percent. In 1991-2 the phyllochron declined from the early to the late sowing, on average, from 136 to 100 °Cd respectively (Table 3.4).

Table 3.4. Final number of leaves and the phyllochron for the early sowing (5 September) and the late sowing (12 November), Cockle Park, 1991-2.

	Early sowing		Late sowing	
	Final number of leaves	Phyllochron	Final number of leaves	Phyllochron
Admiral	15.2	126	10.8	98
Apollo	14.3	138	10.7	93
Apostle	14.8	129	11.1	98
Aristocrat	13.3	144	9.7	104
Avalon	14.0	126	10.7	95
Axona	13.1	148	10.4	96
Brigadier	14.1	134	10.6	97
Fortress	15.0	128	10.4	103
Galahad	14.3	134	10.8	99
Haven	15.1	128	10.3	106
Hereward	14.7	136	10.3	113
Hunter	15.0	125	11.2	98
Hussar	14.6	129	10.4	96
Mercia	13.4	145	9.8	104
Norman	14.3	129	10.5	100
Riband	13.4	150	9.3	111
Slejpner	14.3	134	11.1	90
Soissons	14	128	9.8	100
Spark	13.6	140	10.1	108
Tara	14.2	133	10.9	93
Tonic	12.6	153	10	100
Torfrida	13.8	148	10	100
Urban	14.5	136	10.5	102

The greatest reduction, about 35 percent of the early sowing phyllochron, was seen in the two spring varieties, Tonic and Axona, but the late winter variety, Slejpner, had a comparable reduction. The least change, 17 percent, was found for Haven and Hereward.

Final number of leaves fell, on average, from 14.1 in the early sowing to 10.4 in the late sowing. There was a strong correlation ($r = 0.80$, 44 d.f.) between final number of leaves and phyllochron, and the least change in final number of leaves was experienced by Axona and Tonic, while Haven, Fortress, Riband and Soissons showed the most change.

Similar trends were found in 1992-3 (Fig. 3.10), where the phyllochron declined from early to middle to late sowing. For Rascal the phyllochron almost halved from the early to the late sowing, compared with a 37 percent reduction in Beaver over the same sowings. Final number of leaves changed little in Rascal (10.1 - 10.9 leaves), compared with a range for Beaver of 14.1 to 9.8 leaves.

In the two common varieties, Avalon and Riband, final number of leaves in the early sowing, 1991-2, was 14.1 and 13.4, respectively, compared with 12.9 and 12.2 in the comparable sowing in 1992-3. There was a smaller difference between years for number of leaves in the late sowing.

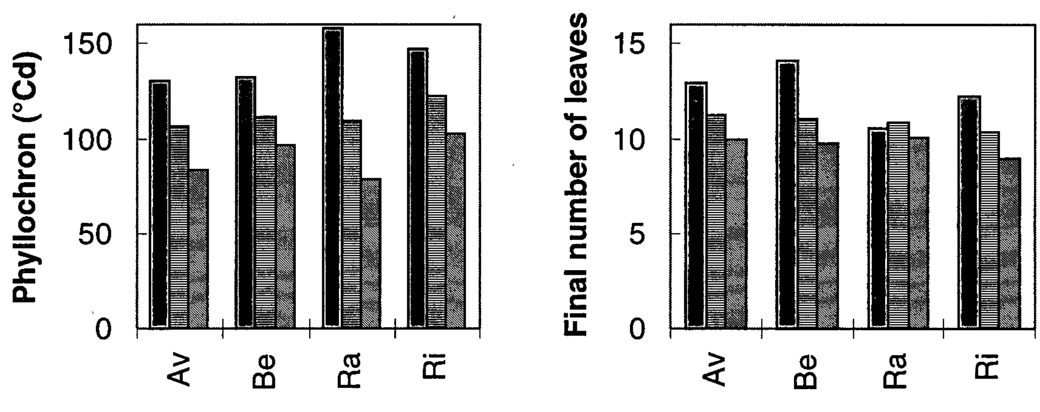


Fig. 3.10. Phyllochron and final number of leaves, Cockle Park, 1992-3. Early sowing (4 September), , mid sowing (1 October), and late sowing (13 November), . Av, Avalon; Be, Beaver; Ra, Rascal and Ri, Riband.

3.3.8. Tillering

3.3.8.1. Rosemaund and Arthur Rickwood

Tiller counts were made at RM on 28 February and 5 April 1991, and at AR on 12 April 91 and 6 April 92. There were consistent differences among the three observations; RM 1990-1 had the greatest and RW 1990-1 had the least number of tillers at all sowing. In all cases the greatest number of tillers per unit area was observed at sowings 3 - 5 (Figs 3.11 - 3.16).

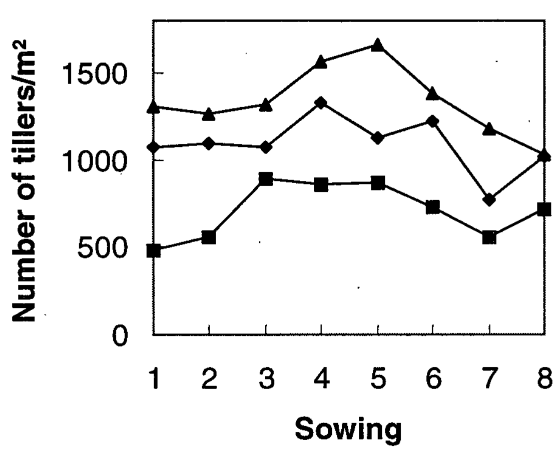


Fig. 3.11. Number of tillers vs. sowing. The symbols are: ◆, RM - 5 April 91; ■, RW, 2 April 91; ▲, RW 6 April 92.

In 1990-1, Apollo, Avalon, Riband and Pastiche were sown at both sites and neither the variety nor sowing x variety interaction were significant (Fig. 3.12, 3.13). At AR 91-2, Riband, Beaver and Avalon and Rascal were sown. There were significant differences among the varieties but no sowing x variety interaction which might indicate a greater susceptibility to low temperatures by Rascal when sown early (Fig. 3.14).

In all cases the number of tillers per plant was greatest at the first sowing and generally declined to the last sowing, showing that there was some compensation for the lower number of plants per unit area (Fig. 3.15). The significance of the treatments were the same as for tillers per unit area, i.e. the S x V interaction was not significant and the difference among varieties was significant only at AR 91-2.

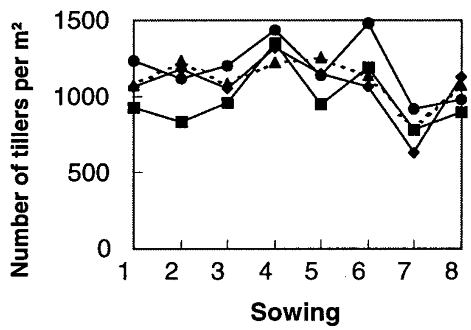


Fig. 3.12. Rosemaund, 1990-1. Number of tillers on 5 April. The symbols are: —◆—, Apollo; —■—, Avalon; - - ▲ - - , Riband ; —●—, Pastiche.

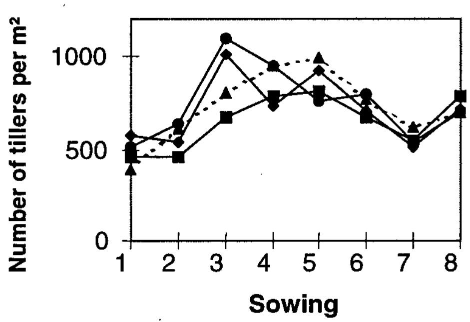


Fig. 3.13. Arthur Rickwood, 1990-1, Number of tillers on 12 April. Symbols as in Fig. 3.12.

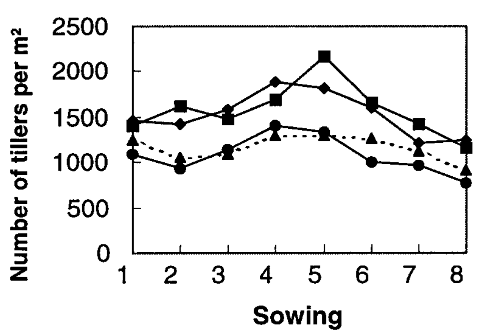


Fig. 3.14. Arthur Rickwood,1991-2. Number of tillers on 6 April. The symbols are: —◆—, Riband; —■—, Beaver; - - ▲ - - , Avalon and —●—, Rascal.

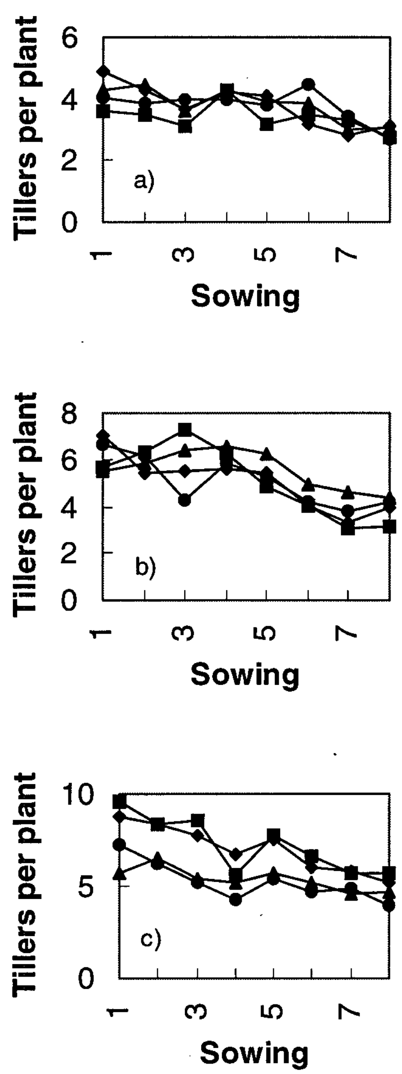


Fig. 3.15. Number of tillers per plant vs. sowing. a)Rosemaund 1990-1, 5 April; b) Arthur Rickwood 1990-1, 12 April and c) 1991-2, 6 April.
The symbols are:
a) and b) ◆, Apollo; ■, Avalon; ▲, Riband and ●, Pastiche.
c) ◆, Riband; ■, Beaver;
▲, Avalon and ●, Rascal.

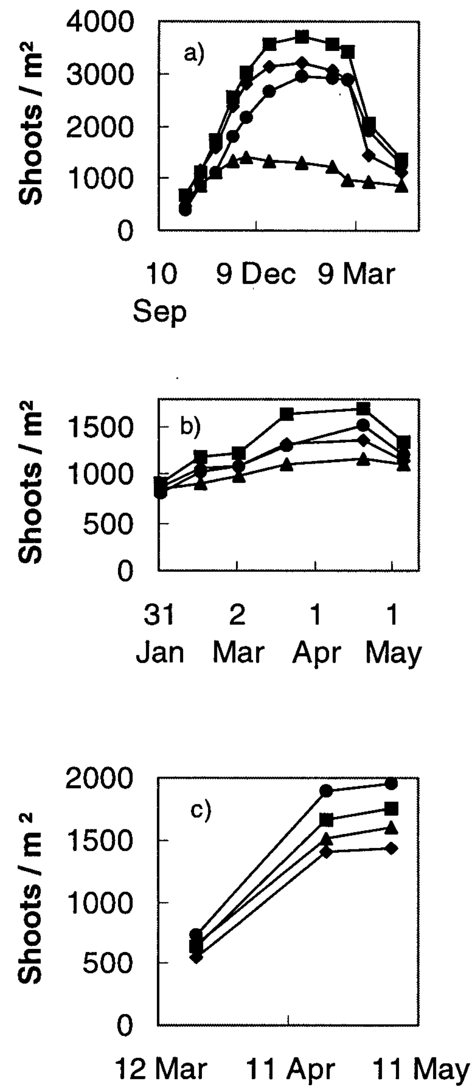


Fig. 3.16. Cockle Park, 1992-3. Number of shoots per m² vs. sample date. a) sowing 1; b) sowing 2 and c) sowing 3.
The symbols are:) ◆, Riband; ■, Beaver;
▲, Avalon and ●, Rascal.

In 1991-2 there were more tillers at each sample throughout the season in sowing 2 (November) than in sowing 1 (September). This anomalous result was probably a consequence of the dry seed bed in the first sowing and was not considered further.

In 1992-3, tiller counts were made on Avalon, Beaver, Rascal and Riband. The number of tillers per unit area was measured on different dates for each sowing, so that the effect of sowing date and variety was assessed from the trends of number of tillers vs. time (Fig. 3.16). There were fewer samples in sowings 2 and 3 so that the date when maximum number of tillers or onset of tiller death occurred were more difficult to assess.

In each of the sowings, particularly sowing 1, there were clear differences in response to sowing date among the varieties, but these were not consistent across sowing. In sowing 1 the maximum number of tillers was much smaller in Rascal than in the winter varieties. It was attained early in December and then declined slowly. In the winter varieties the maximum number of tillers was attained at the end of January and number of tillers declined rapidly from about the beginning of March. Rascal also produced least tillers in sowing two, but the difference from the other varieties was relatively less than in sowing 1 and in the third sowing there was little difference between Avalon and Rascal.

It was not possible to identify closely the time and number of maximum number of tillers in Sowings 2 and 3, but it was clear that maximum number of tillers occurs later and was lower with later sowing.

3.4. Discussion

The analysis of the timing of several development stages showed that all responded to sowing date, with those stages which occur earliest in the life cycle showing the strongest response (Fig. 3.1). There were, however, differences in response among varieties, years and sites in the degree of response. These differences may be significant in crop management as the timing of developmental stages may affect yield potential; this is discussed further in the general discussion, section 6. They arise primarily from the response of the plant to daylength and temperature.

3.4.1. Variety effects

3.4.1.1. Double ridge stage

The effect of differences response to low temperature (vernalization) are seen particularly in the contrast between the winter and spring varieties (RM, AR and CP 1991-2 and 1992-3). Rascal, a spring wheat with a low or nil response to vernalization, developed rapidly when sown in the high temperatures and relatively long days in September, but Avalon and Riband were not exposed to the low temperatures necessary to fulfil their vernalization requirement. On the other hand, plants sown in October or November were exposed to low, vernalization-effective temperature during the seedling stage and were fully vernalized soon after seedling emergence (Kirby, 1992). Winter wheat plants sown at this time of year produce the same final number of leaves as spring varieties (Kirby, 1992) and respond to temperature and daylength in the same way as spring varieties. Therefore, from sowings made in October or November both the spring (Rascal) and the winter varieties (Avalon and Riband) responded similarly to sowing date (Fig. 3.2).

There was also a difference between the winter varieties as Avalon had a response intermediate between Riband and Rascal (Fig. 3.2).This may indicate a lower vernalization requirement. The two varieties differ in 'latest safe date' for sowing in the spring (NIAB, 1994) and it has been reported that Avalon will flower in the absence of vernalization (Travis *et al.*, 1988; Johnstone *et al.* (1990) found that it had a relatively low vernalization response.

Development in the multi-variety experiments at CP, 1991-2 and 1992-3, also demonstrated the effect of a zero or low vernalization requirement in Tonic and Rascal and in the winter, non-vernalization requiring variety, Cadenza all of which formed double ridges before the New Year.

The role of photoperiod in determining the rate of development may be illustrated by the French winter wheat, Soissons. In both CP 91-2 and 92-3 its pattern of development differed from that of varieties such as Avalon and Riband (Fig 3.5). The relatively late date of the double ridge stage from the early sowing indicated that it had a strong vernalization requirement. This is consistent with its classification in the French 'list'. When sown late it was the earliest to form double ridges, indicating that its development was not restrained by the short days of winter, once its vernalization requirement was satisfied. Thus Soissons appears to have a strong response to vernalization and a weak response to daylength (Worland *et al.*, 1994).

To judge from the NIAB latest safe date classification of Spark ('March' cf. late Jan. for Riband and mid Feb. for Avalon) it has a low vernalization requirement. Yet it is one of the latest to form double ridges from both early and late sowing. This behaviour may be explained by assuming that Spark has a particularly strong response to daylength.

A further factor which may affect rate of development is inherent earliness ('earliness per se', 'basic vegetative period' (Slafer, 1996; Worland, 1996). When the responses to photoperiod and vernalization are saturated (i.e. pre-vernalised plants grown in long days or 24 hour daylength) varieties still differ in length of life cycle. The assumption that there may be differences in inherent earliness among the varieties investigated in this report may explain some of the observed differences in length of life cycle. For example, Avalon, Rascal and Riband when sown in November were more or less vernalised at seedling emergence and completed their development in relatively long days, nevertheless differed in time to the double ridge stage (Fig. 3.2).

3.4.1.2. Ear emergence or anthesis

The differences among varieties in response to sowing date of the later development stages were similar to those observed for double ridges and in similar arguments about responses to daylength and low temperature can be invoked to explain them. Differences in response to photoperiod in the post double-ridge stage (vernalization is considered to be complete by this stage) clearly reinforced and modified the differences observed at the double ridge stage. Soissons, though classified as medium to late in terms of the relative date of the double ridge in the early sowing, was the earliest to ear emergence or anthesis in both early and late sowing, possibly indicating a weak response to daylength in the double-ridge to ear emergence or anthesis phase (Figs. 3.5, 3.6). Torfrida also changed its relative position among the varieties from the double-ridge to ear emergence or anthesis stages (Figs. 3.5, 3.6)

3.4.2. Difference between years and sites

At RM 89-90 and RM 90-1 the date at which the double ridge stage occurred was similar for the first two or three sowings but then diverged so that, for the later sowings, the difference between comparable sowings varied from 12 to 25 days (Fig. 3.7). The temperatures from September to December were similar (Appendix table 1, weather) and during this period the early sowings advanced to the double ridge stage. In 1990-91, January and February temperatures were lower than in 1989-90, particularly in February when the mean temperatures were 7.3 and 1.4°C for 1989-90 and 1990-91 respectively. In the latter year this delayed the date at which the double ridge stage occurred in the later sowings.

In 1992-93 the double ridge stage for the first three sowings was earlier than in the other years(Fig. 3.7). This may be attributable to the low mean temperature in October (7.5°C compared to 9.8 - 11.8°C for the other three (Appendix table 1)). This apparently resulted in more effective vernalization of the plants sown in September so that they developed rapidly during the relatively warm November. The temperatures experienced by the plants in the later sowings were more similar to those of 1990-91 and 1991-2 and there was less difference in dates of the double ridge stage.

At RM 92-3 Rascal and Riband also attained the double ridge stage earlier from the September sowings than RM 91-2 (Table 3.5).

Table 3.5. The date and thermal time from sowing (base 0°C) of the double ridge from comparable sowings, early in September

	Date	Thermal time (°Cd)	Date	Thermal time (°Cd)
		Rosemaund		
	Sown 10 Sep 1991		Sown 12 Sep 1992	
Avalon	6 Jan 1992	958	8 Dec 1992	805
Riband	18 Feb 1992	1119	14 Jan 1993	885
Rascal	6 Jan 1992	958	3 Nov 1992	501
		Cockle Park		
	Sown 5 Sep 1991		Sown 4 Sep 1992	
Avalon	31 Jan 1992	1046	18 Jan 1993	883
Riband	1 Mar 1992	1203	4 Feb 1993	965

As in the case of Avalon this was probably due the difference in the October temperatures in the two years which reduced the thermal time for full vernalization in 1992-3 and therefore the thermal time from sowing to the double ridge stage. (The sowing dates in 1991 and 1992 were separated by only two days, and therefore the daylength during the period from sowing until the double ridge stage was similar and would not affect thermal time.) The strong response of Rascal (958 vs. 501°Cd) indicates that this variety also may have some vernalization response. These results for Rascal, together with those for Axona in the CP experiments, which developed in a similar manner to winter varieties such as Avalon, and the results with other spring wheat varieties (Kirby, 1992)indicate that a 'spring' classification, e.g. in the NIAB recommended lists does mean a complete absence of vernalization response.

At Cockle Park there was a similar contrast in the October temperatures which reduced the thermal time of the sowing to double ridge stage phase of Avalon and Riband in 1992-3 relative to that in 1991-2 (The spring varieties were different (Tonic 1991-2 and Rascal 1992-3) and could not be compared.

In the comparison of sites in 1992-3 the slower development at Cockle Park compared with Rosemaund and A. Rickwood (Fig. 3.9) was largely due to the lower temperatures at Cockle Park (Appendix table 1). The longer thermal times from sowing to the double ridge stage (except for Avalon, sown on 13 November) indicate that the shorter daylengths in the September-March period at the more northerly site may also have slowed development.

Table 3.6. Comparison of the thermal time from sowing to the double ridge stage at Rosemaund and Cockle Park, 1992-3.

	Avalon		Rascal	
Sowing date	3 or 4 September	13 November	3 or 4 September	13 November
RM 92-3	852	794	502	679
CP 92-3	872	722	621	705

3.4.3. Phyllochron and final number of leaves

In all varieties in both years (CP 91-2, CP92-3) the value of the phyllochron fell from the early to the late sowing, i.e. the rate of leaf emergence increased, consistent with other reports ((Baker et al., 1980; Kirby & Perry, 1987)). The response to date of sowing was greatest in Axona and Tonic and least in Hereward and Haven. Because of the strong response to date of sowing e.g. Rascal CP 92-3, which produced leaves most slowly in the early sowing was quickest in the late sowing (Fig. 3.10). This means it is not possible to categorise varieties solely according to a single value for the phyllochron (Weir et al., 1984).

Baker *et al.* (1980) proposed the function:

$$r = a + bC$$

to explain the change in the rate of leaf emergence in response to date of seedling emergence, where r is the rate of leaf emergence and C is the rate of change of daylength. For Maris Huntsman (Baker et al., 1980) the rate of leaf emergence increased by 0.026 leaves per °Cd for each hour per day change in the rate of change of daylength.

In the experiment reported here the change in the rate of leaf emergence ranged from 0.021 (units: leaves (°Cd) / hd^{-1}) for Hereward to 0.049 for Tonic in 1991-2 and from 0.031 for Beaver to 0.072 for Rascal in 1992-3. Although the spring varieties Axona, Rascal and Tonic had the greatest response to rate of change of daylength some winter varieties had comparable values (e.g. 1991-2; Apollo, 0.048; Tonic, 0.048; Slejpner 0.049 and Axona, 0.049).

The varietal differences in the phyllochron and its response to date of sowing is significant in relation to the rate of tillering as this is dependent on rate of leaf emergence (see discussion section for tillering). It is also an important component in some models which predict growth and/or development (Weir *et al.* 1984, Kirby and Weightman, 1996). The final number of leaves on the main shoot and its response to date of sowing was strongly correlated with the phyllochron and varieties with the greatest change in the phyllochron had the least change in final number of leaves, e.g. Rascal (Fig. 3.10).

The maximum number of tillers formed is partly dependent on the final number of leaves as can be seen by comparing maximum number of leaves and maximum number of tillers in CP 92-3, although this could only be analysed in detail for the first sowing (see discussion section for tillering). The lower final number of leaves for Avalon and Riband in the first sowing of 1992-3, compared with that of 1991-2 appears to have been due to the lower October temperature in 1992 (*cf.* dates of double ridge stage), further evidence that response to date of sowing is moderated by seasonal factors.

3.4.4. Tillering

The tiller counts at Rosemaund and Arthur Rickwood were made in seasons in which the early sowing were made in dry seed beds which affected dry mass growth. Therefore the low number of tillers in the first three sowings were probably related to dry mass growth and low plant numbers (Section 4), although in contrast to dry mass per plant, tillers per plant were greatest in the first sowings (Fig. 3.15) possibly because response to low number of plants.

At CP 92-3, the data showed that in the early sowing, tillering was consistent with the subjective field observation that early sown crops tiller more freely than crops sown later in the season, but the data were too few to quantify maximum number of tillers.

The differences in tillering pattern amongst the varieties in CP 92-3, sowing 1, was due almost entirely to differences in the rate of leaf emergence and final number of leaves. When number of shoots per plant were examined in relation to the number of emerged leaves, the response conformed to the model of shoot number as a Fibonacci function of number of emerged leaves, with cessation of tiller production at the terminal spikelet stage (Fig. 3.17; (Friend, 1965); (Masle & Sebillotte, 1981); (Kirby, 1985)). The validity of the model for sowings 2 and 3 could not be inspected because of the timing of the observations and paucity of data. It is probable, however that the tillering response to sowing date is determined by the interactions between sowing date and variety for final number of leaves and leaf emergence rate.

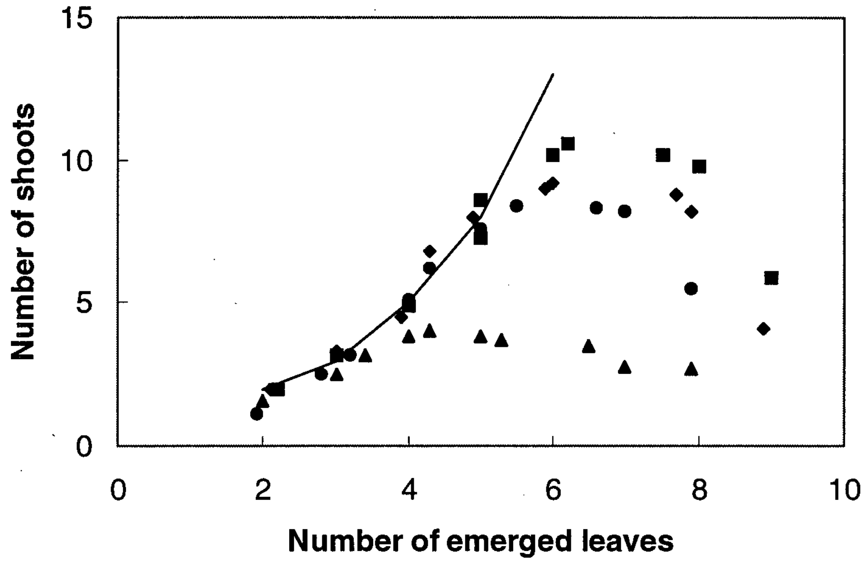


Fig. 3.17. Cockle Park, 1992-3. Number of shoots per plant vs. number of emerged main shoot leaves. The line is the number of tillers predicted by the Fibonacci function.
The symbols are:) ◆, Avalon; ■, Beaver; ▲, Rascal and ●, Riband ,

3.5. Conclusions

- Varieties differ in their developmental response to sowing date. Differences are greatest from early sowings.
- The response is modified by differences in weather and site. Differences in temperature over a relatively short period in the autumn can effect development rate.
- Developmental differences enable selection of varieties which match growth to the optimum environment and, or avoid stress.
- Varietal differences in response to sowing date are due to physiological difference in response to daylength and low temperature. There also may be differences in inherent earliness which affect the length of life cycle.

4. GROWTH

This section of the report deals with crop growth in relation to date of sowing, variety and season. Analysis showed that the final (harvest) mass of the crop was much affected by agronomic factors such as seed bed conditions and lodging and that these overshadowed physiological effects such as differences in the rate of canopy expansion.

The first sub-section (4.1) examines the hypotheses set out in the introduction in more detail using a modelling approach. This provides a theoretical base to compare with the observations of dry mass (Sub-sections 4.2.6 and 4.2.7) and final yield (Section 5). Sub-sections 4.2.1 - 4.2.5 examine in detail those phenomena which were found to influence dry mass growth including canopy growth (Sub-section 4.2.3). In each of these sub-sections the results are discussed and conclusions are drawn.

Finally dry mass growth is described (Sub-section 4.2.6) and in sub-section 4.2.7 the way in which purely agronomic factors such as seed bed condition and lodging, as well as physiological factors, such as canopy growth affected final dry mass are discussed.

4.1. Models of dry mass growth and grain yield

Modelling provides a method of testing the assumptions about the effect of sowing date on dry mass growth and grain yield. Two models were used; the original version of ARCWheat (Weir *et al.*, 1984), and that of Gillett (1997 - PhD thesis) referred to as the Gillett model (GM). Both models were calibrated with respect to UK conditions and varieties (Avalon and Mercia for ARCWheat and GM, respectively). Neither allows for drought effects on growth or yield and, in the ARCWheat version used, there was no provision for variation in N supply.

Several studies have shown that the duration of the grain filling period (anthesis to maximum grain dry mass, physiological maturity) is relatively constant in thermal time and unaffected by temperature, radiation receipt or CO_2 concentration (Wheeler *et al.*, 1996; Sofield *et al.*, 1977; Mitchell *et al.*, 1993). To study the consequence of constant duration in thermal time, a simple model of grain growth duration was used to investigate variation in temperature and radiation during the grain filling period.

4.1.1. Methods

Weather data used to run the models were from ADAS Rosemaund. Standard meteorological data were obtained from the centre Agmet station. Radiation data for the period from September 1989 to April 1993 were supplied by the Institute of Hydrology except for the period from May - August 1993 which was obtained from an automatic weather station (Delta-T Devices), in both cases from instruments sited near to the experimental area.

The coefficients used in the models were those given in Weir *et al.* (1984) and Gillett (1997). In the case of GM the total soil N was set at 350 kg/ha. Simulated sowing dates were 1st and 15th of September, October, November and December. To model duration and radiation receipt of the grain filling phase of growth, the same meteorological data described above were used. For anthesis dates from 10 May to 20 June, the daily thermal time from anthesis was summed until 700°Cd (base temperature 0°C) or more had accumulated (Gallagher *et al.*, 1976; Loss *et al.*, 1989). The duration of the period in days and the sum of the daily radiation receipt over the period was then calculated.

4.1.2. Results and discussion

4.1.2.1. Grain yield

Grain yield was predicted using ARCWheat for the seasons 1989-90, 1990-1, 1991-2 and 1992-3 (Fig. 4.1). In all years, yield declined with later sowing date although, in 1990-1 and 1992-3, the rate of decline was small or nil over the last four simulated sowing dates (30 October - 15 December). The rates of decline, estimated by regression of yield predicted by the model on sowing date, were 33, 17, 45, and 21 kg/ha/day for 1989-90, 1990-1, 1991-2 and 1992-3, respectively. Of the four years predicted, 1990-1 was comparatively low yielding, ranging from 2.3 - 1.1 t/ha of grain less than the average of the other years.

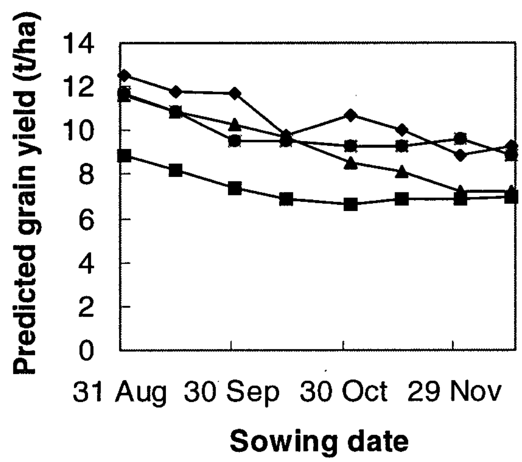


Fig. 4.1. Predicted yield for Rosemaund in four seasons. The symbols are: ◆, 1989-90; ■, 1990-1; ▲, 1991-2 and ●, 1992-3. For details, see text.

4.1.2.2. Dry mass

Dry mass per unit area on 15 December, 19 February and 9 April was extracted from the prediction of growth by ARCWheat and GM for 1990-1, 1991-2, and 1992-3.The trends with sowing date were the same for both models, that is dry mass declined rapidly from sowing 1 to 5 and less rapidly from sowing 6 to 8 (Fig. 4.2).

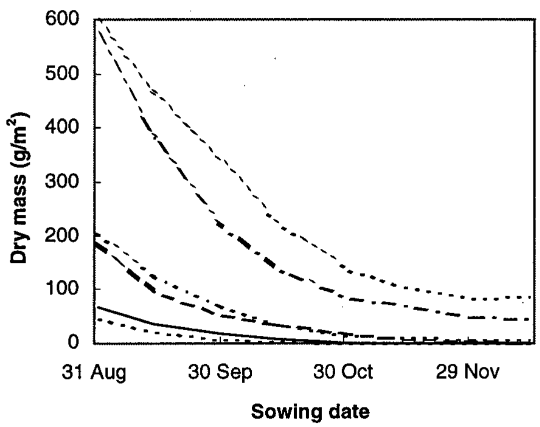


Fig. 4.2. Predicted dry mass at three dates during growth period for Rosemaund, 1990-1. Codes for the lines are: ARCWheat predictions ;——, 15 December; — – —, 19 February and — – – —, 9 April. The associated dashed lines are the GM predictions.

4.1.2.3. Duration and radiation receipt of the simulated grain filling period.

The simulated duration (in days) of grain filling declined as anthesis occurred progressively later in the season (Fig. 4.3). For anthesis occurring early in May, grain filling duration was between 50 and 55 days, declining to about 45 days in mid June. The longest durations were in 1990-1, reflecting the relatively low temperatures in June and, conversely, the relatively high temperatures during May and June shortened the durations in 1992-3.

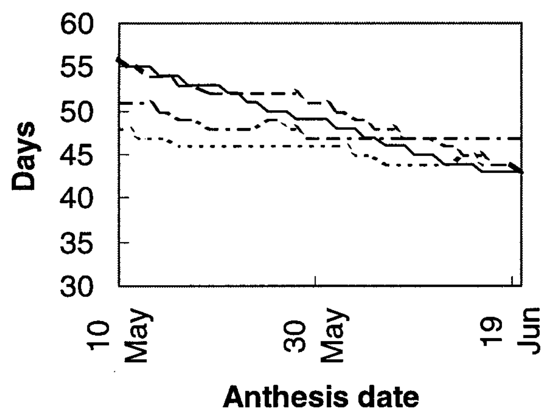


Fig. 4.3. Predicted duration of the grain filling in days for anthesis dates from 1 May to 20 June. Codes for the lines are: ——, 1989-90; — — —, 1990-1; ......, 1991-2 and — – —, 1992-3. For details, see text.

Trends for accumulated radiation during the grain filling period were, in most cases, similar to those for duration generally declining from about 900 MJ/m^2 for anthesis at the beginning of May to about 750 MJ/m^2 for anthesis in mid-June (Fig. 4.4). This trend was not apparent in 1992-3 as the accumulated radiation values did not decline as the simulated date of anthesis was progressively later.

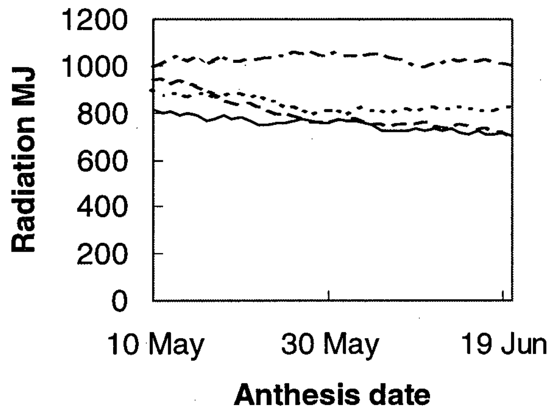


Fig. 4.4. Predicted accumulated radiation receipt during grain filling periods for anthesis dates from 10 May to 20 June. ——, 1989-90; — — —, 1990-1; ......, 1991-2 and — - —, 1992-3. For details, see text.

Anthesis is delayed as sowing date is later in the season, although the interval between dates of anthesis is less than the interval between sowing dates. The model therefore indicates that the grain filling duration becomes shorter for later sown crops because anthesis is later. The higher temperatures which reduce duration also increase the rate of grain filling, but not sufficiently to offset the shorter period and therefore grain dry mass is usually reduced by high temperatures (Wheeler *et al.*, 1996).

Because the seasonal march of temperature and radiation are out of phase and daily temperature continues to rise after radiation reaches its maximum, crops with early anthesis experience the highest radiation levels during grain filling. This also may enhance grain growth rates (Sofield *et al.*, 1977).

4.1.3. Conclusions

- Greatest final dry mass and grain yield were predicted from the earliest sowing and declined progressively from simulated later sowings.
- At any time through the growth period greatest dry mass was predicted from the earliest sowing and was progressively reduced with later sowing
- The predicted grain filling period was shorter and total incident radiation during the grain filling period was lower as the time of anthesis was delayed from mid-May to mid-July.

4.2. Growth

4.2.1. Seedling emergence

4.2.1.1. Materials and methods

Fifty percent seedling emergence was estimated in all years except RM 92-3. At RM 90-1 and RM 91-2 estimates were made for each individual plot but in the other cases an estimate over all blocks and varieties was made for each sowing. Details of cultivations and weather can be found in Appendices 1 and 2 .

4.2.1.2. *Results*

4.2.1.2.1. Rosemaund and Arthur Rickwood

The time from sowing to seedling emergence was very variable (Table 4.1).

Table 4.1. Rosemaund and Arthur Rickwood. Days from sowing to seedling emergence (mean of varieties).

Sowing	Site and year RM 89-90	RM 90-1	AR 90-1	RM 91-2	AR 91-2	AR 92-3
1	13	25	41	17	28	9
2	11	22	31	22	20	8
3	13	21	20	16	17	7
4	14	13	19	12	11	14
5	13	16	15	18	16	24
6	21	21	21	20		25
7	29	19	23	26		22
8	35	20	23	41		29

At RM 89-90 and AR 92-3 the duration increased with later sowing as temperatures at sowing time became lower, whereas at, for example, AR 90-1 the longest interval from sowing to seedling emergence was in sowing 1.

When the period of seedling emergence was expressed as thermal time (base temperature 0°C), the longest duration was found in sowing 1 at RM 90-1, AR 90-1, RM 91-2 and AR 91-2 and declined to about 150 °Cd in sowing 4 or 5 (Fig. 4.5). At RM 89-90 and in sowings 5 - 8, in all cases the interval from sowing to seedling emergence was about 150°Cd.

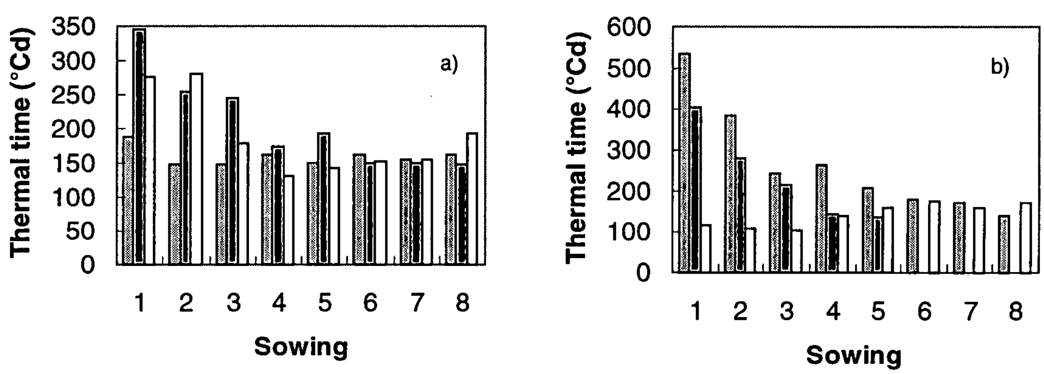


Fig. 4.5. Thermal time from sowing to seedling emergence for sowings 1 - 8. a) Rosemaund and b) Arthur Rickwood. .Codes for the bars are: , 1989-90; , 1990-1 and , 1991-2.

The significance of the treatment effects and the V x S interaction were examined in RM 90-1 and RM 91-2 (Table 4.2).

Table 4.2. Rosemaund. Thermal time to seedling emergence. Probability of significance of difference among treatments and interactions from ANOVA. Bold entries are significant at <0.05.

	Source of variation Block	Sowing date	Variety	V x S
D.f.	3	7	3	21
RM 90-1	0.099	**<0.001**	**<0.001**	0.163
RM 91-2	0.217	**<0.001**	**0.003**	**0.016**

The variety effect at RM 90-1, although significant was due to range of only 7°Cd in the variety means, i.e. a difference of about 0.5 - 2 days depending on temperature. In sowing 1, RM 91-2, all plots of Rascal emerged on the same day, 163°Cd after sowing, whereas for Avalon the mean duration was 320, with individual plot values ranging from 193 - 431°Cd. In the other sowing dates the variety means and the variation amongst plots were generally more uniform. The difference among varieties in sowing 1 was probably due to variation in soil condition and cultivation among the plots and was probably responsible for the V x S interaction, rather than inherent differences in varietal ability to emerge under the prevailing soil conditions.

4.2.1.2.2. Cockle Park

The durations from sowing to seedling emergence in sowing 1 at CP 91-2 were much extended, compared with the norm (150 °Cd; Weir, *et al.*, 1984); for Avalon, Riband, Slejpner and Tonic they were 319, 369, 369 and 319 °Cd respectively. In sowing 2 all varieties emerged 180°Cd after sowing. In CP 92-3 the durations were 161, 159 and 192 °Cd for sowings 1, 2 and 3 respectively and no variation was noted among varieties.

4.2.1.3. Discussion

When sown in conditions of adequate soil water and at normal depth, wheat emerges in about 150°Cd. If the amount of soil water is sub-optimal, seeds may not germinate or the thermal time for emergence may be increased. Water content of the upper layer of soil, into which the seed is sown will depend in part in the recharge after the previous crop ceases transpiration. Assuming that the previous crop was harvested or senescent at the beginning of August, a measure of available water was obtained from cumulative rainfall after 1 August.

Inspection of the cumulative rainfall for AR and RM (Fig. 4.6) showed that, in the two years (1990-1 and 1991-2) where seedling emergence in the early sowings was delayed, the cumulative rainfall was less than 50 mm until the end of September. In 1989-90 (RM) and 1992-3 (AR) more rain fell during August and by the date of the first sowing there was potentially about 50 mm of available water. At CP 91-2 the cumulated rain from 1 August for sowing 1 (5 September) and sowing 2 (15 November) was 41 and 134mm, respectively, and at CP 92-3 for sowing 1 (4 September), sowing 2 (1 October) and sowing 3 (13 November) it was 99, 199 and 281 mm, respectively. This represents the maximum and ignores evaporation, the amount of which depends on the intensity and timing of rainfall episodes. Furthermore, soil water accumulated in the upper horizon may be not be available to the seed after ploughing inverts the soil layers or may be lost by enhanced evaporation during surface cultivation.

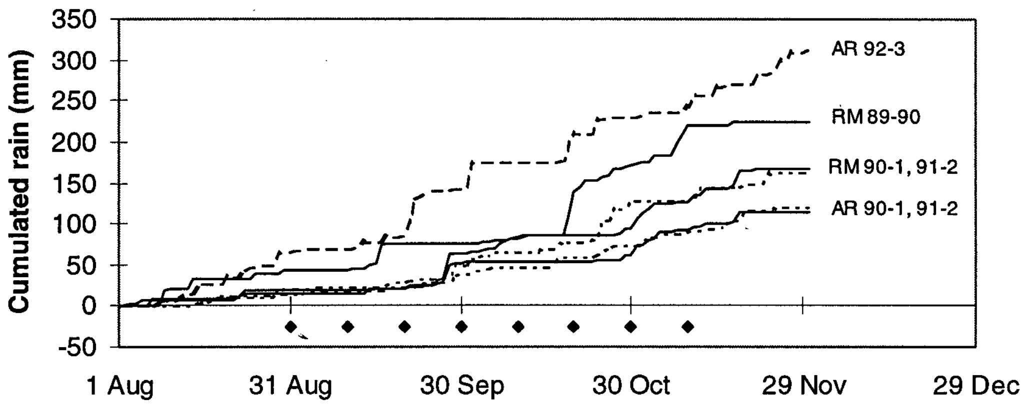


Fig. 4.6. Cumulative rainfall from 1 August. The approximate dates for sowing 1 to 8 are shown. The codes for RM and AR, 1990-1 and 1991-2 are; - - -, 90-1 and ——, 91-2.

Therefore it was probable that the long thermal time interval from sowing to seedling emergence in the early sowings in 1991 and 1992 was due to shortage of water. At CP 91-2 dry seed bed conditions following the first sowing were noted. The way in which the probable shortage of water affected germination and seedling emergence was not investigated. High soil water deficits are known to delay seedling emergence and reduce percentage emergence; alternatively soil may have been so dry that the seeds did not germinate until the soil was wetted by subsequent rainfall.

4.2.1.4. Conclusions

In the early sowings of the years 1990-1 and 1991-2 both of which had a relatively dry August and September, the thermal time from sowing to emergence was considerably longer than 150 °Cd probably due to dry seed beds. A cumulated rainfall of less than 50mm from 1 August appeared to delay seedling emergence.

4.2.2. Number of plants

4.2.2.1. Methods

At RM and AR , a constant number of seeds (375 per m²) were sown throughout the experiment except at RM 89-90. Plant counts were in the autumn and spring or only in the spring (Table 4.3). The number of seeds sown at CP 91-2 was 400 and 600 seeds/m² in sowings 1 and 2, respectively and at CP 92-3, 400, 400 and 600 seeds/m² in sowings 1, 2 and 3 respectively. At CP 91-2 counts were made at each sample (based on growth stage, i.e. at a different date for each variety) until anthesis. At CP 92-3 plant counts were made at each sample (same date for all varieties) until anthesis.

4.2.2.2. Results

4.2.2.2.1. Rosemaund and Arthur Rickwood

The effect of sowing date, site and season is shown for the first plant count of the season (Fig. 4.7); variety and S x V effects are not shown as, generally, neither was significant (Table 4.3). In the case of AR the first counts were made in January or February and the values shown may be affected by plant death over the winter.

Table 4.3. Rosemaund and Arthur Rickwood. Number of plants. Probability of significance of difference among treatments and interactions from ANOVA. Bold entries are significant at <0.05.

	Source of variation			
	Block	Sowing date	Variety	V x S
D.f.	3	7	3	21
RM 90-1				
Autumn	0.673	**0.001**	0.107	0.823
Spring	0.485	**0.043**	0.152	0.922
AR 90-1				
28/2/91	0.170	**0.006**	0.821	0.114
12/4/91	0.504	**0.016**	0.420	0.282
RM 91-2				
9/12/91	0.012	**<.001**	0.102	0.354
AR 91-2				
8/1/92	0.434	**0.002**	0.230	0.150
24/2/92	0.928	**<.001**	0.231	0.415
6/4/92	0.073	**<.001**	0.732	0.349
RM 92-3				
Autumn	0.931	**<.001**	**<.001**	**0.003**
Spring	0.294	0.581	0.601	0.545
AR 92-3				
900°Cd	0.072	**<.001**	**<.001**	**<.001**

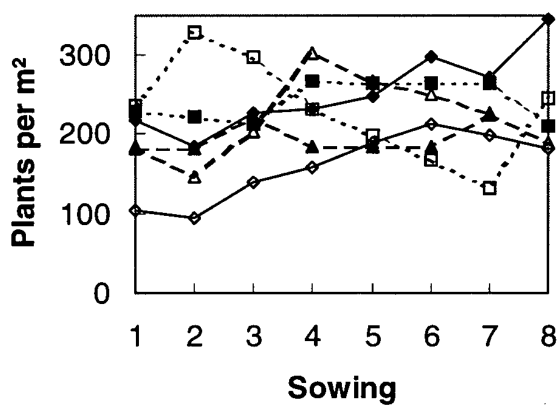


Fig. 4.7. Number of plants vs. sowing at the first plant count. Closed symbols, RM; open symbols AR. ◆, 90-1; ▲, 91-2 and ■ 92-3.

There were no consistent trends of number of plants vs. sowing date (Fig. 4.7). In some instances (e.g. RM 90-1) there was an increase with later sowing, while in others (e.g. AR 92-3) the number of plants was greatest in the early sowings.

4.2.2.2.1..1 Seasonal changes in number of plants

In most cases there was no change or a decline in plant numbers in each sowing as the season progressed (Fig. 4.8, b-d). The reduction was usually greatest in sowings 4 - 7 and, at most, represented a 23 percent loss in plants per m². In RM, 1990-1, the reverse trend was observed and there was an increase in the number of plants between the autumn and spring plant count (Fig. 4.8a).

Table 4.4. Rosemaund 1990-1. Increase in number of plants from the autumn to the spring plant count, as a percentage of the autumn count

	Sowing							
	1	2	3	4	5	6	7	8
Increase %	19	47	32	37	20	9	-11	1

The increase in plant number was proportionately greatest in sowing 2 and declined more or less progressively from sowing 2 - 8, the last two sowing dates showing an decrease or no change (Table 4.4).

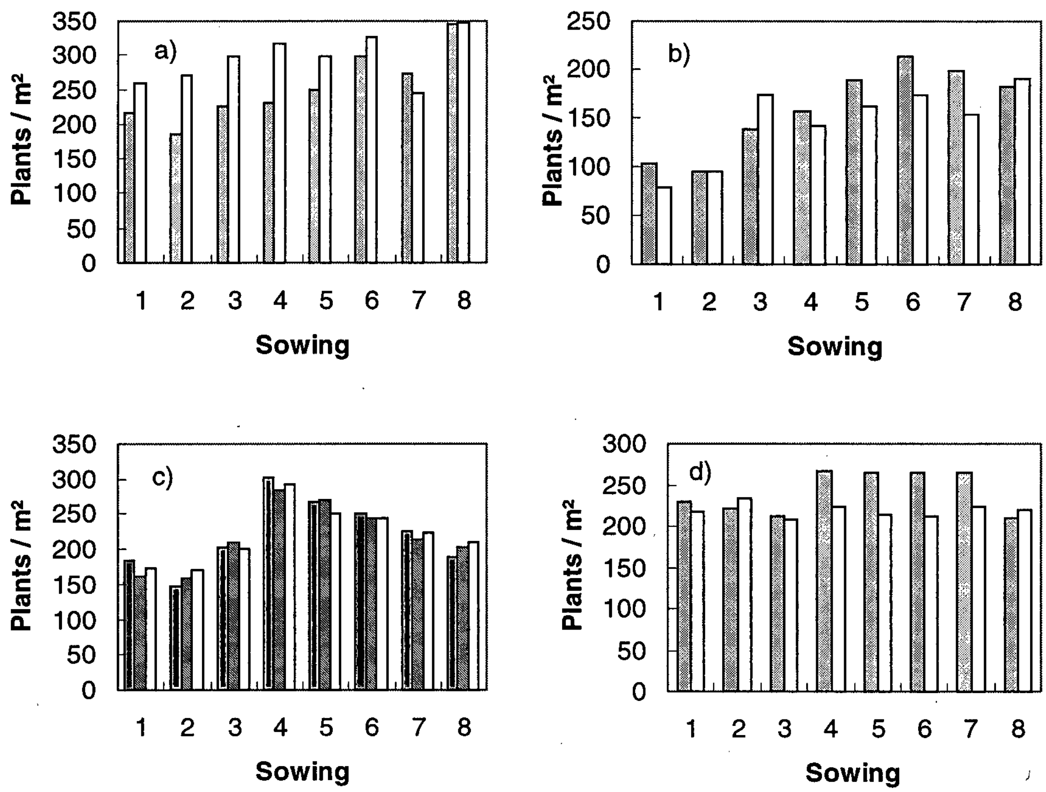


Fig. 4.8. Seasonal changes in number of plants at each sowing. a) RM 90-1, shaded bar, autumn; open bar, spring: b) AR 90-1, shaded bar, 28 February; open bar, 12 April: c) AR 91-2, shaded bar, 8 January; diagonally hatched bar 24 February, open bar, 6 April and d) RM 92-2, shaded bar, autumn; open bar spring.

4.2.2.2.1..2 Interactions

Only in 1992-3 was there a differential response to sowing date among the varieties. There was no discernible, systematic difference in response of varieties to sowing date; rather, the significant interaction was attributable to strong non-systematic variation in number of plants amongst sowings (Table 4.5).

Table 4.5. AR 92-3. Number of plants at 900°Cd after sowing.

	Sowing 1	2	3	4	5	6	7	8
Avalon	196	313	260	163	188	140	121	144
Beaver	263	360	285	340	148	194	171	269
Rascal	217	285	298	273	260	190	133	194
Riband	271	352	344	154	198	150	102	377

4.2.2.2.2. Cockle Park

Throughout the period from seedling emergence to anthesis in 1991-2 plant numbers were higher ($P < 0.001$)in sowing 2 than in sowing 1 although establishment, based on the nominal seed rate, was 70 % in sowing 1 compared with 59% in sowing 2 In both sowings there was a decline ($P < 0.001$) in number of plants from terminal spikelet to anthesis. There was no difference among varieties in the response of plant numbers to time at either sowing date ($P = 0.789$).

In the first two sowings in 1992-3 there was good establishment (79 and 74 % of the nominal number of seeds sown in sowing 1 and 2 respectively). In sowing 3 establishment was lower (43%) so that although the seed rate was higher (600 seeds per m^2) the number of plants was lower (Fig. 4.9). There were no difference amongst varieties.

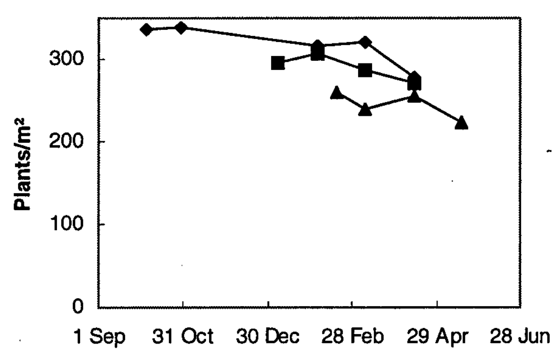


Fig. 4.9. CP 92-3. Number of plants vs. time. The symbols are: ◆, sowing 1; ■, sowing 2; ▲, sowing 3.

4.2.2.3. Discussion

The lower number of plants in the early sowings at RM and AR in 1990-1 and at AR 91-2 was associated with low September rainfall (sub-section 4.2). At CP 91-2, however, despite delayed seedling emergence in sowing 1, establishment was better than in sowing 2.The increase in the number of plants over the winter period at RM 90-1 may also have been due to the small amount of rain which fell in August and September in that season (Fig. 4.6); some seeds may have lain un-germinated until after the autumn plant count and emerged over the winter.

The decline in numbers of plants in AR 1990-91 and RM 1992-3 did not seem to be a consequence of low temperature. In the former case the counts were made on 28 February and 12 April; during this period temperatures did not fall below -3.2°C. The winter temperatures at RM in 1992-3 were the least extreme of any of the years of the experiment and the lowest temperature recorded between the dates of the plant counts was -5.2°C. At Cockle Park the most rapid loss of plants occurred after the terminal spikelet stage and continued until anthesis.

Therefore 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.

4.2.2.4. Conclusions

- In seasons with low September rainfall the number of plants generally increased with later sowing.
- With adequate September rainfall the number of plants declined or was unaffected in the later sowing.
- Number of plants generally declined as the season progressed. This was not always attributable to low temperatures and, in general, appeared unaffected by date of sowing.
- Number of plants was generally not affected by variety or V x S interactions.

4.2.3. Green area index

4.2.3.1. Methods

Green area index was measured as described in the General Introduction (see Part 1, Section 1.5). No leaf area measurements were made at Rosemaund or Arthur Rickwood.

4.2.3.2. Results

Leaf area index and green area index (GAI) showed similar responses to treatment and only GAI is reported. In most samples sowing date, variety and their interaction was significant ($P < 0.001$) (Table 4.6).

Table 4.6. Cockle Park 1992-3, green area index. Significance of sowing date (S) and variety (V) treatments and the S x V interaction. Only sowing 1 in October and sowings 1 and 2 in February was sampled. Significant effects are shown in bold. (- degrees of freedom; two sowings only.)*

	Sowing date	Variety	S x V
D.f.	2	3	6
October		**<0.001**	
February	**<0.001** (1)*	**0.006**	**0.061** (3)*
March	**<0.001**	**<0.001**	**<0.001**
April	**<0.001**	**0.001**	**<0.001**
Flag leaf emergence	**0.045**	**<0.001**	**<0.001**
Ear emergence	**0.028**	**<0.001**	**<0.001**
Anthesis	0.059	0.080	**<0.001**
A + 200°Cd	**0.001**	**0.123**	**0.003**

4.2.3.2.1. Variety and V x S

In the October sample Avalon and Rascal had the greatest GAI (GAI was 0.8, 0.6, 0.8 and 0.5 for Avalon, Beaver, Rascal and Riband respectively). The same ranking of varieties was observed in the February sample. In the March and April samples the ranking of Rascal changed so that it had the least GAI (Fig. 4.10).

From the flag leaf emergence sample onwards the ranking of varieties changed and Beaver and Riband generally had the greatest GAI. Also, the response to sowing date changed, first in Rascal, which at flag leaf emergence had a lower GAI in sowing 1 than in sowing 2, followed by Avalon in the ear emergence sample (Fig. 4.10). At the anthesis and subsequent sample all varieties had a lower GAI in sowing 1 than sowing 2 (Fig. 4.10).

An estimate of the total canopy over the season (green area duration) was made using the trapezoidal rule (Table 4.7). Over the whole season it was greater in sowing 1 than sowing 2, which was greater than sowing 3. A strong S x V interaction was partly due to the small total canopy of Rascal in sowing 1.

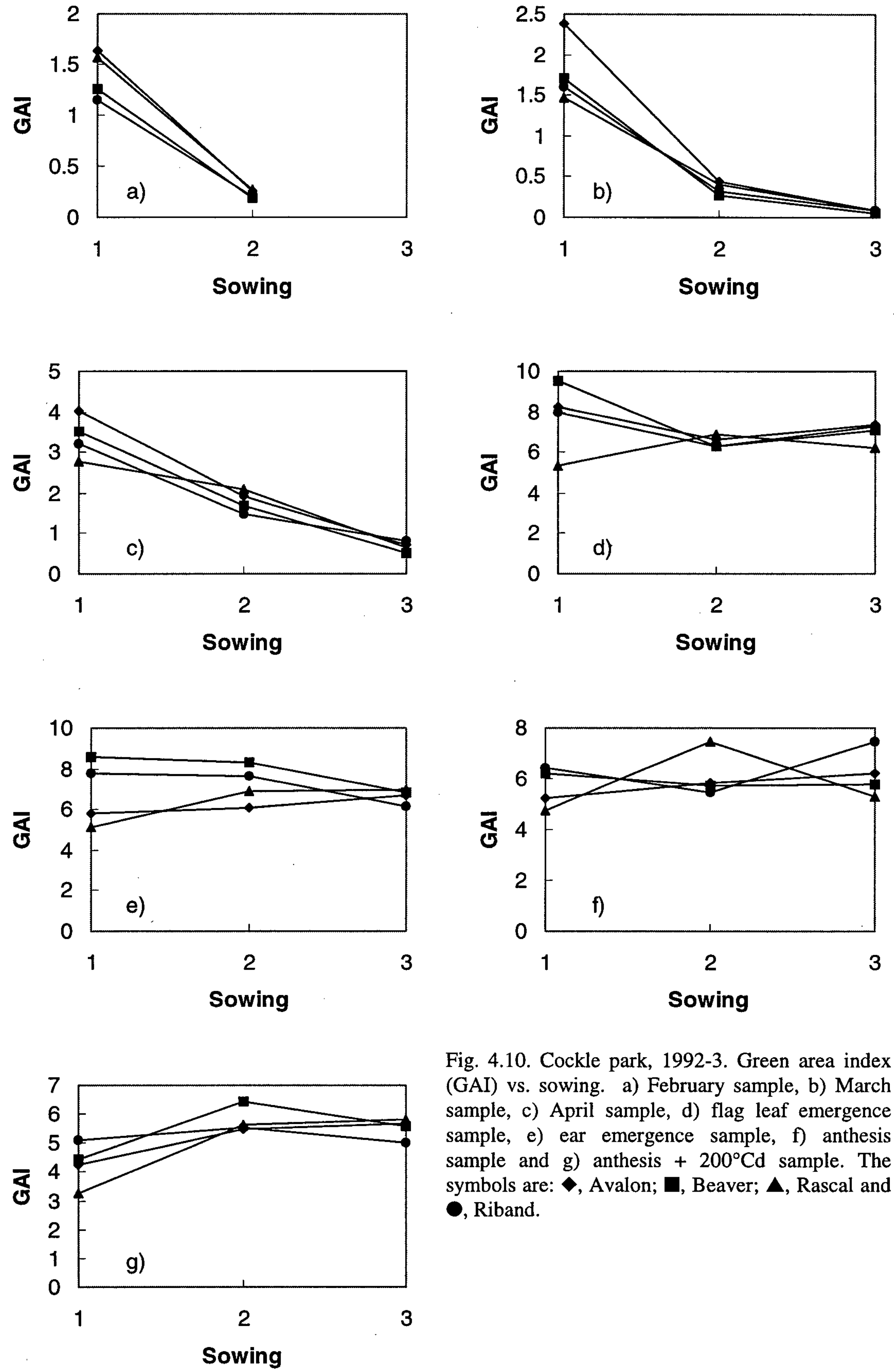


Fig. 4.10. Cockle park, 1992-3. Green area index (GAI) vs. sowing. a) February sample, b) March sample, c) April sample, d) flag leaf emergence sample, e) ear emergence sample, f) anthesis sample and g) anthesis + 200°Cd sample. The symbols are: ◆, Avalon; ■, Beaver; ▲, Rascal and ●, Riband.

Table 4.7. Cockle Park 1992-3. Green area duration (days).

	Avalon	Beaver	Rascal	Riband
Sowing 1 (4 Sep 92)	801	893	614	760
Sowing 2 (1 Oct 92)	522	544	544	541
Sowing 3 (13 Nov 92)	468	525	440	497

4.2.3.2.2. Sowing date

In the three early season samples (February (sowings 1 & 2), March and April) the greatest GAI was recorded in sowing 1 and the least in sowing 3 (Fig. 4.10). At flag leaf emergence the response to sowing date was less, as reflected in the lower probability value (Table 4.6). From ear emergence onwards GAI was lower in sowing 1 than sowing 2 and negative response to early sowing increased with later sampling (Fig. 4.10).

4.2.3.3. Discussion

The trends for GAI in the early part of the season (October to April samples) conformed to the hypothesis about the effects of sowing date and were consistent with the predictions by the ARCWheat and AG models, that is early sowing leads to earlier expansion of the canopy and greater GAI than late sowing. However, the superiority of canopy size in the early part of the season, due to early sowing, was not maintained through the post flag leaf - ear emergence phase because of the early and severe lodging which occurred in sowing 1. During the grain filling period the GAI was least in sowing 1 and the severe lodging may also have affected leaf orientation in the canopy, reducing assimilation compared with the unlodged treatments.

The change in the ranking of Rascal, which in sowing 1 of the October and February samples had a similar GAI to that of Avalon and greater than Beaver and Riband, but which fell to the lowest rank in the March and subsequent samples may have been due to frost damage which was related to its early development .

Variety differences at the flag leaf and later samples are influenced by the change from sampling all treatments at the same date to sampling at specified stages. The greater GAI of Beaver and Riband during this phase is partly attributable to the longer time to particular stages and therefore to a longer duration of leaf expansion. The difference among varieties in the way in which response to sowing date changed as the season advanced was related to differences in susceptibility to lodging. For example, Beaver had greater GAI than Riband in sowing 1, flag leaf and ear emergence samples, but in the anthesis and subsequent sample the greater lodging resistance of Riband may have contributed to its superior GAI, compared with Beaver (Fig. 4.10).

4.2.3.4. Conclusions

- Early sowing led to greater canopy expansion and greater green area durations
- Early and severe lodging in the first sowing reduced the GAI, which, from ear emergence onwards, was lower in the first sowing than the later sowings

4.2.4. Lodging

4.2.4.1. Methods

4.2.4.1.1. Rosemaund and A. Rickwood

Lodging occurred at Rosemaund in 1989-90, 1991-2 and 1992-3 and at A. Rickwood in 1992-3. Plots were scored between one and five times before harvesting (Table 4.7).

Table 4.8. Rosemaund and Arthur Rickwood. Dates when lodging was scored.

RM 1989-90	RM 1991-2	RM 1992-3	AR 1992-3
28 June	15 July	1 June	27 May
13 July		25 June	30 June
16 August		12 July	12 July
		9 August	26 July
			19 August

Lodging was scored as the percentage of the plot in which the plants had lodged, but in some cases the lodged area was graded on the angle to which the plants had fallen over. At RM 1992-3, two levels of lodging were recognised, 'lodging' and 'leaning' and in the last sample, in addition, 'lodged flat'; at AR 92-3 this grading was used in the second sample but in the last three samples a lodging index system was used (Index 1 - 4, representing increasing severity of lodging). To obtain a single measure of lodging at each sample, a weighted score was calculated for each plot, depending on the scoring system, as follows: (leaning + lodging x 2)/2, (leaning + lodging x 2 + lodged flat x 3)/3 or (index 1 + index 2 x 2 + index 3 X 3 + index 4 x 4)/4.

An overall estimate of the degree of lodging over the whole period when the plot was lodged an integrated score was calculated using the trapezoidal rule, as follows:

$$(l_1 + l_2)/2 \times (t_2 - t_1) + (l_2 + l_3)/2 \times (t_3 - t_2)...$$

where $l_1, l_2..., t_1, t_2...$ are the weighted lodging scores at sample times 1, 2, etc.

4.2.4.1.2. Cockle Park

Lodging occurred in both 91-2 and 92-3. In 91-2 lodging was scored on three occasions. On each occasion, for each plot, the area of the plot affected (percent of total area) and the angle of lodging (to the horizontal) was scored.

Table 4.9. Cockle Park. Dates when lodging was scored.

CP 91-2	CP 92-3 (Sowing 1)
13 July	19 July
24 July	5 September
4 August	

In 92-3 the percentage of plot area lodged to less than 45 degrees from the horizontal was scored. No overall score was calculated because of the long interval between samples.

4.2.4.2. Statistical analysis

All data were transformed to ln(1 + percent lodging) before analysis of variance.

4.2.4.3. Results

With few exceptions the ANOVA showed that the effects of sowing date, variety and S x V interaction were significant both for the individual sample weighted scores and for the integral score.

4.2.4.3.1. Rosemaund and Arthur Rickwood

4.2.4.3.1..1 Progress of lodging

Lodging occurred first in sowing 1, then sowing 2 and so on. At RM 89-90 and RM 92-3 significant lodging (>20%) occurred only in sowings 1-3. In RM 91-2 and AR 92-3 more than 20% lodging occurred in all sowing except sowing 8, RM 91-2. Lodging was usually first noted some time after ear emergence and increased in severity throughout the grain filling period (Fig. 4.11).

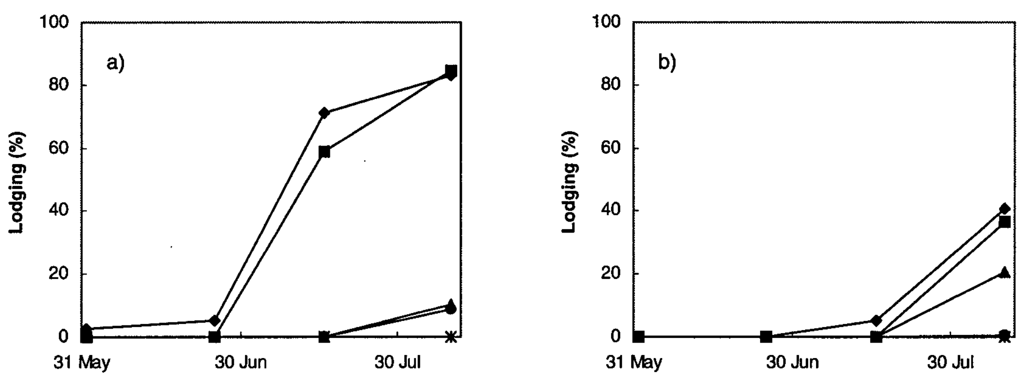


Fig. 4.11. Weighted lodging score vs. date. a) Avalon, b) Riband. The symbols are: ◆, sowing 1; ■, sowing 2; ▲, sowing 3; ●, sowing 4 and x, sowing 5.

Among varieties lodging was noted first in Avalon (RM89-90) and Avalon and Rascal in RM 92-3 and AR 92-3. In 1992-3 Beaver tended to start lodging later than Avalon and Rascal but the rate at which lodging progressed was similar or greater. Riband lodged first at about the same time as Beaver, but the rate of increase in lodging percentage was slower.

4.2.4.3.1..2 Overall severity of lodging

The greatest overall amount of lodging, estimated by the integral score, was in sowing 1 and declined with later sowings (Table 4.10).

Table 4.10. Rosemaund and Arthur Rickwood. Integral lodging scores (% days), except RM 91-2 which is percentage lodging for a single scoring. Note that the scores cannot be compared between sites or years, as scoring method and frequency of scoring varied.

	Sowing 1	2	3	4	5	6	7	8
RM 89-90								
Apollo	543	197	17	165	0	4	0	0
Avalon	3406	1584	535	0	4	0	0	0
Riband	2152	13	9	0	0	0	4	4
Pastiche	60	511	0	0	0	0	0	0
RM 91-2								
Riband	13	25	13	0	2	0	0	0
Beaver	90	58	50	30	45	33	38	0
Avalon	45	28	33	10	18	11	45	0
Rascal	20	13	23	3	33	3	10	0
RM 92-3								
Riband	603	440	245	9	0	20	0	0
Beaver	2131	1773	1872	178	2	99	187	160
Avalon	2749	2337	125	105	0	2	0	0
Rascal	5363	4356	868	2	66	5	0	0
AR 92-3								
Riband	5323	4209	2239	1803	1580	1663	1604	1731
Beaver	9612	6972	5598	2651	2008	1965	2259	2314
Avalon	11440	9157	5133	2237	1665	1654	1638	1703
Rascal	7613	11517	10328	3647	1827	2169	1678	2121

In all instances Avalon (RM 89-90) or Avalon and Rascal (RM 91-2 and RM and AR 92-3) had the greatest overall lodging over sowings 1-4, but Beaver lodged most in sowings 4-8.

4.2.4.3.2. Cockle Park

In 91-2 some lodging was scored in both sowing 1 and 2. The amount and severity of lodging was very variable within varieties. The analysis of variance of percent lodging (transformed to logarithms) showed no significant effect of sowing date or variety and the coefficient of variation was large.

Lodging occurred only in sowing 1 in Expt. A, 1992-3 (Table 4.11). It was first noted in Avalon at ear emergence when all plots were virtually flat and in Rascal at anthesis when secondary tiller growth was reported. At the first scoring on 19 July, about mid-way through grain filling, Avalon, Rascal and some plots of Beaver were severely lodged. At the second scoring on 5 September, about 15 days after harvest, Avalon, Beaver and Rascal were all almost completely lodged. Riband had a mean lodging score of 42%, but this was derived from individual plot scores of from 0 to 60%.

Table 4.11. Cockle Park 1992-3, Expt. A. Percentage lodging. There was no lodging in sowing 2

	Sowing 1	
	19/7/93	5/9/93
Avalon	85	91.2
Beaver	40	85
Rascal	93.7	95
Riband	0	42.5

In Expt.B, 1992-3, lodging was most severe in sowing 1; it was mostly absent in sowing 2, save for a few varieties were it was less than 12%. At the first scoring (19 July) it ranged from 86 percent in Cadenza to no lodging in Lynx and Spark.

4.2.4.4. Discussion

The big differences in lodging among varieties in response to date of sowing 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.

Apart from inherent differences in standing power, the main factors affecting lodging are plant mass, particularly ear mass, and stem length which will affect the turning moment of the stem when a force (wind) is exerted on it. Rainfall will also increase plant mass and soften the soil, increasing the susceptibility to root lodging.

In all cases where lodging occurred, the early sowings were most severely affected. While it is not possible to objectively compare sites or years, because of differences in sampling frequency and method of scoring, the most sever lodging probably occurred in 1992-3. In this year at RM and AR the dry mass at anthesis (GS65) was greatest in the early sowings (1-4) and declined in the later sowings (Fig. 4.18). At CP, where lodging commenced at or before ear emergence the April and the flag leaf samples also showed that sowing 1 had the greatest dry mass (Fig. 4.15).

Lodging did not occur in 1990-1 or 1991-2, years when seedling emergence was slow and when dry mass at anthesis in the early sowings was similar to or less than that of the later sowings (Figs. 4.18 & 4.19).

Early sowing has been reported to increase culm length (Fielder 1988; (Kirby, 1985). This trend was not present in RM 89-90 where there was lodging in the early sowings (Table 4.11, Fig. 4.12a).

Neither the distribution nor the daily intensity of rainfall suggested that the soil conditions conducive to lodging were associated with the susceptible period for the early sowings. There were no data to suggest that any of the disease factors (i.e. stem base diseases) associated with lodging were more prevalent at any sowing date.

4.2.4.5. Conclusions

- Lodging was most severe in early sowings. It was absent or occurred at reduced intensity in sowings made after the beginning of October.
- The differences between varieties was explicable in terms of their general standing power.
- 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.

4.2.5. Stem length

4.2.5.1. Methods

Straw length at harvest time was measured as straw length to the base of the ear in the standing crop at RM 89-90 and RM 91-2. Straw length was not measured at Cockle Park.

4.2.5.2. Results

At RM in 1989-90 crop height tended to be greatest in sowings 3, 4 and 5, falling to a minimum at sowing 6 and then increasing from sowing 7 to 8 (Fig. 4.12a). The S x V interaction (Table 4.12) arose partly from the bigger increase in length from sowing 1 to 5 in Apollo and Avalon compared with Riband and Pastiche.

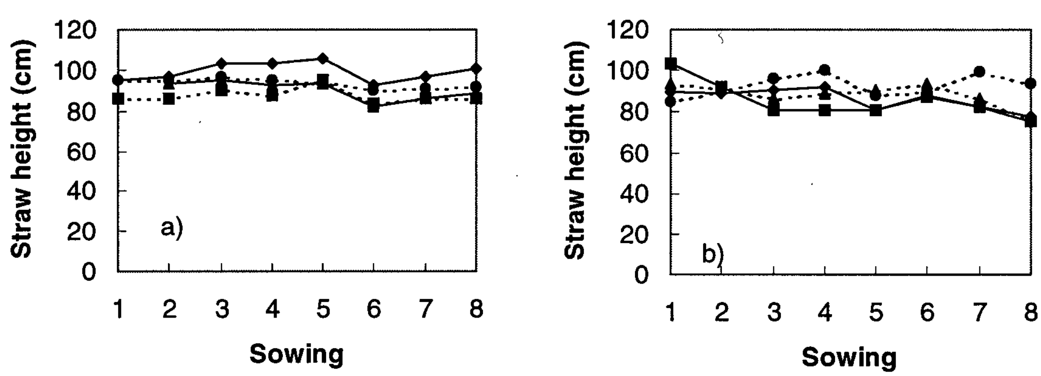


Fig. 4.12. Straw height vs. sowing. a) RM 89-90.The symbols are: ◆,Apollo; ■, Avalon; ▲, Riband and ●, Pastiche. and b) RM 91-2. The symbols are: ◆, Riband; ■, Beaver; ▲, Avalon and ●, Rascal.

Table 4.12. Rosemaund. Summary of probability levels in ANOVA of straw length data. Bold entries indicate significance at p < 0.05

	Block	Sowing date	Variety	SxV
D.f.	1 (3)	7	3	21
RM 89-90	**0.015**	**0.006**	**<0.001**	**0.001**
RM 91-2	0.389	**0.047**	**0.042**	0.176

At RM 91-2, there was a significant sowing date effect resulting from an overall trend for crop height to decline with later sowing (Table 4.12 and Fig. 4.12b). In Beaver there was an 27 percent reduction in height from sowing 1 to 8, less in Riband and Avalon

(Fig. 4.12b). Rascal, which on average had the longest straw showed no clear trend with sowing date.

4.2.5.3. Discussion

There is some evidence that straw length declines with later sowing due possibly to a reduction in the number of internodes (Kirby *et al.*, 1985; Kirby, 1994; Fielder, 1988). On the two occasions in this experiment when the crop height was measured, the evidence was conflicting. In RM 91-2 there was a decline in crop height with later sowing in the three out of four varieties (Fig. 4.12b). No association between early sowing and long straw was found in RM 89-90.

4.2.6. Dry mass growth

4.2.6.1. Methods

Details of temperature and duration of drying and oven type, are given in Vol. I, Part 1, Section 6. Various sampling strategies were used (Table 4.13). At RM and AR, in 1990-1 and 1991-2, sequential samples were taken through the season and all treatments were sampled on the same day. In 1992-3, in addition to samples made on various dates through the season, some samples were taken at specified thermal times after sowing (Table 4.13a), that is, the sowing date treatments were sampled at different dates. At CP 1991-2, samples were taken at specified development stages and at CP 1992-3, a combination of dates and development stages were used (Table 4.13b). As with samples taken at specified thermal times after sowing, sampling at development stages meant that the sowing date variety treatments were sampled on different dates.

Table 4.13. Dates and stages of dry mass samples. a) Rosemaund and Arthur Rickwood Samples were also taken at RM 92-3 at 800, 1000 and 1350 °Cd after sowing and at AR,92-3 at 900 and 1600 °Cd after sowing. b) Cockle Park.

a)

RM 90-1	AR 90-1	RM 91-2	AR 91-2	RM 92-3	AR 92-3
7/1/91	28/2/91	17/12/91	8/1/92	17/12/92	14/12/92
19/2/91	12/4/91	17/2/92	24/2/92	14/6/93	GS65
5/4/91	11/7/91	16/4/92	6/4/92	13/8/93	Pre harvest
27/6/91	12/8/91	8/6/92	9/6/92		
12/8/91		8/7/92	29/7/92		

b) *Table 4.13 contd.*

1991-2	1992-3
Double ridge stage	October (sowing 1)
Terminal spikelet stage	2 February (sowings 1 and 2)
Flag leaf emergence	8 March
Mid-senescence	13 April
Harvest	Flag leaf emergence
	Ear emergence
	Anthesis
	Anthesis + 200°Cd
	Anthesis + 500°Cd
	Harvest

4.2.6.2. Results

4.2.6.2.1. Emergence to anthesis (early season dry mass)

4.2.6.2.1..1 Rosemaund and Arthur Rickwood

4.2.6.2.1..1.1 Sowing date

The response of dry mass to sowing date at the first sample (December - February, Table 4.13a) differed amongst the site x year occasions. In the cases of RM 91-2, RM 92-3 and AR 92-3, the first sowing had the greatest dry mass which declined significantly to the lowest dry mass in the latest sowing (Fig. 4.13, Table 4.14a). The dry mass vs. sowing date trends in these three cases contrasted with the trend found in RM 90-1, AR 90-1 and AR 91-2 (Fig. 4.13 and Table 4.14a), where there was little difference in dry mass among sowings 1-4 (RM 90-1) or where the maximum occurred at sample 4 (AR 90-1 and AR 91-2).

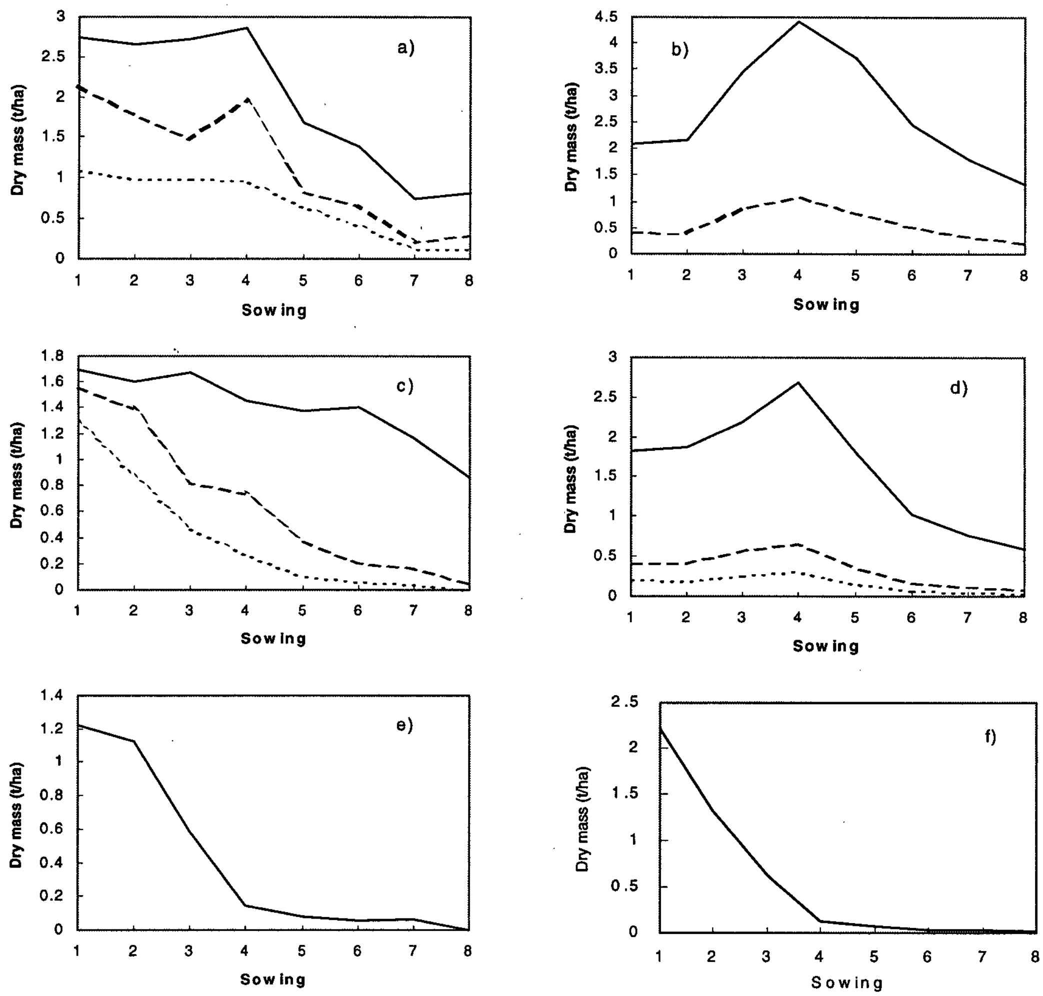


Fig. 4.13. Dry mass vs. sowing for pre-anthesis samples. a) RM 90-1; – – –, 7 January; — — —, 19 February; ———, 5 April, b) AR 90-1 ;— — —, 28 February, ———, 12 April; c) RM 91-2, – – –, 17 January; — — —, 17 February; ———, 16 April, d) AR 91-2; – – –, 8 January; — — —, 24 February; ———, 6 April, e) RM 92-3; ———, 17 December, f) AR92-3, ———, 14 December.

Table 4.14. Summary of probability levels in ANOVA of dry mass data. Bold entries indicate significance at $p < 0.05$ a) Rosemaund and Arthur Rickwood b) Cockle Park 1992-3. Only first and second sowing dates were sampled at 2 February; degrees of freedom (D.f.) were sowing date, 1; S x V, 3.

D.f.	Block 1	Sowing date 7	Variety 3	SxV 21
RM 90-1	No data log transformed			
7 January	0.217	**<0.001**	0395	0.426
19 February	0.154	**<0.001**	**0.008**	0.498
5 April	0.164	**<0.001**	**<0.001**	0.91
27 June	0.936	**0.002**	0.114	0.133
12 August	0.576	0.539	**0.026**	0.791
g / plant5 April	**0.049**	**<0.001**	**<0.001**	0.434
AR 90-1	All data log transformed			
28 February	**0.006**	**<0.001**	0.148	0.186
12 April	0.102	**<0.001**	**0.003**	0.327
11 July	0.906	0.086	**0.010**	0.148
12 August	0.925	0.122	**0.032**	0.813
g / plant 28 February	0.063	**0.001**	0.870	0.796
g / plant 12 April	0.148	**<0.001**	0.629	0.640
RM 91-2	17 December, 17 February & g / plant 8 June log transformed			
17 December	0.373	**<0.001**	0.471	**0.021**
17 February	0.484	**<0.001**	**<0.001**	0.079
16 April	0.113	**0.004**	0.153	0.223
8 June	**<0.001**	0.388	0.929	0.376
8 July	not analysed - too many missing values			
g / plant 17 December	0.640	**0.007**	0.820	0.136
g / plant 8 June	**0.001**	0.275	0.270	0.098

Table 14 contd.

D.f.	Block 1	Sowing date 7	Variety 3	SxV 21
AR 91-2	8 January, 24 February, 6 April , g / plant 8 January & g / plant 24 February log transformed			
8 January	0.143	**<0.001**	**<0.001**	0.020
24 February	0.172	**<0.001**	**0.002**	0.680
6 April	0.053	**<0.001**	**0.002**	0.543
9 June	0.490	**0.032**	0.052	0.710
29 July	0.450	0.770	**0.036**	0.208
g / plant 8 January	0.394	**<0.001**	**<0.001**	**0.028**
g / plant 24 February	0.082	**<0.001**	**<0.001**	0.227
RM 92-3	17 December log transformed (no sowing 8)			
17 December	0.863	**<0.001**	0.054	0.938
GS 65	0.410	**0.003**	0.105	0.428
Pre -harvest	0.750	0.567	0.481	0.806
AR 92-3	14 December log transformed.			
14 December	0.068	**<0.001**	0.365	0.935
GS 65	0.192	**<0.001**	**<0.001**	**<0.001**
Pre -harvest	0.508	0.900	**<0.001**	**0.041**

b)

D.f.	Sowing date 2	Variety 3	SxV 6
2 February	**<0.001**	**0.005**	**0.045**
8 March	**<0.001**	**<0.001**	**0.001**
13 April	**<0.001**	**<0.001**	**0.002**
Flag leaf emergence	0.063	**<0.001**	**0.006**
Ear emergence	0.053	**<0.001**	0.220
Anthesis	0.643	**<0.001**	0.358
Anthesis + 200°Cd	0.061	**<0.001**	**0.002**
Anthesis + 500°Cd	0.258	**<0.001**	**<0.001**
Harvest	0.220	**<0.001**	**0.009**

There was a significant correlation between the first sample and samples taken at anthesis (GS 65) or earlier (Table 4.15), indicating that the dry mass vs. sowing date trends established by the time of the first sample (Fig. 4.13) generally persisted until anthesis. In 1992-3, where some dry mass samples were taken at a thermal time after sowing (i.e. at different dates) a plot of dry mass vs. time indicates that the dry mass relationship established at the first sowing also persisted until GS65 (Fig. 4.14).

*Table 4.15. Rosemaund and Arthur Rickwood. Correlation (r) between the mean dry mass of the first sample and the mean dry mass of samples taken at GS 65 or before. There were 6 degrees of freedom except in RM 91-2 when there were 5. Symbols for probability (P) are **, P < 0.01, *, P < 0.05 and n.s. is non-significant.*

	Samples	r	P
RM 90-1	7/1 vs. 5/4	0.987	**
	7/1 vs. 27/6	0.952	**
AR 90-1	28/2 vs. 12/4	0.990	**
RM 91-2	17/12 vs. 17/2	0.808	*
	17/12 vs. 16/4	0.566	n.s.
	17/12 vs. 8/6	0.780	*
AR 91-2	8/1 vs. 6/4	0.981	**
	8/1 vs. 9/6	0.792	*
RM 92-3	17/12 vs. 14/6	0.969	**
AR 92-3	14/12 vs. GS 65	0.727	*

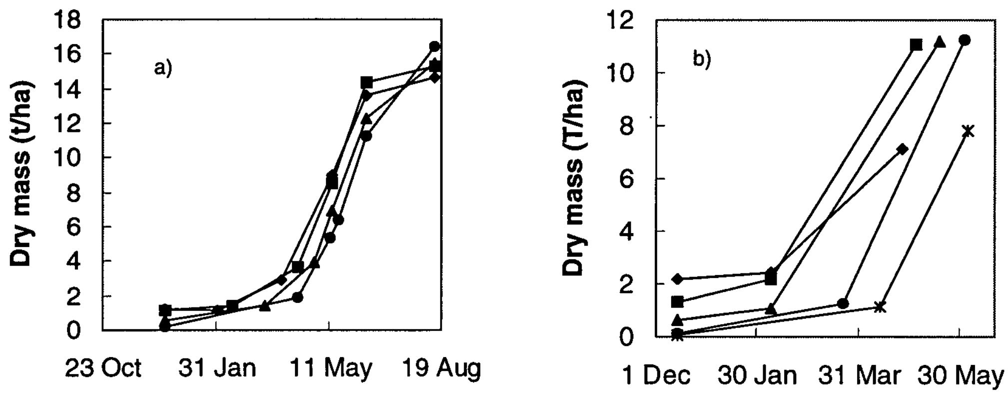


Fig. 4.14. Dry mass vs. time for a) RM 92-3 and b) AR 92-3. Selected sowings only; the symbols are: ◆, sowing 1; ■, sowing 2; ▲, sowing 3; ●, sowing 4; -x-, sowing 5.

4.2.6.2.1..1.2 Variety

Overall cases, most sample dates had a significant difference among varieties (Table 4.14a). In 1990-1, Apollo and Riband had the greatest mean dry mass at any sample, generally ranking either 1 or 2. In 1991-2 and 1992-3, there was no consistency of rank order between samples, sites or years.

4.2.6.2.1..1.3 Sowing date x variety

Generally the probability that varieties responded differently to sowing date was very low (Table 4.14a).There were only four site x year instances of a significant sowing date x variety interaction and, in each of these, at one sample only.

4.2.6.2.1..2 Cockle Park

4.2.6.2.1..2.1 Sowing date

The sampling for the CP 91-2 was done on a development stage basis, so that it was not possible directly to compare dry mass at a particular date. Inspection of the growth curves showed that for all four varieties dry mass in sowing 1 exceeded that in sowing 2 on comparable dates up to the flag leaf emergence stage.

In CP 92-3 the February, March and April samples showed a significant sowing date effect (Fig. 4.15). By the next sample (flag leaf emergence), the sowing date effect was not significant (Table 4.14b) and there was only a weak relation with the dry mass of the March sample (Table 4.16). By anthesis there was a negative relation with early (March) dry mass.

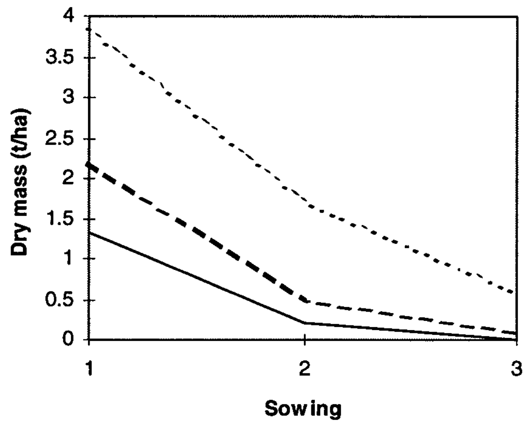


Fig. 4.15. CP 92-3. Dry mass vs. sowing. The codes for the lines are : – – –, April sample; — — —, March sample; ———, February sample.

Table 4.16. Cockle Park. Correlation between the dry mass at the March sample and subsequent samples and between the final, harvest sample and previous samples.

	Correlation with March sample	Harvest sample
April	0.971	-0.266
Flag	0.446	0.377
Ear emergence	-0.13	0.663
Anthesis	-0.389	0.761

4.2.6.2.1..2.2 Variety and sowing date x variety

Because of the sampling strategy for CP 91-2, the variety differences at a stage were due to differences in the length of development phases, and not necessarily in growth potential.

The significant S x V interactions (Table 4.14b) for CP 92-3 were due to changes in ranking of the varieties between sowing dates; for example in the March sample Rascal had the highest dry mass in sowing 1, whereas Riband had greatest dry mass in sowing 3 (Fig. 4.16). However the rankings were not maintained from sample to sample and it was not possible to identify varieties which were favoured or otherwise by a particular date of sowing. (Fig. 4.16)

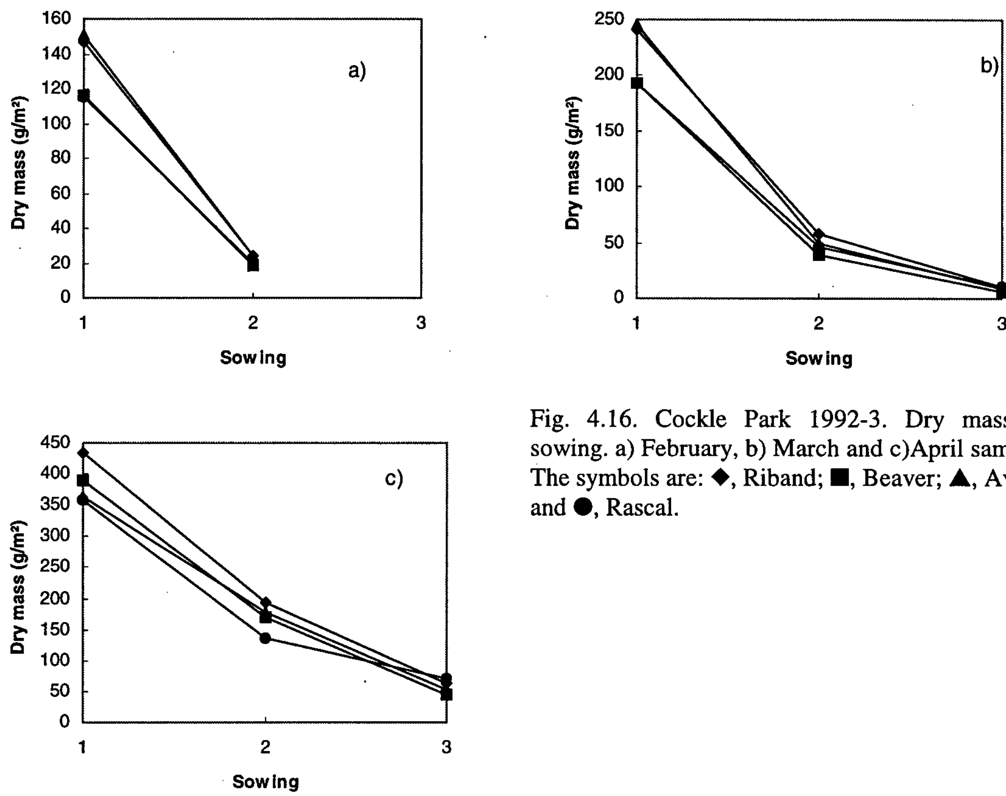


Fig. 4.16. Cockle Park 1992-3. Dry mass vs. sowing. a) February, b) March and c)April samples. The symbols are: ◆, Riband; ■, Beaver; ▲, Avalon and ●, Rascal.

4.2.6.2.2. Anthesis to harvest dry mass

4.2.6.2.2..1 Rosemaund and Arthur Rickwood

At the final ('harvest') dry mass sample, there was no significant effect of sowing date on dry mass (Table 4.14a, Fig. 4.18). In four of the six cases there was a significant difference among varieties (Table 4.17)

Table 4.17. Rosemaund and Arthur Rickwood. Mean variety crop dry mass (t/ha)of the harvest sample. Only those cases with a significant variety effect are shown (Table 4.14a).

	Apollo	Avalon	Riband	Pastiche	SED
RM 90-1	21.9	19.3	21.9	19.2	1.12
AR 90-1	18.2	17.0	19.7	18.7	1.04
	Riband	**Beaver**	**Avalon**	**Rascal**	
AR 91-2	13.5	14.7	13.1	14.3	0.55
AR 92-3	22.1	21.9	19.6	19.4	0.66

Only at AR 92-3 was there a significant S x V interaction (Table 4.14a) This was partly due to the proportionately lower reduction of dry mass of Beaver in the early sowings (Fig. 4.17).

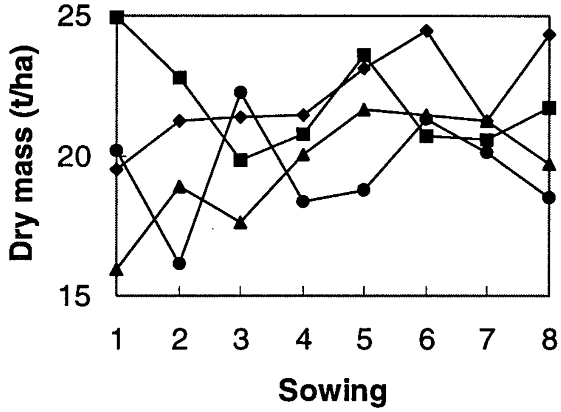


Fig. 4.17. Dry mass vs. sowing for the harvest sample, AR 92-3. The symbols are: ◆, Riband; ■, Beaver; ▲, Avalon and ●, Rascal.

At RM 91-2, RM 92-3, AR 90-1, and AR 92-3 there was a negative correlation over sowing dates between the mean dry mass at the harvest and the penultimate sample. This approached significance at RM91-2 and 90-1 and was highly significant at 92-3 (Table 4.18 and Fig. 4.18).

Table 4.18. Rosemaund and Arthur Rickwood. Correlation between the harvest sample and the penultimate sample (usually GS65). For dates of samples see Table 4.13a. (= P < 0.05.)*

	r
RM 90-1	0.576
AR 90-1	-0.649
RM 91-2	-0.272
AR 91-2	0.677
RM 92-3	-0.614
AR 92-3	-0.809 *

4.2.6.2.2..2 Cockle Park

There was no significant effect of sowing date on dry mass from anthesis onwards (Table 4.14b). There were significant correlations between the dry mass at harvest and that at anthesis and ear emergence, but none with the early samples (Table 4.16).

There were no differences in the response of varieties to sowing date in the ear emergence and anthesis samples (Table 4.14b). Differences among varieties reflected differences in length of life cycle; thus Beaver had the greatest dry mass in all sowings, generally followed by Riband with the early varieties, Avalon and Rascal having the lowest dry mass.

The interactions in the post-anthesis samples (Table 4.14b) were mainly due to the changes in ranking of Rascal which generally had the lowest dry mass in sowing 1 but ranked second or third in the third sowing. Beaver consistently had the highest dry mass in all sowings at all samples from anthesis onwards.

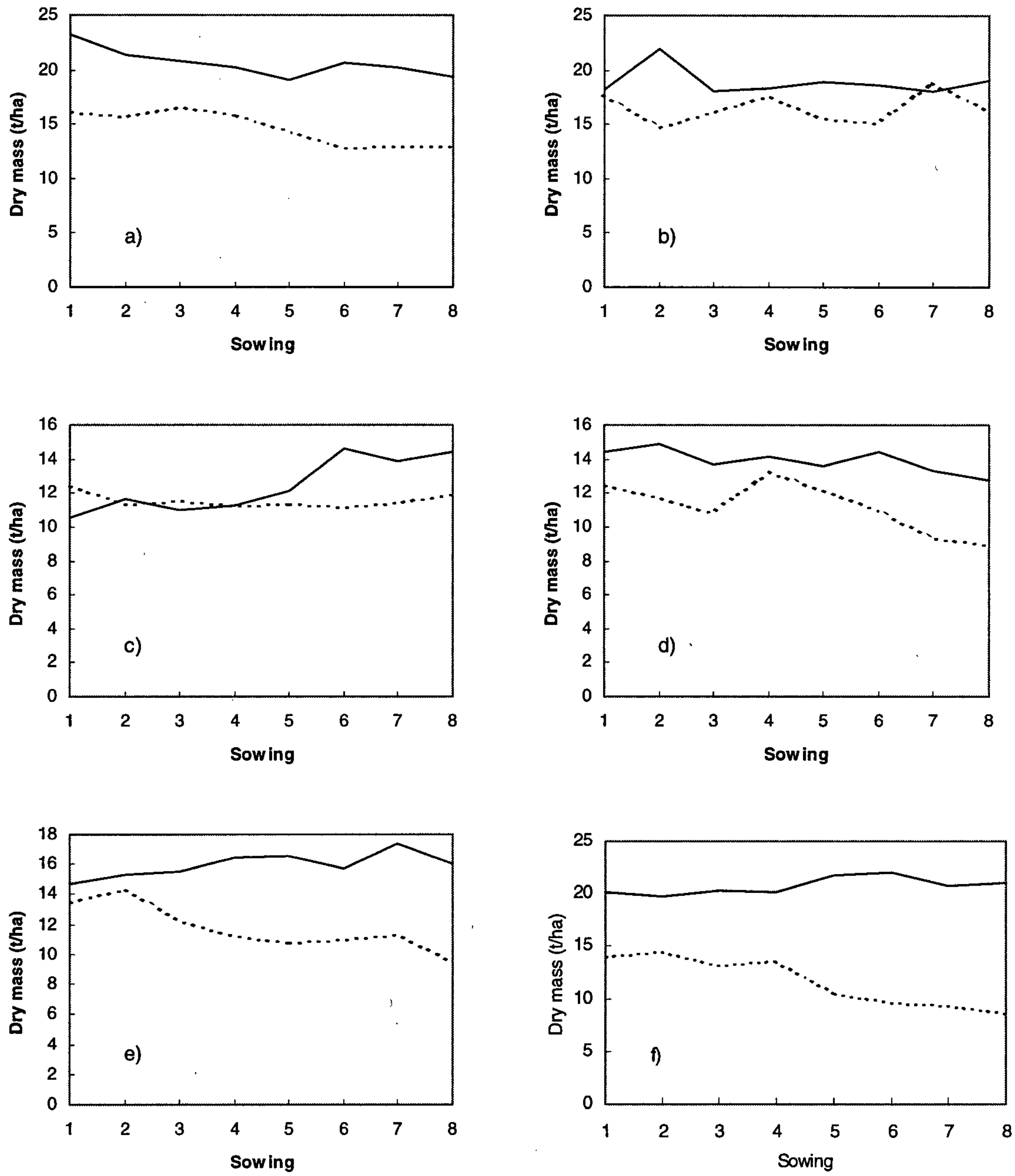


Fig. 4.18. Dry mass vs. sowing for harvest and penultimate samples (see Table 4.13). a) RM 90-1, b) AR 90-1, c) RM 91-2, d) AR 91-2, e) RM 92-3, e) AR 92-3. The dashed line is the penultimate sample and the full line is the harvest sample.

4.2.7. General discussion

4.2.7.1.1. Dry mass pre-flag leaf emergence

Over all site x season combinations, there was no consistent response of dry mass to sowing date, but two types of response could be distinguished. In one, exemplified by AR 92-3 and CP 92-3, dry mass declined as the date of sowing became later. In the other type, illustrated by AR 90-1 and AR 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 response curves were generally associated with years in which rainfall amounts were low over the first three to four sowing dates, leading to long thermal times to emergence, low plant populations and erratic seedling emergence (Fig. 4.19). However, the effect on dry mass per unit area was not due to reduced plant populations because when dry mass per plant was plotted versus sowing date, the response curve was similar to that for dry mass per unit area (Fig. 4.20). Although seedling emergence in thermal time was delayed in the early sowings, in real time the seedlings emerged first from sowing 1, second from sowing 2 and so on. Therefore the 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.

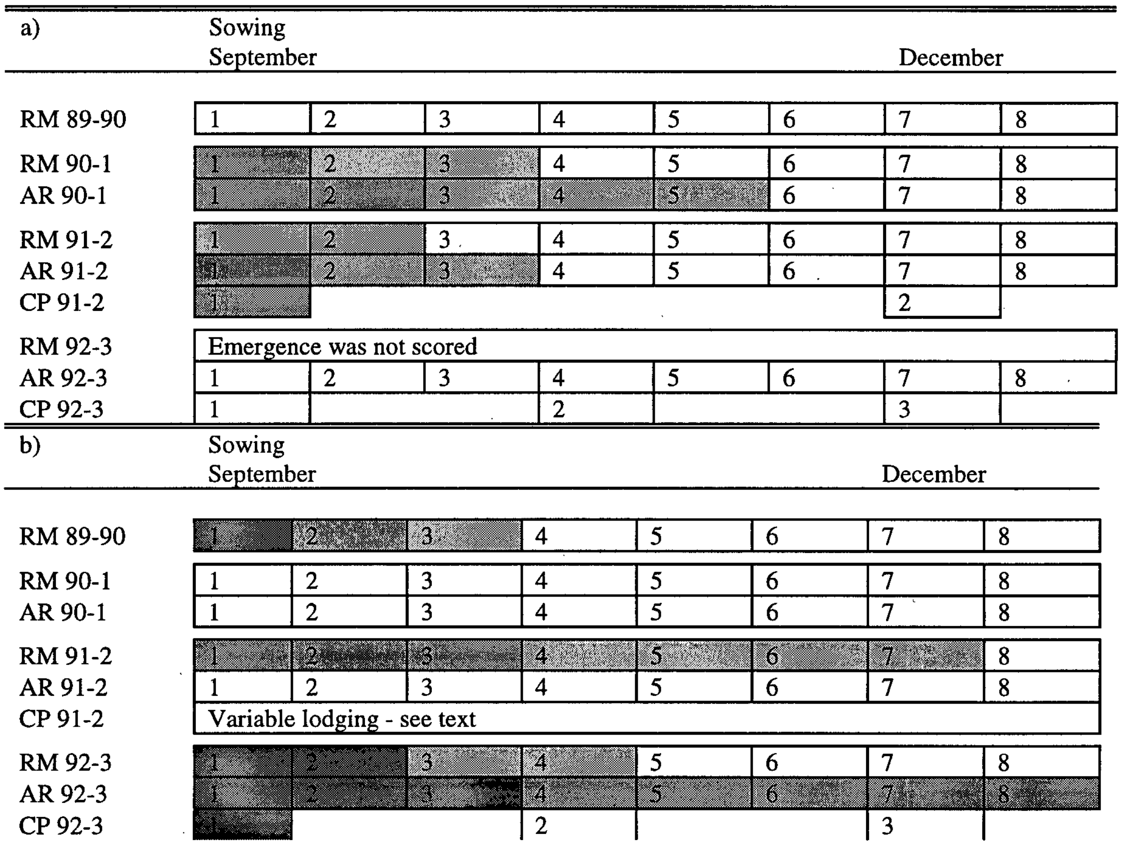


Fig. 4.19. a) Diagram to show the occurrence of delayed seedling emergence.
b) Diagram to summarise the severity of lodging. The assessment was made on the basis of the weighted score in the last lodging score for Avalon in each site x year combination. (Avalon was common in all instances.). In both cases, the darker the shading, the more severe the effect.

The response curves of dry mass vs. sowing date in which dry mass declined with later sowing (e.g. AR 92-3 and CP 92-3) are similar to those predicted by the model (Fig. 4.21), thus confirming the hypothesis that, under optimum growing conditions, early sowing makes available increased resources which are exploited by a photosynthetic canopy which is produced earlier and is of greater total size. This latter fact could not be confirmed for AR 92-3, but at CP 92-3, GAI was greatest in the sowing 1 and least in sowing 3 and full radiation interception (i.e. GAI > 3 - 4) occurred first in sowing 1, then sowing 2 and finally sowing 3.

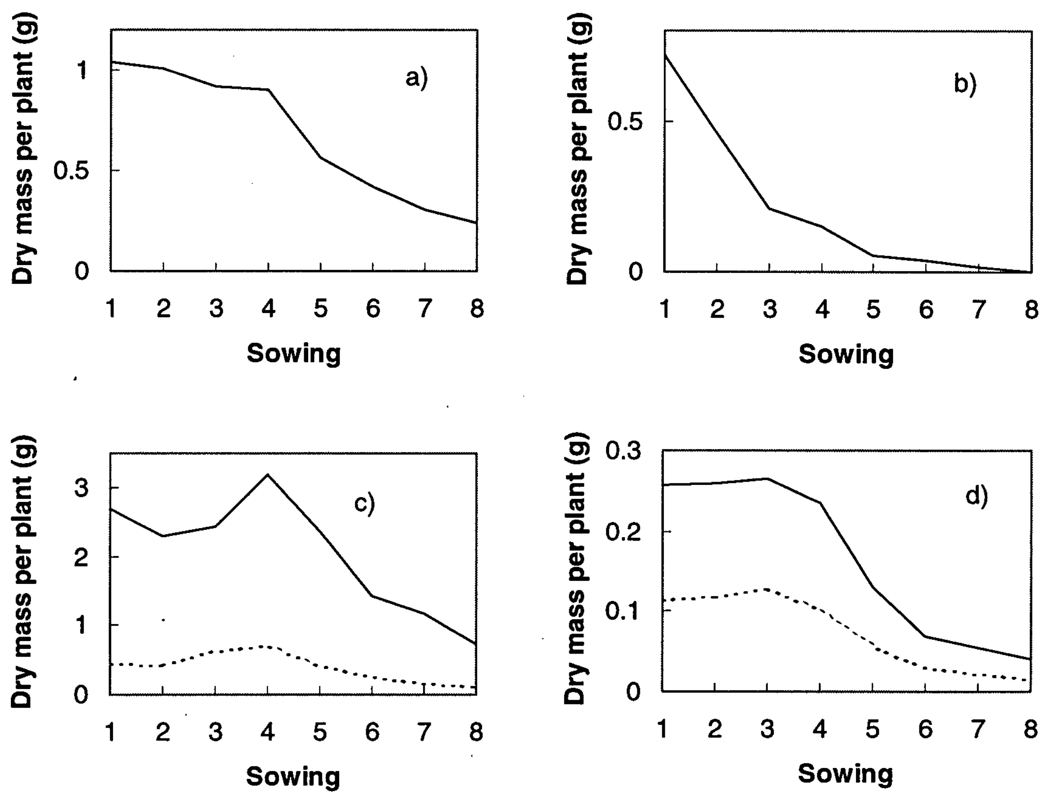


Fig 4.20. Dry mass per plant vs. sowing. a) RM 90-1; ——, 5 April, b) RM 91-2; ——, 17 December, c) AR 90-1; – – –, 28 February and ——, 12 April and d) AR 91-2; – – –, 8 January and ——, 24 February.

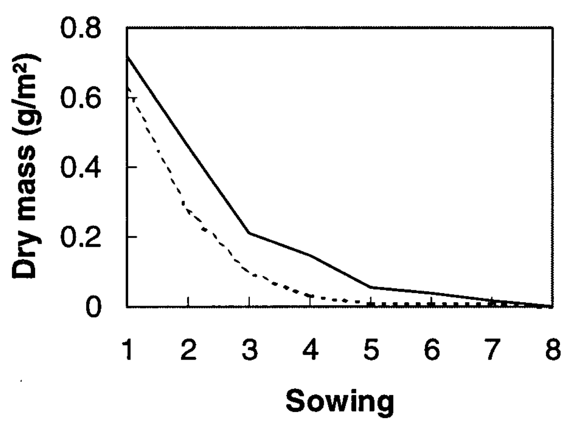


Fig. 4.21. Rosemaund 1991-2. Observed (——) and predicted (ARCWheat model, – – –) dry mass vs. sowing

In all instances except for CP 92-3 the dry mass accumulated early in the season was generally correlated with dry mass at about the time of anthesis (Table 4.15 and Table 4.16). In the case of CP 92-3 the was severe lodging (>90 percent) at flag leaf emergence or before, which led to rapid loss of green area and which probably impaired growth and led to the negative correlation between early season and anthesis dry mass.

4.2.7.1.2. 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 (RM 90-1 AR 91-2 and CP 92-3) there was a positive correlation. In three of the other cases there was a negative correlation this was attributable to lodging (Table 4.18); in those sowing date treatments with the most lodging, growth in the period from anthesis to harvest was much reduced, compared with sowing dates in which there was little or no lodging. At CP 92-3 lodging commenced at flag leaf or ear emergence and, by anthesis, the dry mass relationship with sowing date was changed from that seen in the earlier samples, so that at anthesis dry mass was lowest in the early sowing. Only at AR 90-1 was there a negative relation between dry mass at the anthesis and harvest samples(r = -0.649) which was not attributable to lodging. This site x year combination was also remarkable for the small amount or growth between anthesis and harvest.

The conclusion drawn from these results is that, although under optimum conditions, i.e. in the absence of water stress at sowing, dry mass is greatest from the earliest sowing, lodging at or before anthesis can substantially reduce dry mass at harvest time, relative to treatments with no lodging.

4.2.7.1.3. Varietal adaptation to sowing date

An important objective of this 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 obscured. Only in a few, rather extreme cases did differences in developmental physiology among the varieties affect growth. For example, Rascal at CP 92-3 had the greatest dry mass at the first sample in sowing 1, related to its greater GAI. At subsequent samples this superiority disappeared, probably because its earlier development rendered it more susceptible to frost which killed some shoots (see Section 2 - Development). There were also indications that the later varieties, Beaver and Riband, had greater dry mass at the end of the vegetative growth phase, but the outcome of this for final, harvest dry mass was blurred by differential lodging.

4.2.8. Conclusions

- Dry seed beds in early sown crops delays 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 growth, and negate the possible advantages of greater early growth resulting from early sowing.
- In the absence of agronomic hazards crop growth results confirmed the general hypothesis 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.

5. YIELD AND YIELD COMPONENTS

5.1. Methods

Harvest index (grain dry mass/total shoot dry mass) was estimated from quadrat samples from the growth analysis plot. The samples were taken at about the same time as the combine harvest, ears were hand threshed and grain and stems plus chaff were separately dried and weighed. Yield and thousand grain weight were measured from the combine harvested grain. Thousand grain weight was estimated from two 500 grain samples per plot. Both yield and thousand grain weight are expressed on the basis of 15 percent water, 85 percent dry matter.

Grain growth rates were measured at CP 92-3, Expt. A. Starting shortly after anthesis up to 18 samples were taken from the growth analysis plots at intervals of from 2 to 4 days. At each sampling six ears per plot were gathered and the grains from floret 1 of the spikelets at one third and one half positions on the ear were extracted and dried, i.e. counting from the collar, the integer of (total number of spikelets/2 or 3).

5.2. Results

5.2.1. Rosemaund and Arthur Rickwood

5.2.1.1. Grain yield

In all instances except RM 90-1 there were significant differences in grain yield due to sowing date, variety and the sowing date x variety interaction (Table 5.1)

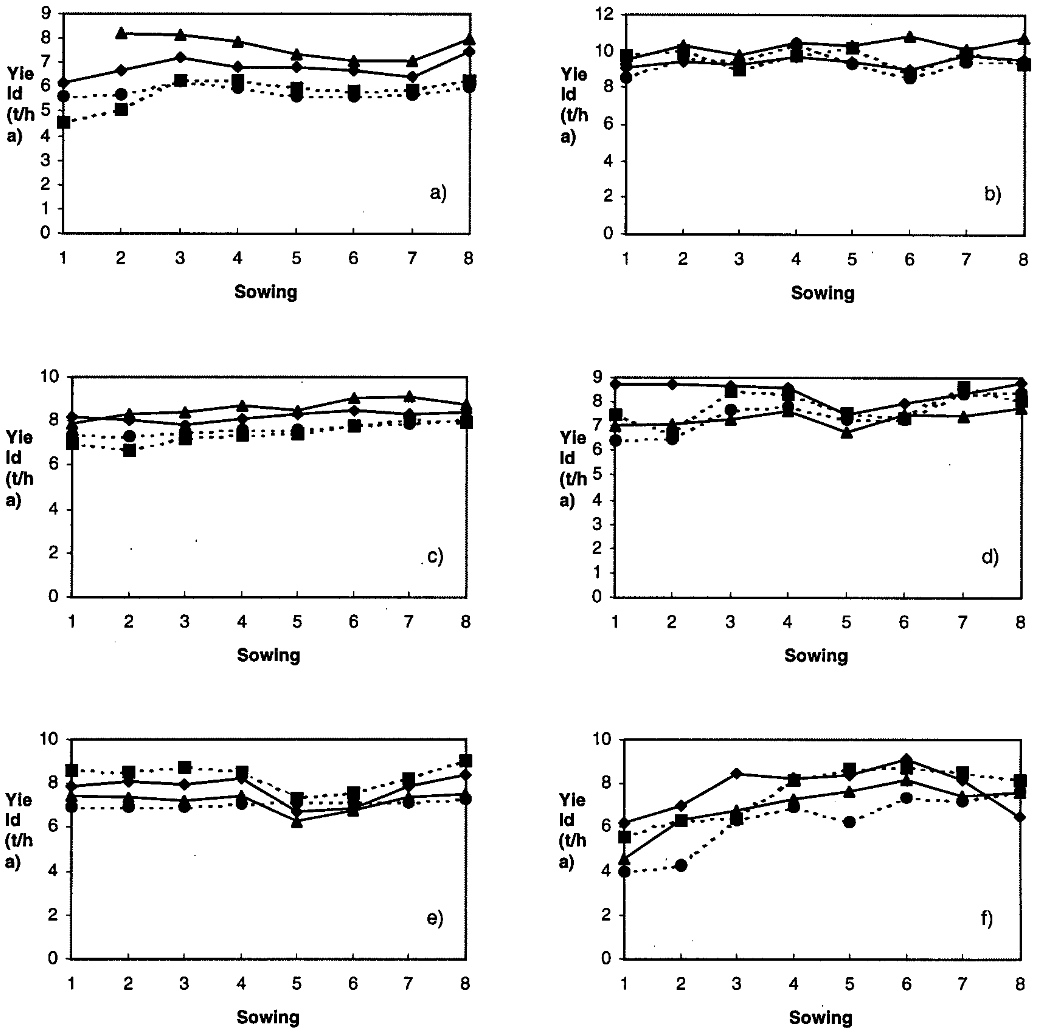
Table 5.1. Rosemaund and Arthur Rickwood. Probability of significance of difference among treatments and interactions from ANOVA. Bold entries are significant at <0.05. a)Yield and b) thousand grain weight.

a) Yield

	Source of variation			
	Block	Sowing	Variety	V x S
D.f.	3	7	3	21
RM 89-90	**<.001**	**<.001**	**<.001**	**<.001**
RM 90-1	0.817	0.087	**0.011**	0.921
AR 90-1	0.141	**<.001**	**<.001**	**0.046**
RM 91-2	0.264	**0.039**	**<.001**	**0.042**
AR 91-2	**0.012**	**<.001**	**<.001**	**<.001**
RM 92-3	0.680	**<.001**	**<.001**	**<.001**
AR 92-3	0.752	**0.002**	**<.001**	**<.001**

b) Thousand grain weight

	Source of variation			
	Block	Sowing date	Variety	V x S
D.f.	3	7	3	21
RM 89-90	0.056	0.636	**<.001**	0.909
RM 90-1	0.928	0.687	0.122	0.145
RM 91-2	0.178	0.627	**<.001**	**0.014**
AR 91-2	0.123	0.101	**0.005**	0.900
RM 92-3	0.189	**0.003**	**<.001**	0.090
AR 92-3	0.135	**<.001**	**<.001**	0.133



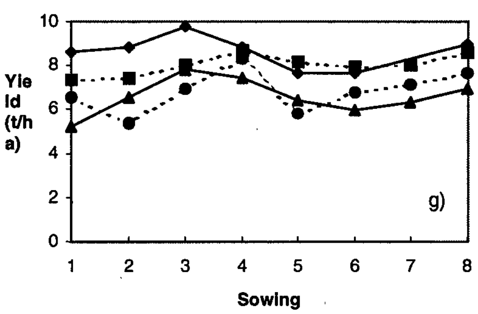


Fig. 5.1 Grain yield (85% d.m.) vs. sowing. a)RM 89-90, b) RM 90-1, c) AR 90-1, d) RM 91-2 e) AR 91-2, f) RM 92-3 and g) AR 92-3. The symbols are: a), b)and c) ◆, Apollo; ■, Avalon; ▲, Riband and ●, Pastiche: d), e), f), and g) ◆, Riband; ■, Beaver; ▲, Avalon and ●, Rascal.

Amongst the S x V interactions, Avalon in all years and Rascal in 1991-2 and 1992-3 generally had relatively low yields in the first two or three sowings. Otherwise, no generalisations about S x V interactions were possible (Fig. 5.1)

The general response to sowing date within each site x year instance was for yield to increase with later sowing until a maximum was achieved usually from an October sowing. With further delay in sowing date yield declined, but the sowing date at which maximum yield (optimum sowing date) occurred was not well defined (Fig. 5.1).

In spite of the S x V interaction, the variety ranking within sowing dates did not change much between sowing dates. Thus, in RM 89-90, RM 90-1 and AR 90-1 Riband was mostly the highest yielder and Avalon and Pastiche had the lowest yields (Fig. 5.1). In 1991-2 and 1992-3, Riband or Beaver generally had the highest yields and Avalon and Rascal had the lowest yields.

5.2.1.2. Harvest index

The main factor affecting harvest index was variety. In no case was the sowing date x variety interaction significant and only in 1992-3 was there an effect of sowing date (Table 5.1). In that year at both RM and AR this was due to low values in sowings 1 and 2 (Fig. 5.2).

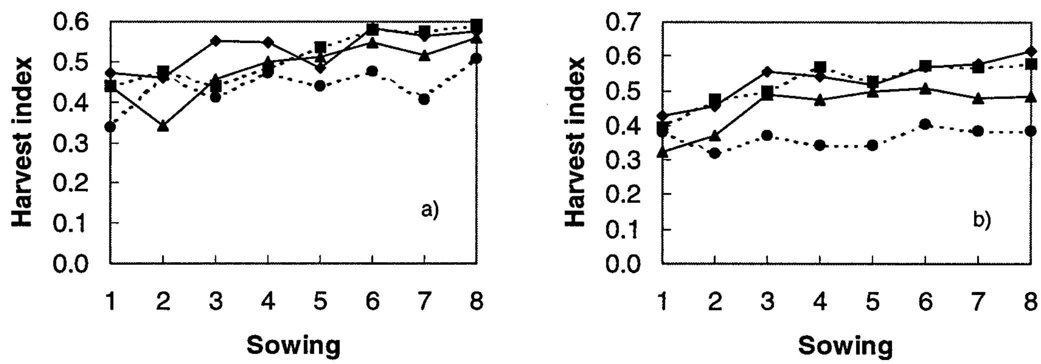


Fig. 5.2. Harvest index vs. sowing. a) RM 92-3; b) AR92-3. The symbols are: ◆, Riband; ■, Beaver; ▲, Avalon and ●, Rascal.

In all cases except one (RM 91-2) Riband had the highest harvest index (Table 5.2). In 1991-2 and 1992-3 Rascal had a substantially lower harvest index than the other varieties, particularly at AR 92-3.

Table 5.2. Rosemaund and Arthur Rickwood. Mean harvest index over sowings for varieties.

	RM 90-1	AR 90-1
Apollo	0.43	0.44
Avalon	0.49	0.42
Riband	0.50	0.47
Pastiche	0.50	0.41

	RM 91-2	AR 91-2	RM 92-3	AR 92-3
Riband	0.41	0.46	0.53	0.53
Beaver	0.41	0.46	0.51	0.52
Avalon	0.43	0.43	0.48	0.45
Rascal	0.37	0.41	0.44	0.37

5.2.1.3. Thousand grain weight

In all instances there were significant differences in thousand grain weight among the varieties (Tables 5.1 and 5.3).

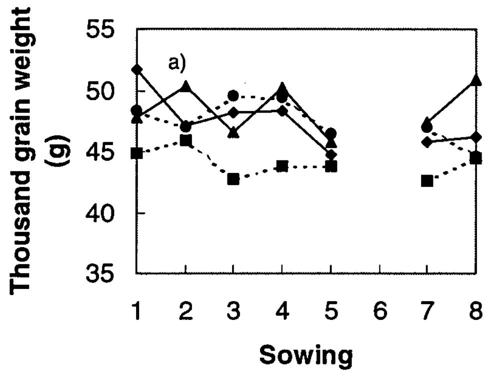
Table 5.3. Rosemaund and Arthur Rickwood. Mean thousand grain weight (g, 85% dm) over sowings for varieties.

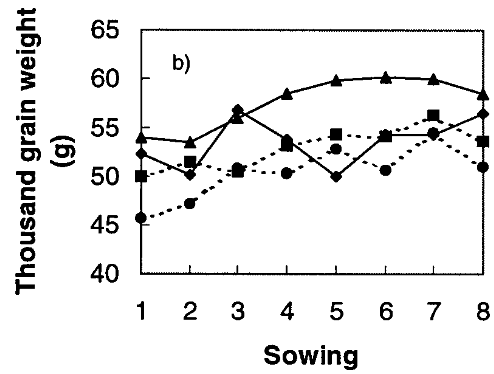
	RM 90-1	AR 90-1
Apollo	44.7	60.1
Avalon	42.5	58.6
Riband	46.7	59.7
Pastiche	42.2	60.6

	RM 91-2	AR 91-2	RM 92-3	AR 92-3
Riband	49.9	42.2	53.5	48.5
Beaver	43.4	40.8	52.9	45.5
Avalon	46.9	42.9	57.5	47.1
Rascal	47.2	43.5	50.3	45.0

Only in RM 91-2 was there a significant S x V interaction due to a decline in the thousand grain weight of Riband from a fall from about 50g in sowing 1 to 44 g in sowing 7 (Fig. 5.3).

There were significant sowing date effects 1992-3. At both sites this was due to an increase in thousand grain weight in the later sowings, particularly over the first two or three sowings (Fig. 5.3)





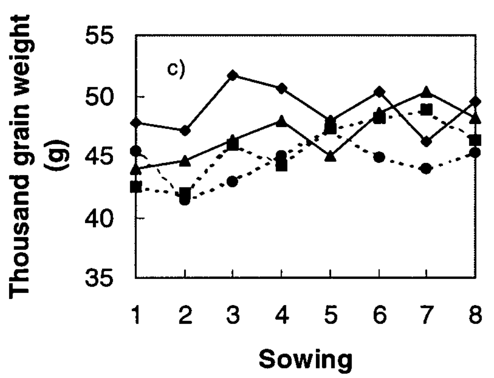


Fig. 5.3. Thousand grain weight (85% d.m) vs. sowing. a) RM 91-2; b) RM 92-3 and c) AR 92-3. The symbols are: ◆, Riband; ■, Beaver; ▲, Avalon and ●, Rascal.

5.2.2. Cockle Park

5.2.2.1. Grain yield

5.2.2.1.1. Sowing date

In 1991-2 the mean grain yield differed between sowing 1 to 2 by 0.45 t/ha (Table 5.4 & 5.5).

Table 5.4. Cockle Park. Significance of differences in grain yield.

year	Experiment	Probability sowing date	variety	sowing date x variety
1991-2		**0.044**	**<0.001**	**<0.001**
1992-3	Expt. A	**<0.001**	**<0.001**	0.304
1992-3	Expt. B	**<0.001**	**<0.001**	**<0.001**
1993-4		**<0.001**	**<0.001**	0.96

In the 1992-3 there was, on average, an greater yield from later sowing. In Expt. A the increase from sowing 1 to 2 was 1.40 t/ha and from sowing 1 to 3, 1.47 t/ha (Table 5.5). In experiment B the average increase from sowing 1 to 2 was 0.83 t/ha (Table 5.5). In 1993-4, while there was a reduction in yield from sowing 1 to 2 (0.75 t/ha) there was an increase in yield from sowing 2 to 3 so that there was only a small difference between sowing 1 and 3 (a decline of 0.05 t/ha).

Table 5.5. Cockle Park. Grain yield (t/ha, 85% d.m.) and difference between sowings. Varieties are ranked with those with greatest sensitivity to late sowing at the top of the list. (Negative values indicate that there was a yield increase in the later sowings)

	1991-2		
	Sowing 1	Sowing 2	S1-S2
Apollo	9.3	8.1	1.3
Haven	11.2	10.0	1.2
Hunter	11.2	10.0	1.1
Urban	7.4	6.4	1.0
Tara	9.6	8.7	1.0
Spark	9.5	8.6	0.9
Mercia	9.2	8.4	0.8
Fortress	10.8	10.0	0.8
Galahad	9.6	8.8	0.7
Soissons	9.7	8.9	0.7
Norman	10.2	9.5	0.7
Riband	10.7	10.1	0.6
Avalon	9.2	8.6	0.5
Aristocrat	9.0	8.6	0.4
Apostle	9.4	9.0	0.3
Sleipner	10.0	9.8	0.3
Brigadier	11.2	10.9	0.2
Hereward	10.3	10.2	0.1
Axona	8.2	8.1	0.1
Hussar	10.7	10.6	0.1
Admiral	10.7	10.7	0.0
Torfrida	9.5	9.8	-0.3
Tonic	8.6	9.3	-0.7

	Experiment A, 1992-3				
	Sowing 1	Sowing 2	Sowing 3	S1-S2	S1-S3
Riband	10.7	12.0	11.7	-1.2	-0.9
Avalon	8.4	10.2	10.1	-1.8	-1.8
Beaver	9.7	11.5	12.0	-1.8	-2.3
Rascal	7.1	9.9	10.1	-2.8	-3.0

	Experiment B, 1992-3		
	Sowing 1	Sowing 2	S1-S2
Mercia	8.8	8.4	0.4
Spark	8.8	8.6	0.3
Estica	9.3	9.0	0.2
Zodiac	9.4	9.3	0.1
Lynx	9.6	9.6	0.0
Rialto	9.4	9.7	-0.3
Torfrida	8.6	8.9	-0.3
Hereward	8.6	9.0	-0.4
Admiral	9.0	9.4	-0.5
Tara	8.1	8.7	-0.6
Hunter	9.0	9.8	-0.8
Hussar	8.8	9.9	-1.1
Haven	8.5	9.7	-1.3
Soisson	8.5	9.8	-1.3
Brigadier	8.3	10.0	-1.7
Buster	8.1	10.2	-2.0
Tonic	5.9	9.3	-3.4
Cadenza	5.4	10.1	-4.7

	1993-4				
	Sowing 1	Sowing 2	Sowing 3	S1-S2	S2-S3
Avalon	10.1	8.7	9.7	1.4	-1.0
Avital	10.3	9.3	10.3	1.0	-1.0
Rascal	8.7	7.7	8.2	1.0	-0.5
Zentos	9.3	8.5	9.2	0.8	-0.6
Riband	10.8	10.2	11.1	0.6	-0.9
Beaver	11.5	11.2	11.9	0.4	-0.7

5.2.2.1.2. Variety

Generally high yielding varieties (NIAB ranking) such as Riband and Beaver had the highest yields, irrespective of the response to sowing date (Table 5.5). Spring varieties (Rascal, Tonic and Axona) generally had amongst the lowest yields.

5.2.2.1.3. Variety response to sowing date

In 1991-2 and 1992-3, experiment 2 there was a significant interaction between sowing date and variety (Tables 5.4 & 5.5).

In these two experiments, there were 12 varieties which were included in both sowings. Apart from Tonic which was least responsive in both years, all other varieties changed their ranking with regard to response to sowing (i.e. the difference in yield between sowing 1 and 2). For example Torfrida which showed almost the least response in 1991-2 (ranked 11/12) had a relatively strong response in 1992-3 (ranked 3/12). Conversely, Haven which ranked 1 for response in 1991-2 was less responsive in 1992-3 (9/12). Varieties with the most consistently low response were Tonic (12/12 and 12/12) and Hussar (8/12 and 9/12 in 1991-2 and 1992-3 respectively) whereas Spark (4/12 and 2/12), and Tara (6/12 and 3/12) had the most consistently high response.

5.2.2.2. Harvest index

5.2.2.2.1. Sowing date

Only in 1992-3 did sowing date significantly affect harvest index (Table 5.6). In both experiment A and B this was due to low values in sowing 1 (Table 5.7).

Table 5.6. Cockle Park. Significance of differences in harvest index.

Year	Experiment	Probability Sowing date	Variety	Sowing date x variety
1991-2		0.730	<0.001	0.143
1992-3	Expt. A	0.002	<0.001	0.079
1992-3	Expt. B	<0.001	<0.001	<0.001
1993-4		0.305	<0.001	0.071

5.2.2.2.2. Variety

In all experiments there were very highly significant differences among varieties.

5.2.2.2.3. Variety response to sowing date

The interactions in experiment B were, in part, due to the very low harvest indices in sowing 1 of Tonic, Buster and Cadenza (Table 5.7).

Table 5.7. Cockle Park 1992-3, harvest index. In experiment B, varieties are ranked in order of sensitivity to late sowing (sowing 1 - sowing 2)

Expt. A	Sowing 1	Sowing 2	Sowing 3
Avalon	0.37	0.42	0.45
Beaver	0.38	0.46	0.45
Rascal	0.38	0.44	0.42
Riband	0.45	0.49	0.51

Expt. B	Sowing 1	Sowing 2	S1-S2
Spark	0.38	0.42	-0.04
Mercia	0.37	0.42	-0.05
Hereward	0.37	0.42	-0.05
Estica	0.37	0.43	-0.06
Zodiac	0.38	0.45	-0.06
Soisson	0.40	0.46	-0.06
Hunter	0.38	0.44	-0.07
Tara	0.35	0.43	-0.08
Rialto	0.35	0.43	-0.08
Admiral	0.34	0.43	-0.09
Torfrida	0.37	0.46	-0.09
Lynx	0.38	0.47	-0.09
Hussar	0.35	0.45	-0.10
Haven	0.35	0.45	-0.10
Brigadier	0.38	0.50	-0.12
Tonic	0.29	0.42	-0.13
Buster	0.31	0.46	-0.14
Cadenza	0.27	0.45	-0.18

5.2.2.3. Yield components

5.2.2.3.1. Number of ears per unit area

Number of ears in 1991-2 was consistently greater in sowing 2 than sowing 1 (Sowing date effect P = 0.045) and there significant differences among varieties (P < 0.001), the mean over sowings ranging from 425/m² for Spark to 295/m² for Riband. A significant interaction (P = 0.04) resulted from large varietal differences in response to sowing, ranging from 34 per cent for Axona to less than 6 percent for Riband and Apollo.

In experiment B, 1992-3, there was a big difference among varieties in the relative number of ears in the two sowings. (interaction P < 0.001). For example, Cadenza and Tonic had 35 and 23 percent, respectively, more ears in sowing 2 than sowing 1, whereas in the same comparison Haven and Lynx had 23 and 18 percent, respectively, fewer ears. Overall there was no effect of sowing date. Admiral, Cadenza, Rialto and Tonic had the fewest ears (< 715/m²) and Hunter, Mercia and Spark had the most (>830/m²; P < 0.001). Among the intensively studied set, Expt. A, 1992-3, only the variety effect was significant (P < 0.001).

There was no sowing date x variety interaction in 1993-4. The greatest number of ears was observed in Beaver and the least in Riband (variety effect (P < 0.001) A significant sowing date effect (P = 0.004) was due to a greater number of ears in sowing 3 (525, 523 and 580 /m² in sowings 1, 2 and 3, respectively).

5.2.2.3.2. Number of grains per ear

Grains per ear was measured only in 1993-4. Only the variety effect was significant($P < 0.001$). Greatest numbers were observed in Riband (36 grains/ear) and least in Rascal (29).

5.2.2.3.3. Thousand grain weight

In 1991-2 there was no effect of sowing date on thousand grain weight. There were significant differences among varieties ($P < 0.001$) and a significant S x V interaction. The latter arose because some varieties had lower thousand grain weights in sowing 2 than in sowing 1 while in other varieties the opposite trend occurred. Within a variety, however, the difference between sowing were generally less than 3g, about 6 percent.

All treatments had significant effects in Expt. A, 1992-3 due mainly to the contrast between sowing 1 versus sowings 2 and 3 ($P < 0.001$) (Table 5.9). While there was little difference between the overall means for sowings 2 and 3, the thousand grain weight of sowing 1 was 8 percent lower. The effect was greatest for Beaver (15 percent lower in sowing 1 than in sowing 2) than in Riband (7 percent lower in sowing 1 than in sowing 3) which resulted in the S x V interaction ($P < 0.013$).

Amongst the 18 variety in Expt., the mean thousand grain weight over all varieties was 9 percent lower in sowing 1 than in sowing 2. Among the individual varieties the difference ranged from more than 15 lower in sowing 1 than 2 in Brigadier, Buster, Cadenza and Tonic to less than 3 percent in Estica, Lynx, Soisson and Zodiac.

In 1993-4 There was no effect of sowing date on thousand grain weight. Differences among varieties ($P < 0.001$) ranged from 47.2g for Rascal to 53.4 for Riband. In Rascal, Avital and Avalon the thousand grain weight fell by up to 7 percent from sowing 1 to sowing three, while in Riband Beaver and Zentos it rose by up to 7 percent (V x S, $P < 0.001$).

5.2.3. Grain growth (Cockle Park)

The growth parameters of the grains at the two positions on the ear (third and half) were strongly correlated and only the results for the grain at the half ear position are shown. The data showed a typical sigmoid pattern of growth (Fig. 5.4)

Linear regression and the generalised logistic functions were fitted to the data (Loss *et al.*, 1989) The logistic gave a good description of growth (Fig. 5.5) and in all cases accounted for between 99 and 99.8% of the variance. Linear regression was fitted to the data for the period when growth rate was more or less constant (Fig 5.5), that is excluding the first three samples after anthesis and samples taken after the grain had reached maximum dry mass. It accounted for 98.4% of the variance, although inspection of the residuals revealed that there was some systematic departure from the linear trend.

The estimates of rate and duration provided by the logistic are shown Table 5.8. Some were clearly biased by sampling variation or other experimental errors. These were particularly significant towards the end of the period of growth and some of the high values for the calculated duration of growth should be viewed with caution. For example, in Rascal sowing 1 (Fig. 5.4) it is uncertain from the last five points whether the grain had achieved maximum dry matter. The upward trend of the last two points exerted a high leverage on the estimation of the coefficients of the function, the effect of which was to increase the value of C and reduce the value of B. In Beaver, sowing 3 (Fig. 5.4), anthesis was protracted and difficult to detect. The estimate of the time of anthesis was probably too late and this accounts for the leftward shift of the growth curve, relative to the other varieties (Fig. 5.4).

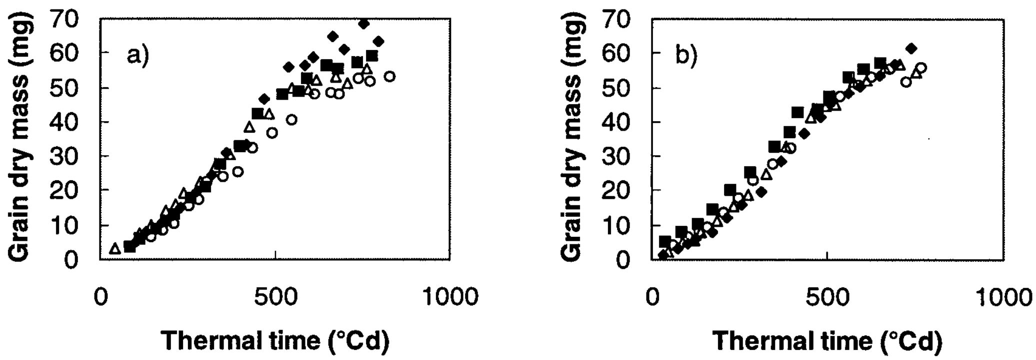


Fig. 5.4. CP 92-3. Grain dry mass vs. thermal time for a) sowing 1 and b) sowing 3. The symbols are: ◆, Riband; ■, Beaver; Δ, Avalon and O, Rascal.

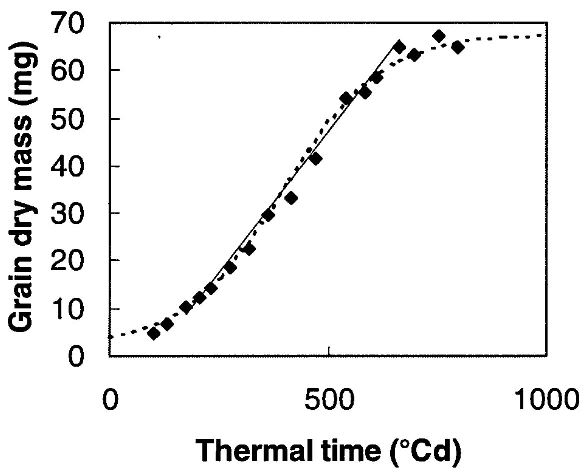


Fig. 5.5 CP 92-3. Grain dry mass vs. thermal time. The symbols are: ◆, observations; – – –, logistic function; ——, linear function.

The analysis of grain growth rate calculated by linear regression showed that both sowing date and variety effects were significant (Table 5.8). Generally, except for Rascal, the rate of growth declined from sowing 1 to sowing 3. A significant S x V interaction arose from the low grain growth rate for Rascal and the high value for Riband in sowing 1 (Table 5.8).

Table 5.8. Cockle Park, 1992-3. Maximum growth rate and duration of grain growth, calculated from the logistic function and growth rate estimated by linear regresssion.

	Avalon	Beaver	Rascal	Riband
	Maximum growth rate (mg per °Cd)			
Sowing 1	0.111	0.126	0.096	0.146
Sowing 2	0.132	0.130	0.120	0.140
Sowing 3	0.126	0.109	0.119	0.121
	Duration of growth (°Cd)			
Sowing 1	727	729	867	733
Sowing 2	707	674	711	749
Sowing 3	706	820	706	813
	Linear regression coefficient (mg per °Cd)			
Sowing 1	0.100	0.104	0.085	0.119
Sowing 2	0.101	0.100	0.095	0.105
Sowing 3	0.094	0.092	0.093	0.096

The final, maximum dry mass of the grain was estimated from the mean of the last three samples (Table 5.9)

Table 5.9 Cockle Park, 1992-3. Mass per grain (mg) for the 'half ear' grains and the average mass per grain (mg) from the thousand grain weight.

	Avalon	Beaver	Rascal	Riband
	'Half ear' grain			
Sowing 1	61.2	65.9	60.3	73.8
Sowing 2	65.3	63.3	62.6	72.3
Sowing 3	64.1	63.5	62.4	65.9
	Thousand grain weight			
Sowing 1	48.4	47.9	45.4	50.3
Sowing 2	52.1	55.5	48.9	51.4
Sowing 3	52.9	52.4	47.4	53.9

5.2.3.1. Discussion

There were some anomalies among the data, probably because of lodging in sowing 1, e.g. in the case of Rascal the relatively low growth rate and long duration of grain fill were associated with early and severe lodging. This may have attributed to variable data, particularly around the time of maximum grain dry mass, which biased the estimation of the asymptote.

If anomalous data are excluded the duration 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). There was no correlation between duration of growth and maximum dry mass of the grain.

Linear regression and the logistic function gave similar estimates of growth rate (Table 5.8) and there was strong correlation ($r = 0.85$, $P < 0.01$) between the two methods. There was a significant relation ship between growth rate and maximum dry mass ($r = 0.84$, $P < 0.01$ for both methods). The estimated growth rates were consistent with those found by others workers (Loss *et al.* 1989). The results for this experiment tend to confirm the findings of several other reports which have suggested that grain size is determined more by differences in rate rather than duration of growth (Sofield *et al.*, 1977; Nass & Reiser, 1975; Bruckner & Froberg, 1987.

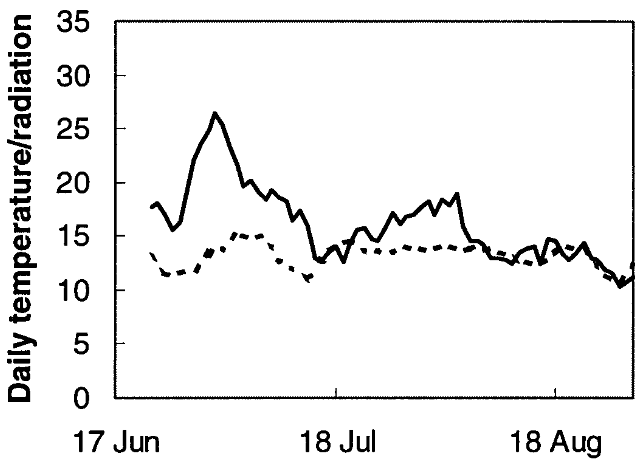


Fig. 5.6. Cockle Park, 1992-3. Six day moving average of temperature (°C), - - - and radiation (MJ/m²), ———.

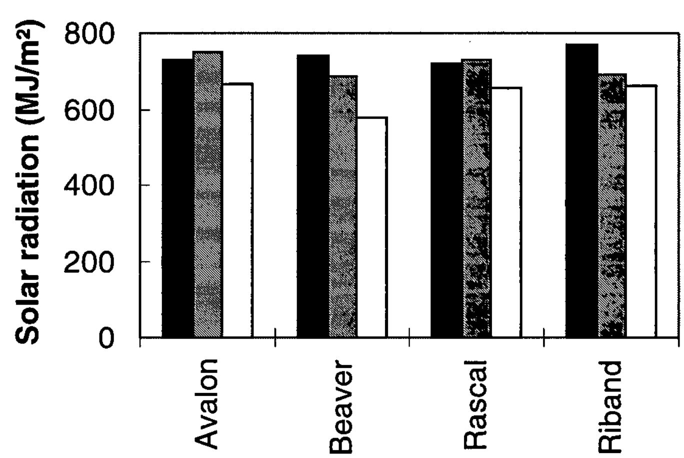


Fig. 5.7. Cockle Park, 1992-3. Cumulated radiation for a period of 716 °Cd after anthesis. Sowing 1, • ; sowing 2, • ; sowing 3, • .

Temperature and radiation data for the overall period of grain growth (17 June - 29 August) show a general decline in radiation per day throughout the period but apart from short term fluctuations the temperature showed no trend (Fig. 5.6). Total radiation receipt during grain filling, based on the mean duration of 716°Cd, showed that the highest values in sowing 1 and the least in sowing 3 (Fig. 5.7). Rascal, with the earliest dates of anthesis, had the highest values of total radiation during the grain fill period and Beaver, the latest to anthesis in all sowings, the least. Excluding Rascal, sowing 1, there some relation between total radiation and rate of grain fill ($r = 0.63$, $P = 0.05$). Because of the relatively stable daily temperature the duration of grain fill varied only between 51 and 53 days.

There was no correlation between the mass of the half-ear position grain and 1000 grain weight of the combine harvest sample partly because of the relatively lower values for 1000 grain weight in sowing 1. The weight per grain (based on 1000 grain weight) was considerably lower than the weight of the 'half-ear' grain. This was expected as the grains sampled for grain growth were from floret 1 of the mid part of the ear. Mass per grain is lower in the basal and distal spikelets and in the upper florets all of which contribute to the 1000 grain weight estimate in a bulk sample (triboi reference to grain size gradient). Thus the apparent effect of sowing date (lodging) on thousand grain weight was not so marked in the individual grain growth data. This may indicate that sowing date (lodging) affected thousand grain weight by changing the proportion of small or unfilled, shrivelled grains, rather than a general effect on all grains.

5.2.3.2. Conclusions

- Duration of grain growth did not vary with sowing date or variety.
- Differences in final grain mass were attributable to difference in growth rate.
- There was a relation between grain growth and total radiation during the grain growth period.
- The earlier anthesis occurred, because of sowing date or variety, the greater the radiation during the grain fill period.

5.2.4. Curve fitting (Rosemaund and Arthur Rickwood)

5.2.4.1. Method

Although a general trend of yield vs. date of sowing is apparent in the raw data (Fig. 5.1), experimental variation from sowing to sowing made precise identification of the sowing date for maximum yield difficult to identify. To smooth the yield vs. date of sowing trends the data were fitted using a quadratic function:

$y = c + bx + ax^2$ Eqn. 1.

and a linear plus exponential function:

$y = \alpha + r\beta^x + \delta x$ Eqn. 2.

where y is the estimated yield, a, b, c, α, ,r, β and δ are constants and x is time in days. Then, from the first differential of the functions with dy/dx set to zero, the time of maximum yield (S_{opt}) was calculated. Substituting S_{opt} for x gave maximum yield (y_{opt}).

The functions were fitted using the FITCURVE directive of GENSTAT (Genstat 5 reference manual, 1988). A parallel curve analysis was done for each site and year to determine if a single S_{opt} was appropriate for all the varieties. The approach taken, for the quadratic curve, was to fit a progression of successively more complex models to the data for all four varieties. The sequence was to fit a single curve to the data for all four varieties , to fit parallel curves to the four varieties and to fit a separate curve to each variety. This would result in all four varieties having the same S_{opt} in the first two instances and different S_{opt} in the third instance. A similar procedure was followed with the linear plus exponential model but an additional model was considered. The series of model mentioned were fitted keeping the non-linear parameter, r, of the model fixed across all varieties. The additional model fitted was separate curves for each variety with the r parameter also being estimated separately for each variety. This was the most complex linear plus exponential model used. Each time a more complex model was used it was expected to account for more of the yield variability as expressed by the model sum of squares. The increase in the sum of squares was tested, with an F test, against the back-ground error to determine if the increase was statistically significant. The results of these tests led to final choice of model.

Because of the long thermal time to seedling emergence in certain instances (see section 4.2.1) the curves were fitted using an 'effective' sowing date. This was calculated as the day 150°Cd before the observed seedling emergence.

5.2.4.2. Results

In many cases fit to the data were very similar for both the quadratic and the linear plus exponential functions (Fig. 5.8). The estimates of the parameters and a measure of goodness of fit (R^2) are shown in Appendix table 4).

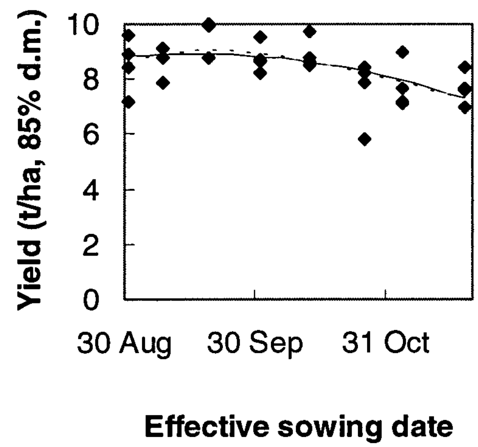


Fig. 5.8. AR 92-3, Riband. Grain yield vs. effective sowing date. ♦, observed yields; ———, Quadratic curve; - - - ,Linear plus exponential curve.

In about half the cases the line fitted by the linear plus exponential function was asymptotic, i.e. *y* continued to increase to plus infinity or minus infinity and no estimate of s_{opt} and therefore of y_{opt} was possible (Table 5.10).

Table 5.10. Fitted values of effective date of maximum yield, (S_{opt}), maximum yield (Y_{opt}) for the quadratic and linear plus exponential functions and observed date and yield and differnces among them. (n.v. indicates no value could be calculated.)

Sowing date which gave maximum yield (S_{opt})
Quadratic function

	RM 89-90	RM 90-1	AR 90-1	RM 91-2	AR 91-2	RM 92-3	AR 92-3
Riband	23-Dec	24-Oct	24-Oct	12-Jul	4-Oct	24-Oct	16-Sep
Beaver				16-Oct	1-Oct	14-Nov	19-Oct
Avalon	23-Oct	11-Oct	24-Oct	12-Oct	5-Oct	28-Oct	9-Oct
Rascal				19-Oct	21-Oct	19-Oct	10-Oct
Apollo	17-Oct	14-Oct	30-Oct				
Pastiche	11-Oct	9-Oct	23-Oct				

Table 5.10 contd.

Linear plus exponential function

Riband	n.v.	n.v.	n.v.	n.v.	3-Oct	n.v.	19-Sep
Beaver				n.v.	1-Oct	n.v.	11-Oct
Avalon	14-Oct	15-Sep	n.v.	n.v.	3-Oct	n.v.	1-Oct
Rascal				n.v.	19-Oct	n.v.	2-Oct
Apollo	8-Oct	16-Sep	n.v.				
Pastiche	3-Oct	15-Sep	n.v.				

Date differences (exp - quad)

Riband	n.v.	n.v.	n.v.	n.v.	-1	n.v.	3
Beaver				n.v.		n.v.	-8
Avalon	-9	-26	n.v.	n.v.	-2	n.v.	-8
Rascal				n.v.	-2	n.v.	-8
Apollo	-9	-28	n.v.				
Pastiche	-8	-24	n.v.				

Maximum yield (Yopt)

Quadratic function

Riband	6.98	10.56	9.01	9.36	8.17	8.77	8.9
Beaver				8.11	8.72	8.8	8.39
Avalon	6.31	9.43	7.99	7.57	7.49	7.88	7.06
Rascal				8.01	7.2	7.41	7.59
Apollo	7.05	9.55	8.38				
Pastiche	6	9.73	7.93				

Linear plus exponential function

Riband	n.v.	n.v.	n.v.	n.v.	8.24	n.v.	9.05
Beaver				n.v.	8.78	n.v.	8.34
Avalon	6.21	9.7	n.v.	n.v.	7.52	n.v.	7.25
Rascal				n.v.	7.19	n.v.	7.5
Apollo	7.09	9.52	n.v.				
Pastiche	6.04	9.87	n.v.				

Yield differences (exp - quad)

Riband	n.v.	n.v.	n.v.	n.v.	0.07	n.v.	0.15
Beaver				n.v.	0.06	n.v.	-0.05
Avalon	-0.1	0.27	n.v.	n.v.	0.03	n.v.	0.19
Rascal				n.v.	-0.01	n.v.	-0.09
Apollo	0.04	-0.03	n.v.				
Pastiche	0.04	0.14	n.v.				

Table 5.10 contd.

Observed date of maximum yield							
Riband	21-Sep	31-Oct	22-Oct	11-Oct	11-Oct	2-Nov	21-Sep
Beaver				20-Oct	11-Oct	2-Nov	1-Oct
Avalon	18-Oct	8-Nov	22-Oct	11-Oct	11-Oct	2-Nov	21-Sep
Rascal				21-Sep	11-Oct	13-Oct	1-Oct
Apollo	18-Oct	21-Oct	1-Nov				
Pastiche	29-Sep	1-Oct	11-Oct				

Date of observed of max. yield - S_{opt}							
Riband	-93	7	-2	91	7	9	5
Beaver				4	10	-12	-18
Avalon	-5	28	-2	-1	6	5	-18
Rascal				-28	-10	-6	-9
Apollo	1	7	2				
Pastiche	-12	-8	-12				

Note - effective sowing date is similar to sowing date as later sowing did not have delayed emergence.

Observed maximum yield							
Riband	8.2	10.9	9.1	8.8	8.4	9.1	9.7
Beaver				8.7	9.0	8.8	7.7
Avalon	6.3	10.3	8.1	7.8	7.5	8.2	8.7
Rascal				8.4	7.3	7.7	8.3
Apollo	7.5	9.8	8.4				
Pastiche	6.2	10.4	8.1				

Observed max. yield - Y_{opt}							
Riband	1.24	0.29	0.07	-0.56	0.21	0.33	0.75
Beaver				0.59	0.29	-0.05	-0.69
Avalon	-0.01	0.83	0.12	0.23	0.00	0.29	1.62
Rascal				0.40	0.08	0.24	0.71
Apollo	0.41	0.24	0.05				
Pastiche	0.24	0.71	0.12				

Two of the estimates (Riband, RM 89-90 and Avalon, RM 90-1) of y_{opt}, using the quadratic function were not relevant because the *a* coefficient was positive(Eqn. 1; Table 5.9). Therefore the fitted line was concave upwards and equating *dy/dx* to zero estimated the minimum. The estimate of S_{opt} for Avalon, RM 91-2 was outside the range of sowing dates (Table 5.10).

In the cases of RM 90-1 and AR 90-1, fitted curves for all varieties were parallel, that is they had a common S_{opt}.

5.2.4.3. *Discussion*

Both the quadratic and the linear plus exponential functions fitted the data more or less equally (Table 5.9). In all cases the estimates of S_{opt} were later for the quadratic than the linear plus exponential function. They were within 9 days of each other, except for RM 90-1 where the difference was about 26 days (Table 5.10). In RM 90-1 there was relatively little response to sowing date, which, in addition to giving different optima also estimated a positive quadratic term for Avalon, from which no maximum yield could be estimated. Parallel curve analysis of both functions indicated a common S_{opt}.

The maximum difference of estimates of y_{opt} between the functions was about three percent of the observed yield (AR 92-3, Avalon) and the majority of differences were less than one percent (Table 5.10).

The linear plus exponential function was least useful, as in a number of cases the form of the curve precluded estimation of y_{opt} and S_{opt}.

The sowing date on which maximum yield was observed was, in half the cases, within eight days of the estimate of S_{opt} by the quadratic function(Table 5.10). (Because seedling emergence was delayed only in the early sowings and the maximum yields and S_{opt} occurred after the end of September, sowing date and effective sowing date were very little different).The biggest differences occurred when the general trend was one of an almost linearly decreasing yield with later sowing date. Large differences also occurred when the last sowing date produced a relatively high yield and when the curve predicted a minimum yield. The maximum difference between y_{opt} and the maximum observed yield was 1.62 t/ha (19% of the observed yield), but most differences were less than 0.04 t/ha (5%) (Table 5.10).

Inspection of the estimates of S_{opt} did not indicate any systematic difference between varieties. For example, in the 1992-3 experiments, the earliest variety, Rascal, had the latest S_{opt} in two instances and the earliest S_{opt} in one, while the late variety ,Beaver, had one earliest and one latest S_{opt} over the four comparisons (Table 5.10). In almost all instances Riband had the greatest yield.

5.2.4.4. Conclusions

- In most instances both the quadratic and the linear plus exponential functions gave similar and reasonable ($R^2 > 68\%$) fits to the data
- The quadratic function was generally most useful, although in some cases the pattern of data led to irrelevant estimates of S_{opt}.
- 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.

5.3. Discussion

5.3.1. Yield components

Variety was the only treatment which had a consistent effect on thousand grain weight. Where sowing date or the sowing date x variety interaction were significant, the differences appeared to be due to lodging (compare Fig. 5.3 and Table L4).

For number of ears per m^2 (CP only) also, the only consistent effect was due to variety. The sowing date effects were confounded with differences in seed rate (see Methods) and the S x V interactions were probably due to differential lodging, e.g., Cadenza and Tonic which responded most strongly to sowing date (Section 5.2.2.3.1) had the greatest lodging scores.

5.3.2. 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. Where these factors appeared to have an effect it was generally associated with lodging. In 1992-3, the significant sowing date effect was related to severe lodging of the early sowing dates (Fig. 5.2, Table L4) and in the case of CP 92-3, experiment B, there was a significant correlation between the response of HI to sowing date (Table 5.7) and lodging in sowing 1 on 19 July ($r = -0.746$, $P < 0.001$).

5.3.3. Grain growth

The grain growth study was made on the grain from floret 1 of spikelets from in the lower-mid part of the ear of the main shoot. For Beaver and Riband, which lodged least, this grain grew most rapidly (linear regression estimate) and had the greatest mass in sowing 1 and this was related to greater total radiation during grain growth (Fig. 5.7).

The significance of this in the context of grain yield is difficult to estimate, There was no relation with average mass of all grains or with grain yield. Growth during the grain filling period was affected by lodging in sowing 1, particularly in Avalon and Rascal, which would influence leaf longevity and canopy arrangement and, therefore, radiation interception. A possible hypothesis is that changes in source strength operated through an effect on the growth of those grains in sites with lower growth potential (i.e. at the base and tip of the ear and in floret 3 and above (Triboi)) rather than on grains with the greatest potential, i.e. the greatest sink strength.

5.3.4. Yield

Inspection of Fig. 5.1 and S_{opt} in Table 5.10 shows that, at Rosemaund and Arthur Rickwood, maximum yields (Y_{opt}) were were attained by October sowings. The trends at Cockle Park were less clear but maximum yields were often obtained from sowing 2 or 3 (Table 5.5).

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 RM 91-2, RM 92-3, AR 92-3 and CP92-3 (experiment A); Tonic vs. Apollo and Haven at CP 91-2 and Tonic and Cadenza vs. Spark and Mercia at CP 92-3 (experiment B) (Fig. 5.1 and Table 5.5).

However, even when there were significant V x S interactions variety rankings 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.

In 1992-3 at RM and AR, early sowing was associated with severe lodging (Table 4.9) and a plot of yield vs. integrated lodging score showed that yield was partly dependent on the amount of lodging (Fig. 5.9). Similar responses of yield to lodging were evident at RM 89-90 ($r = -0.458$, $P < 0.01$). At CP 92-3 where lodging occurred only in the first sowing, the lodging score on 19 July was correlated with yield in sowing 1 in Expt. A ($r = -0.964$) and with the yield response to sowing date in Expt. B (Table 5.5; $r = -0.768$, $P < 0.01$).

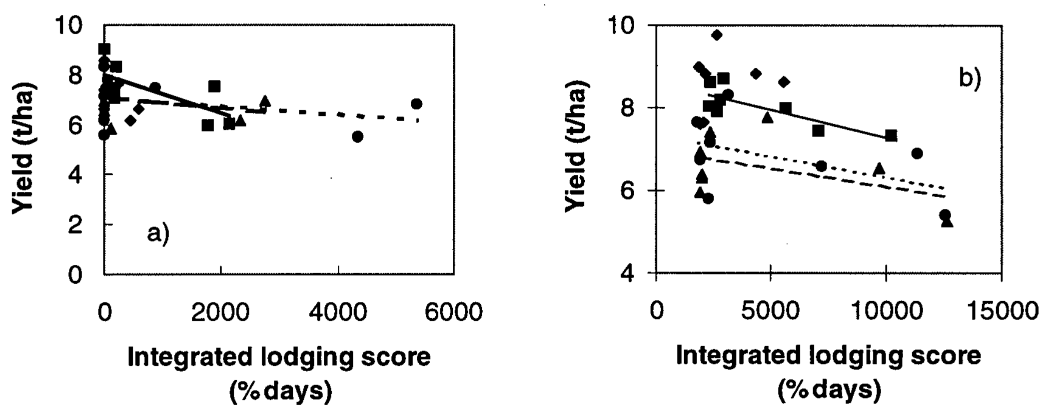


Fig. 5.9. Yield vs lodging for a) Rosemaund 1992-3 and b) Arthur Rickwood. 1992-3. The overall correlations were: RM, r = -0.403; AR, r = -0.428; P<0.01. Key to symbols for variety observations and trendlines: Riband ◆; Beaver, ■ ————; Avalon, ▲ —— —— ——; Rascal ● - - -.

Therefore the stronger response to sowing date by the earlier maturing variety Avalon in the 1992-3 series of experiments was partly attributable to its greater lodging, reflected in the NIAB 'standing power' ratings where Riband scores one point more than Avalon. Rascal and other spring varieties also lodged more readily than most of the winter varieties (Table 4.10). The association between life cycle and the proclivity for lodging seen in these experiments is presumably not causal, although spring varieties, spring sown, would be less vigorously selected than winter varieties for lodging resistance during the breeding process. Because of the severe and differential lodging, strong evidence of any effect of different patterns development among varieties on growth and yield are not detectable.

In 1990-1 and 1991-2 at RM and AR, when there was no, or a small amount of lodging, a similar relation of yield to sowing date was observed, with maximum yields and Sopt occurring during October (Figs. 5.1 and Table 5.10). These two years were marked by low rainfall during August and September(Fig. 4.6) which delayed seedling emergence (Fig. 4.5 and section 4.2.1.2.2) and, more significantly appeared permanently to impair growth (Fig. 4.13). Although clear trends of total dry mass at harvest time versus sowing date were not obvious from the small, quadrat samples(Fig. 4.20), dry mass tended to be as great or greater from the mid-season sowings. In the absence of compensation by variation in harvest index this apparently determined the grain yield response to sowing date (Fig. 5.1, Table 5.10).

Differences in variety adaptation which result from differences in such physiological characters as rate of development would be mainly expressed in the early sowings. Such differences were probably obscured by delayed emergence, for which there was no difference in varietal response.

5.3.5. 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 sowing made in October

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

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

6. GENERAL DISCUSSION

6.1. Differences from model yield

It is apparent that the yield responses found in the experiments described in this report was different both from that expounded in the initial hypothesis and that simulated by the ARCWheat model (Section 4.1). The absolute yield levels predicted differed from the observations, but more significantly, the form of the response curve differed. The major discrepancy was found in the yield from the early sowings. While the model predicted the highest yield from the earliest sowing (1 September) and a continuous decline as sowing is delayed thereafter, the observed yield response, estimated either from the sowing date of maximum yield or from S_{opt} estimated by the fitted curves, showed an increase in yield from later sowing dates, usually peaking at an October sowing date (Table 5.10). At Cockle Park, with only two or three sowing date, maximum yield was observed mostly in the second or third sowing (October or November).

From the date of observed maximum yield, yield levels declined in a similar manner to the model predictions. The different observed and predicted response therefore raises the question as to whether the initial hypothesis was correct or if other factors, possibly related indirectly to date of sowing, might have intervened.

6.2. Yield vs. growth and final biomass

A consideration of harvest index indicated that there was probably no direct sowing date effect or sowing date interaction with variety.

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 early in the season delayed seedling emergence (Fig. 4.5). This delay also appeared to cause permanent impairment of plant growth so that biomass at the time of harvest was depressed in the early sowings (section 4.2.7). In 1992-3,when seedling emergence was normal, pre-anthesis growth conformed to the predictions of the ARCWheat and Gillett models (Fig. 4.2). The occurrence of severe lodging in the early sowings at all sites (Section 4.2.4, Fig. 4.11), however, severely affected post anthesis growth so that the maximum final biomass occurred in the later sowings (Fig. 4.13).

Thus, in all sites and years, the progress of growth was strongly affected by factors only indirectly related to date of sowing. In the case of the lodging years, the variety interaction with sowing date was largely due to differences in standing power, rather than inherent differences in plant development or other physiological characteristics.

In 1992-3 in particular, growth patterns were not affected until lodging commenced at the post ear-emergence stage. In this year, the observed response of dry mass to date of sowing (Section 4.2.6) was consonant with the general hypothesis (Introduction) and the model predictions (Section 4.1). At the last pre-anthesis sample, dry mass was greatest in the early sowing (Section 4.2.6.3). The environment, generally, was most favourable for growth during the grain filling period in the early sowings (Section 4.1.2.3, Fig. 4.3; Section 5.4, Fig. 5.7). Therefore although maximum yield was generally not obtained from early sowings, nothing in the results invalidated the initial hypothesis that growth and yield potential was greatest from early sowing.

6.3. Development, growth and yield

The caveats applied to the results in the previous sub-section apply equally to any consideration of the relation between varietal differences in growth or yield. Only where poor seed bed conditions or lodging were absent could the effect on yield of varietal differences be in development be assessed with confidence. Clearly, amongst the varieties included in the various experiments there was a wide range of development patterns but 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 affected dry mass and leaf area growth (Section 4.2.3). Whether this affect would have carried through to final yield could not be assessed as there was severe, early lodging which affected post ear-emergence growth.

This does not mean that the original hypothesis about the relation between variety development and suitability for particular sowing periods is any the less valid. In the experiment, which used only varieties which are or have been important commercial varieties there were significant developmental differences in response to sowing date. These differences clearly indicated how response to sowing date, season and site might affect growth and possibly yield. True winter varieties such as Avalon and Mercia, sown early, might encounter a combination of low temperatures in September or October followed by above average temperatures which would lead to an abnormally early attainment of the double ridge stage and its associated changes in physiology and morphology. In the event of severe winter conditions (which did not occur in the period of the experiments) death and damage of the young ears might ensue. The precocious development of Soissons, for example, under certain combinations of sowing date and season, might render it vulnerable to ear damage by late frosts. In late varieties such as Beaver and Spark, their developmental pattern is such that under certain circumstances the grain filling period misses the optimum temperature and radiation levels conducive to maximum yield.

From the analysis of the experimental data some deductions were made about how the varieties differed physiologically in their response to the major environmental factors which influence development. These deductions, however, only classified response to daylength and vernalization in relatively general terms. If these concepts are to e developed to analyse and predict variety response, a more quantitative approach is necessary.

6.4. 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. In addition to yield considerations, early sowing is important for locking up nitrogen that might be leached from the soil and for erosion control on light land.

Early sowing results in early development of the crop canopy, utilisation of the substantial radiation received in September and October and accumulation of significant dry mass in the autumn. Spring growth and canopy development proceeds from the base established in the autumn resulting in a adequate maximum canopy area, developed at the optimum time of maximum radiation and greater dry mass. Anthesis occurs when conditions are optimum for grain filling.

Certain varietal characteristics are necessary to exploit the superior resources provided by early sowing. The high temperatures and relatively long days of September may result in too rapid development so that the shoot apex becomes vulnerable to winter damage. 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. Damage to the ear may result from exposure to radiation if anthesis occurs early in the season. Certain varieties, for example Soissons, may have a sufficient vernalization requirement to delay shoot apex development, but rapid development after ear initiation may render the emerging ear vulnerable to frost damage.

Different traits adapt varieties to later sowing. Slow development may delay anthesis so that the 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. These concepts generally in accordance with current ideas on crop physiology. Further work is need to refine them and in particular, give them quantitative expression.

6.5. Future work

6.5.1. Experimental methods

It is easy to give advice with hindsight; nevertheless it is probably worth emphasising some precautions that should be considered in experiments concerned with early sowing. Sowing conditions need careful consideration. Previous cropping and cultivation methods may affect water status, and as a rule of thumb, water shortage may be anticipated if rainfall from the beginning of August until sowing is less than 50 mm. Lodging must be anticipated and special attention paid to timely application of plant growth regulators. Where it is important to estimate yield in the absence of lodging, mechanical support in the form of wide mesh netting, placed at about flag leaf height, before or at about the time of ear emergence should be considered.

6.5.1.1. Experimental design

If growth measurements are planned, then the sampling regime should be selected in the light of which growth parameters are to estimated. For example, if dry mass production is to be analysed, a sampling regime based on growth stage is of doubtful use. The early stages such as double ridges may occur in different varieties at considerable differences in date and it is of little relevance that big differences in dry mass occur. To compare the accumulation of dry mass or N at a time after sowing then involves difficult extrapolation. The most satisfactory regime is to sample all treatments at the same time and to make concomitant observations of development. If any form of curve fitting is anticipated, careful estimation of the final dry mass is essential to estimate the value of the asymptote.

6.5.2. Characterisation of varieties

Even in the restricted range of varieties suitable for sowing in Britain it is clear that there is great diversity of development pattern. Compare, for example, the development of Cadenza, Soissons and Spark in the experiments described in this report (Section 3.3.4). These development patterns adapt the 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 (Slafer, 1996; Slafer and Rawson, 1995; Penrose and Payne, 1996). For most British commercial varieties little is known about the detail of these responses other than anecdotal generalisations, which is often based on circumstantial evidence. Because vernalization and photoperiod response are driven by correlated factors (temperature and daylength), and because different responses for different phases of development are invoked, such anecdotal evidence is often facile and cannot be confirmed.

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. Any 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 under conditions of complete environmental control are out of the question, daylight extension in the field during the short days of winter is possible using relatively cheap tungsten filament bulbs on an outdoor wiring rig.

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 schemes 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.

6.5.2.1. Model approach

The plant development data described in this report illustrate the complexity of the interaction of weather factors and factors which control variety development. Before the analysis of the Rosemaund data the large effect on early development of a short spell of low temperature in October(Section 3.4.2) would probably have not been visualised and had this been associated with a hard winter, might have had significant effects on plant survival and yield. A corollary to this is that 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.

6.5.3. 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. This was emphasised by the lack of any clear response of partition of dry mass (harvest index) to sowing date. 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.

6.5.4. Lodging

This study, like many others, has confirmed the relation between lodging, standing ability and early sowing (Fielder, 1988). Relevant measurements to advance an understanding of the relation between early sowing and the plant and soil factors which affect lodging have, however, been largely ignored. 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.

6.5.5. Dry seed bed effect

While the effects of soil conditions such as particle size and soil water content associated with early sowing on uniformity of seedling emergence and plant population are documented, the effect on subsequent growth and yield appears not to have been reported or recognised. If the long term effects of delayed seedling emergence on growth are confirmed then they are of considerable significance. During the present sowing season (Autumn, 1996) there have been several reports in the farming press of dry seed beds and patchy establishment. Such observations are used to make decisions about resowing, but may also presage low yields.

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, the latter with particular reference to the relation to leaf and tiller emergence. 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.

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7. Appendix Tables

Appendix table 1 Weather

A.1.1. Rosemaund

A.1.1.1. Mean temperature (°C)

	1989-90	1990-1	1991-2	1992-3
Sep	13.8	13.0	14.4	12.4
Oct	11.3	11.8	9.8	7.5
Nov	6.1	6.6	6.1	7.2
Dec	4.5	4.1	3.9	3.4
Jan	6.3	3.3	3.0	5.9
Feb	7.3	1.4	5.0	4.6
Mar	7.7	7.8	7.2	6.5
Apr	7.6	8.0	8.4	9.2
May	11.8	11.2	12.8	11.1
Jun	13.2	11.7	14.9	14.8
Jul	16.9	16.8	15.7	15.1
Aug	18.0	16.6	14.6	14.3

A.1.1.2 Total rainfall (mm)

	1989-90	1990-1	1991-2	1992-3
Sep	33.7	28.8	49.2	131.7
Oct	95.9	78.4	42.6	41.2
Nov	51.9	34.6	60.0	91.7
Dec	158.2	56.9	17.4	62.1
Jan	126.2	88.7	74.8	67.9
Feb	106.3	36.0	22.7	3.5
Mar	16.2	78.6	28.7	14.9
Apr	30.1	55.1	37.2	56.7
May	19.0	3.7	38.7	61.9
Jun	41.5	78.8	44.4	43.9
Jul	13.9	79.6	85.1	52.3
Aug	20.7	15.5	139.0	21.8

A.1.1.3 Radiation ($MJ/m^2/day$)

	1989-90	1990-1	1991-2	1992-3
Sep	9.7	10.9	11.6	4.5
Oct	5.3	5.7	5.2	5.6
Nov	3.5	2.9	2.7	2.8
Dec	1.1	1.8	1.6	1.9
Jan	2.4	2.5	2.1	1.9
Feb	4.4	4.8	4.2	3.8
Mar	10.0	7.3	7.4	7.9
Apr	15.3	*11.8	12.1	10.4
May	18.8	14.8	19.1	19.0
Jun	14.4	13.4	18.6	
Jul	19.6	16.3	14.4	
Aug	14.9	15.3	12.9	

*Value based partly on radiation vs. sunshine hours

A.1.2. Arthur Rickwood

A.1.2.1 Mean temperature (°C)

	1990-1	1991-2	1992-3
Sep	13.4	14.9	13.9
Oct	12.6	10.4	8.0
Nov	7.0	6.7	7.3
Dec	4.4	3.8	3.6
Jan	3.3	3.7	5.9
Feb	1.4	5.3	4.5
Mar	8.3	7.6	6.7
Apr	8.0	9.1	9.7
May	10.5	14.0	12.4
Jun	12.6	16.1	15.2
Jul	17.9	17.2	15.6
Aug	17.7	16.5	15.1

A.1.2.2 Rainfall (mm)

	1990-1	1991-2	1992-3
Sep	23.5	34.4	76.3
Oct	35.5	21	88.2
Nov	47	41.9	81.8
Dec	29.7	16.9	31
Jan	30	48.8	46.6
Feb	22.5	9.6	15.4
Mar	34.8	63.3	18.7
Apr	39.5	39	80.5
May	14.6	48.6	51.6
Jun	86.5	26.2	49.6
Jul	29.4	87.5	67.3
Aug	18.1	66.4	49.8

A.1.3 Cockle Park

A.1.3.1 Mean temperature (°C)

	1991-2	1992-3	1993-4
Sep	12.9	11.1	11
Oct	9.1	6.7	7.1
Nov	5.4	6.0	3.5
Dec	4.4	3.1	3.4
Jan	4.2	4.4	*
Feb	5.1	5.1	*
Mar	6.3	5.8	*
Apr	7.5	7.2	*
May	10.6	9.1	8.2
Jun	13.9	12.5	13.1
Jul	14.7	13.6	*
Aug	13.8	13.0	14

* Too many missing records

A.1.3.2 Rainfall (mm)

	1991-2	1992-3	1993-4
Sep	17.3	76.8	74.3
Oct	61.2	67.9	72.4
Nov	80.9.	70.6	74.3
Dec	40.7	51.2	96.4
Jan	18.8	55.5	56.7
Feb	32.1	17.5	49.0
Mar	90.7	14.0	28.2
Apr	*	112.0	56.9
May	*	125.1	12.3
Jun	15.4	34.0	31.4
Jul	58.1	48.7	*
Aug	93.4	60.7	94.0

*Data missing from sheets supplied by CP

A.1.3.3 Radiation ($MJ/m^2/day$)

	1991-2	1992-3	1993-4
Sep	11.7	7.8	7.3
Oct	4.7	4.6	4.8
Nov	2.5	2.6	2.2
Dec	1.5	1.5	1.7
Jan	2.1	1.8	2.0
Feb	4.2	3.7	3.5
Mar	7.1	8.6	8.6
Apr	12.3	9.5	12.9
May	19.6	12.8	16.0
Jun	20.9	15.6	19.8
Jul	15.7	14.5	19.8
Aug	13.6	10.8	12.3

Appendix table 2 Site details

A.2.1 Rosemaund 1989-90

Soil series	Bromyard	
Soil texture	Silty clay loam	
Soil analysis	pH	6.9
	P	3
	K	3
	Mg	4
Drainage	Good	
Previous crop	1989	Oilseed rape
	1988	Winter barley /spring wheat
	1987	Perennial ryegrass
Cultivations	Chisel plough	
	Rotovated and maschio	
	Rolled	
Fertilizer	8 March	3 kg/ha N
	6 April	104 kg/ha N
Herbicide	15 November	Hytane 2.8 l/ha
	(emerged plots only)	CMPP 3.6 l/ha
		Deloxil 1.5 l/ha
	28 March	Ally, 15 g/ha
		Starane 1 1 l/ha
Fungicide	7 March	Mistral 0.5 l/ha
	(Sowings 1-4)	Sportak 1 l/ha
	26 March	Mistral 0.5 l/ha
	(Sowings 5-8)	Sportak 1 l/ha
	25 April	Dorin 1 l/ha
		Bravo 2 l/ha
	12 June	Punch C 0.625 l/ha
		Patrol 0.5 l/ha
Pesticides	14 October	Decis 200 ml/ha
	Sowing 1-3)	
	15 November	Decis 200 ml/ha
	12 June	Aphox 280 ml/ha
Growth regulators	7 March	Atlas 5C 2.25 l/ha
	(Sowings 1-3)	
	26 March	Atlas 5C 2.25 l/ha
	(Sowings 5-8)	

A.2.2 Rosemaund 1990-1

Soil series	Bromyard	
Soil texture	Silty clay loam	
Soil analysis	pH	6.4
	P	2
	K	3
	Mg	4
Drainage	Good	
Previous crop	1990	Peas
	1989	Potatoes
	1988	Winter barley
	1987	Winter wheat
Cultivations		
Fertilizer	22 August	22 kg/ha P
		50 kg/ha K
	28 March	40 kg/ha N
	23 April	97 kg/ha N
Herbicide	12 November (sowings 1-5)	Mecoprop 4.2 l/ha
	21 March (sowings 6-8)	Mecoprop 4.2 l/ha
Fungicide	13 March (Sowings 1-4)	Mistral 1 l/ha Sportak 1 l/ha
	13 April (Sowings 5-8)	Mistral 1 l/ha Sportak 1 l/ha
	25 May	Dorin 0.75 l/ha Bravo 1.5 l/ha
	2 June	Sanctio 0.2 l/ha Bravo 1.5 l/ha
Pesticides	16 October (Sowing 1-4)	Decis 200 ml/ha
	12. November (Sowing 1-5)	Spanit 1.5 l/ha
	14 March	Decis 200 ml/ha
Growth regulators	13 March (Sowings 1-4)	Cycocel 1.75 l/ha
	15 April (Sowings 5-8)	Cycocel 1.75 l/ha

A.2.3 Arthur Rickwood 1990-1

Soil series	Adventurer's shallow	
Soil texture	Peaty loam	
Soil analysis	pH	6.2
	P	3
	K	3
	Mg	2
	Organic matter (5)	24
Drainage		
Previous crop	1990	Peas
	1989	Sugar beet
	1988	Winter wheat
	1987	Winter wheat
Cultivations		
Fertilizer	3 April	60.4 kg/ha N
Herbicide	14 March	Ally, 30 g/ha
		Starane 1 l/ha
	8 May	Cheetah 3 l/ha
		Starane 1 l/ha
Fungicide	9 May	Dorin 1 l/ha
	22 May	Dorin 1 l/ha
		Bombadier 2 l/ha
	20 June	Patrol 0.75 l/ha
		Radar 0.5 l/ha
Pesticides	24 October	Decis 200 ml/ha
Growth regulators	8 April	Cycocel 2.5 l/ha
Trace elements	11 March	$MnSO_4$ 4.5 kg/ha
	26 April	$MnSO_4$ 9 kg/ha
	15 May	$MnSO_4$ 9 kg/ha

A.2.4 Rosemaund 1991-2

Field Name	Flat field	
Soil series	Bromyard	
Soil texture	Silty clay loam	
Soil analysis	pH	6.9
	P Index	2
	K Index	2
	Mg Index	2
Drainage	Good	Good
Previous crop	1991	Oilseed Rape
	1990	Winter Barley
	1989	Winter Wheat
	1988	Peas
Cultivations	Sowing 1	
	24 August	Rotovated
	30 August	Plough
	Sowing 2	
	31 August	Power Harrow
	10 September	Power Harrow x 2
	10 September (Post Drilling)	Cambridge Rolled
	Sowing 3	
	20 September	Power Harrow x 2
	20 September (Post Drilling)	Cambridge Rolled
	Sowing 4 (1 October)	Power Harrow
	Sowing 5 (11 October)	Tine Cultivator X 2
	Sowing 6 (20 October)	Tine Cultivator X 2
	Sowing 7 (29 October)	Tine Cultivator
	Sowing 8 (1 November)	Tine Cultivator
Fertilizer	23 August	P 52 kg/ha
		K 79 kg/ha
	13 March	N 40 kg/ha
	13 April	N 110 kg/ha
Herbicide	30 September (Sowings 1 & 2)	Panther 2 l/ha, Mecoprop 1.4 l/ha
	15 November (Sowings 3-6)	Panther 2 l/ha, Mecoprop 1.4 l/ha
	15 November (Sowings 7 & 8)	Panther 2 l/ha
Fungicide	21 February (Sowings 1-3)	Sportak 0.9 l/ha, Mistral 0.5 l/ha
	31 March, (Sowings 4-6)	Sportak 0.9 l/ha, Mistral 0.5 l/ha
	18 May (All Sowings)	Impact Excel 2 l/ha, Tern 0.5 l/ha
	9 June (All Sowings)	Multi-W 5 l/ha, Radar 0.5 l/ha
Pesticides	25 September (Sowing 1 & 2)	Folimat 1.5 l/ha
	24 October (Sowing 1-6)	Decis 200 ml/ha
Growth regulators	4 March (Sowing 1 & 2)	Upgrade 1.5 l/ha
	17 March (Sowing 3 & 4)	Upgrade 1.5 l/ha
	9 April (Sowing 5 & 6)	Upgrade 1.5 l/ha
	19 May (Sowing 7 & 8)	Upgrade 1.5 l/ha

A.2.5 Arthur Rickwood 1991-2

Soil series	Prickwillow	
Soil texture	Peaty loam	
Soil analysis	pH	6.2
	P	3
	K	2
	Mg	3
	Organic matter (%)	27
Drainage		
Previous crop	1991	Peas
	1990	Sugar beet
	1989	Winter wheat
Cultivations	Plough & furrow press	
Fertilizer		60 kg/ha N
Herbicide	9 April	Cheetah R 1.5 l/ha
		Briotril 1.5 l/ha
	4 May	Ally, 20 g/ha
		Starane 1 l/ha
Fungicide	9 May	Corbel 1 l/ha
		Sportak 45 0.9 l/ha
	2 June	Patrol 0.75 l/ha
		Radar 0.5 l/ha
	22 June	Patrol 0.75 l/ha
		Radar 0.5 l/ha
Pesticides	5 March	Dimetoate 1700 ml/ha
Growth regulators	11 May	Upgrade 1.5 l/ha
Trace elements	11 March	$MnSO_4$ 4.5 kg/ha
	2 April	$MnSO_4$ 6 kg/ha
	18 May	$MnSO_4$ 6 kg/ha

A.2.6 Cockle Park 1991-2

Soil series	Dunkeswick	
Soil texture	Sandy clay loam	
	pH	6.5
	P index	1
	K index	2
Previous crop	Oilseed rape	
Cultivations	Straw removed, ploughed power harrowed rolled after sowing	
Fertilizer	Seedbed	72 kg/ha P_2O_5 and K_2O
	4 March	40 kg/ha N as ammonium nitrate
	13 April	100 kg/ha N as ammonium nitrate
Herbicide	22 October (early sowing)	Deloxil 1.75 l/ha Ambush 250 ml/ha
Fungicide	8 April	Sportak 0.9 l/ha Corbel 0.5 l/ha
	15 April	Sportak Delta Corbel 1.25 l/ha Patrol 0.5 l/ha
	24 June	Radar 0.25 l/ha Tern 0.25 l/ha
Pesticides	30 June	Aphox 286 g/ha

A.2.7 Rosemaund 1992-3

Field Name	Banky East	
Soil series	Bromyard	Bromyard
Soil texture	Silty clay loam	Silty clay loam
Soil analysis	pH	6.5
	P Index	1
	K Index	2
	Mg Index	4
Drainage	Good	Good
Previous crop	1992	Spring Beans
	1991	Winter Wheat
	1990	Spring Barley/Turnips
	1989	Spring Barley/Turnips
Cultivations	Sowing 1 (3 September)	Plough, Power Harrow x 2
	Sowing 2 (12 September)	Power Harrow
	12 September (Post Drilling)	Cambridge Rolled
	Sowing 3 (23 September)	Power Harrow
	Sowing 4 (5 October)	Power Harrow x 2
	Sowing 5 (13 October)	Power Harrow x 2
	Sowing 6 (23 October)	Power Harrow x 2, Tine
	Sowing 7 (2 November)	Cultivator
	Sowing 8 (13 November)	Power Harrow x 2
		Power Harrow x 2
Fertilizer	24 February	N 41.4 kg/ha
	25 March	N 138 kg/ha
Molluscicide	29 September	Draza 5.5 kg/ha
Herbicide	17 October (sowings 1-3)	Mecoprop 5 l/ha
	8 December (sowings 1-6)	Panther 2 l/ha
	4 February (sowings 7 & 8)	Javelin Gold 5 l/ha
	20 April	Ally 30 g/ha
Fungicide	8 October (Sowings 1-3)	Folimat 1.12 l/ha
	4 November (Sowings 1-3)	Sportak 45 0.9 l/ha
	11 March (Avalon, 1 &2 Rascal, 1,2 &3)	Sportak delta 1.25 l/ha
	1 April (Rascal, 4 Avalon, 3 Riband & Beaver, 1 & 2)	Sportak delta 1.25 l/ha
	19 April (Avalon, 4 Rascal, 5 & 6 Rband & Beaver, 3&4)	Sportak delta 1.25 l/ha
	6 May (Rascal & Avalon, 1 & 2)	Silvacur 1 l/ha
	6 May(All 7 & 8, Avalon, Beaver & Riband, 5 & 6)	Sportak delta 1.25 l/ha
	22 May (Riband & Beaver, 1&2 All, 3 & 4 Avalon & Rascal, 5,6 & 7)	Silvacur 1 l/ha
	29 May (Avalon & Rascal, 6 & 7 All, 8)	Silvacur 1 l/ha
	2 June(Rascal, 1 & 2)	Punch C 0.625 l/ha
Pesticides	8 October (Sowing 1-3)	Folimat 1.12 l/ha
	17 October (Sowing 1-3)	Decis 200 ml/ha
	4. November (Sowing 4)	Decis 200 ml/ha
Growth regulators	22 February (Rascal, 1)	Upgrade 2 l/ha
	11 March(Avalon, 1 & 2 Rascal, 2 & 3)	Upgrade 2 l/ha
	10 April (Avalon, Beaver & Riband, 1 & 2 Rascal, 4)	Upgrade 2 l/ha
	22 April(Rascal, 5 & 6 Riband, 3 & 4 Avalon, 4 Beaver, 3 & 4)	Upgrade 2 l/ha
	18 May (Sowings 7 & 8 Avalon, Beaver & Riband, 5 & 6)	Upgrade 2 l/ha

A.2.8 Arthur Rickwood 1992-3

Soil series	Adventurer's shallow	
Soil texture	Peaty loam	
Soil analysis	pH	7.1
	P	4
	K	3
	Mg	2
	Organic matter (%)	21
Drainage	Good	
Previous crop	1992	Peas
	1991	Sugar beet
	1990	Winter wheat
Cultivations	Ploughed	
	Plough and furrow press	
Fertilizer		60 kg/ha N
Herbicide	8 March	Cheetah R 1 l/ha
		Actipron 1 l/ha
	7 April	Ally, 30 g/ha
		Starane 1 1 l/ha
Fungicide	6 May	Corbel 0.75 l/ha
		Sportak 45 0.9 l/ha
	2 June	Corbel 0.75 l/ha
		Impact Excel 2 l/ha
	21 June	Folicur 0.4 l/ha
Pesticides	7 November	Ambush C 0.25 l/ha
	5 March	Dimethoate 1700 ml/ha
Growth regulators		
Trace elements	14 April	$MnSO_4$ 6 kg/ha + Agral
	21 April	$MnSO_4$ 6 kg/ha+ Agral
	5 May	$MnSO_4$ 6 kg/ha+ Agral

A.2.9 Cockle Park 1992-3

Soil series	Dunkeswick	
Soil texture	sandy clay loam	
Soil analysis		
	pH	6.8
	P index	2
	K index	2
	Mg index	4
Drainage	poor	
Previous crop	1992	Winter oil seed rape
	1991	Winter barley
	1990	Winter barley
Cultivations		
Fertilizer	3 March	40 kg ha^{-1} N
	31 March	80 kg ha^{-1} N
	4 May	40 kg ha^{-1} N
Herbicide	17 February	Javelin 3 l ha^{-1}
Fungicide	22 April	Sportak 0.9 l ha^{-1}
		Corbel 0.5 l ha^{-1}
	1 June	Impact Excel 2 l ha^{-1}
		Mistral 0.5 l ha^{-1}
Pesticides	1 July	Aphox 280 g ha^{-1}

A.2.10 Cockle Park 1993-4

Soil series	Hallsworth	
Soil texture	Clay loam	
Soil analysis		
	pH	6.3
	P index	2
	K index	2
	Mg index	4
Drainage	poor	
Previous crop	1993	Winter oil seed rape
	1992	Winter barley
	1991	Winter barley
Cultivations		
Fertilizer	9 March	40 kg/ha N
	4 April	80 kg/ha N
	6 May	40 kg/ha N
Seed bed fertilizer		60 kg/ha P
		60 kg/ha K
Fungicide	26 April	Sportak 0.9 l/ha
		Corbel 0.5 l/ha
	7 June	Impact Excel 2 l/ha
Pesticides	12 July	Aphox 280 g/ha

Appendix table 3 Development

Observed dates of developmental stages

A.3.1 RM 89-90

	Date of sowing	Apollo	Avalon	Riband	Pastiche
Double ridge					
1	8-Sep	22-Jan	22-Jan		
2	20-Sep	25-Jan	25-Jan		
3	28-Sep	29-Jan	29-Jan	6-Feb	6-Feb
4	9-Oct	8-Feb	8-Feb	8-Feb	16-Feb
5	18-Oct	21-Feb	21-Feb	21-Feb	21-Feb
6	30-Oct	12-Mar	12-Mar	12-Mar	12-Mar
7	7-Nov	19-Mar	19-Mar	19-Mar	19-Mar
8	16-Nov	27-Mar	27-Mar	27-Mar	27-Mar
Terminal spikelet					
1	8-Sep	12-Mar	12-Mar		
2	20-Sep	15-Mar	15-Mar		
3	28-Sep	22-Mar	22-Mar	22-Mar	22-Mar
4	9-Oct	27-Mar	27-Mar	27-Mar	27-Mar
5	18-Oct	9-Apr	9-Apr	9-Apr	9-Apr
6	30-Oct	17-Apr	17-Apr	20-Apr	20-Apr
7	7-Nov	24-Apr	24-Apr	24-Apr	24-Apr
8	16-Nov	30-Apr	26-Apr	26-Apr	30-Apr

A.3.2 RM 90-1

	Date of	Double ridges		Terminal spikelet	
	sowing	Apollo	Avalon	Apollo	Avalon
1	31-Aug	17-Jan	17-Jan	2-Apr	28-Mar
2	10-Sep	6-Feb	22-Jan	9-Apr	2-Apr
3	20-Sep	6-Feb	22-Jan	10-Apr	9-Apr
4	1-Oct	6-Feb	6-Feb	18-Apr	12-Apr
5	11-Oct	30 Feb	20-Feb	23-Apr	16-Apr
6	21-Oct	28-Mar	18-Mar	28-Apr	25-Apr
7	31-Oct	30-Mar	28-Mar	2-May	30-Apr
8	8-Nov	2-Apr	2-Apr	3-May	3-May

A.3.3 RM 91-2

	Date of sowing	Riband	Beaver	Avalon	Rascal
Double ridge					
1	31-Aug		15-Jan	6-Jan	
2	10-Sep	18-Feb	18-Feb	6-Jan	6-Jan
3	20-Sep			14-Feb	
4	1-Oct	2-Mar	27-Feb	27-Feb	15-Jan
5	11-Oct		20-Mar	2-Mar	
6	20-Oct	25-Mar		22-Mar	15-Mar
7	29-Oct			23-Mar	
8	11-Nov	15-Apr	15-Apr	30-Mar	23-Mar
Flag leaf emergence					
1	31-Aug		14-May	11-May	
2	10-Sep	16-May	18-May	12-May	
3	20-Sep		19-May	12-May	
4	1-Oct	17-May	19-May	14-May	
5	11-Oct		21-May	14-May	
6	20-Oct	22-May	23-May	18-May	14-May
7	29-Oct		24-May	18-May	
8	11-Nov	24-May	25-May	22-May	16-May
Ear emergence					
1	31-Aug		27-May	24-May	
2	10-Sep	28-May	31-May	26-May	21-May
3	20-Sep		31-May	27-May	
4	1-Oct	2-Jun	3-Jun	28-May	23-May
5	11-Oct		4-Jun	31-May	
6	20-Oct	3-Jun	3-Jun	30-May	25-May
7	29-Oct		4-Jun	31-May	
8	11-Nov	5-Jun	5-Jun	3-Jun	2-Jun

A.3.4 AR 91-2

	Date of sowing	Riband	Beaver	Avalon	Rascal
Double ridge					
1	3-Sep		3-Feb	3-Feb*	
2	11-Sep	24-Feb	10-Feb	10-Feb	27-Jan
3	21-Sep		24-Feb	3-Feb	
4	1-Oct	17-Feb	9-Mar	10-Feb	27-Jan
5	11-Oct		16-Mar	16-Mar	
6	21-Oct	16-Mar	23-Mar	16-Mar	16-Mar
7	1-Nov		6-Apr	23-Mar	
8	11-Nov	6-Apr	6-Apr	23-Mar	23-Mar
Terminal spikelet					
1	3-Sep		13-Apr	6-Apr*	
2	11-Sep	6-Apr	13-Apr	30-Mar	30-Mar
3	21-Sep		13-Apr	6-Apr	
4	1-Oct	13-Apr	13-Apr	6-Apr	30-Mar
5	11-Oct		27-Apr	21-Apr	
6	21-Oct	27-Apr	27-Apr	21-Apr	21-Apr
7	1-Nov		5-May	27-Apr	
8	11-Nov	5-May	11-May	5-May	27-Apr

* stage of development of tiller (check)

A.3.5 CP 91-2

	Date of sowing	Avalon	Riband	Slejpner	Tonic
Double ridge					
1	5-Sep	31-Jan	1-Mar	2-Mar	26-Nov
2	12-Nov	8-Apr	9-Apr	15-Apr	6-Apr
Terminal spikelet					
1	5-Sep	8-Apr	10-Apr	15-Apr	30-Mar
2	12-Nov	4-May	5-May	7-May	1-May
Flag leaf emergence					
1	5-Sep	20-May	27-May	28-May	19-May
2	12-Nov	30-May	4-Jun	5-Jun	30-May
Ear emergence					
1	5-Sep	4-Jun	10-Jun	11-Jun	2-Jun
2	12-Nov	13-Jun	17-Jun	19-Jun	13-Jun

A.3.6 RM 92-3

	Date of sowing	Riband	Beaver	Avalon	Rascal
Double ridge					
1	3-Sep	18-Dec		8-Dec	16-Oct
2	12-Sep	14-Jan		18-Dec	3-Nov
3	23-Sep	29-Jan		8-Jan	2-Dec
4	5-Oct	19-Feb		12-Feb	2-Feb
5	13-Oct	24-Feb		24-Feb	19-Feb
6	23-Oct	19-Mar		19-Mar	24-Feb
7	2-Nov	30-Mar		23-Mar	16-Mar
8	13-Nov	13-Apr		6-Apr	19-Mar
Terminal spikelet					
1	3-Sep	26-Mar		16-Mar	11-Jan
2	12-Sep	30-Mar		23-Mar	22-Jan
3	23-Sep	9-Apr		6-Apr	19-Mar
4	5-Oct	16-Apr		16-Apr	6-Apr
5	13-Oct	20-Apr		20-Apr	13-Apr
6	23-Oct	26-Apr		25-Apr	16-Apr
7	2-Nov	27-Apr		26-Apr	20-Apr
8	13-Nov	4-May		1-May	23-Apr
Flag leaf emergence					
1	3-Sep	11-May	11-May	9-May	30-Apr
2	12-Sep	18-May	18-May	11-May	4-May
3	23-Sep	18-May	18-May	11-May	11-May
4	5-Oct	20-May	20-May	18-May	18-May
5	13-Oct	22-May	22-May	18-May	18-May
6	23-Oct	25-May	25-May	20-May	18-May
7	2-Nov	27-May	27-May	20-May	20-May
8	13-Nov	29-May	30-May	23-May	20-May
Ear emergence					
1	3-Sep	2-Jun	5-Jun	23-May	15-May
2	12-Sep	5-Jun	7-Jun	25-May	18-May
3	23-Sep	4-Jun	8-Jun	29-May	22-May
4	5-Oct	7-Jun	9-Jun	5-Jun	28-May
5	13-Oct	8-Jun	10-Jun	6-Jun	30-May
6	23-Oct	10-Jun	11-Jun	8-Jun	4-Jun
7	2-Nov	10-Jun	12-Jun	8-Jun	4-Jun
8	13-Nov	13-Jun	15-Jun	13-Jun	7-Jun

A.3.7 AR 92-3

	Date of sowing	Riband	Beaver	Avalon	Rascal
Double ridge					
1	2-Sep		18-Jan	15-Dec	11-Jan
2	11-Sep				16-Nov
3	22-Sep		8-Mar	2-Feb	15-Dec
4	1-Oct		15-Mar	10-Feb	25-Jan
5	12-Oct				8-Mar
6	22-Oct		8-Apr	22-Mar	22-Mar
7	3-Nov				5-Apr
8	12-Nov			8-Apr	29-Mar
Terminal spikelet					
1	2-Sep		22-Mar	22-Mar	5-Jan
2	11-Sep				10-Feb
3	22-Sep		13-Apr	5-Apr	22-Mar
4	1-Oct		26-Apr	16-Apr	13-Apr
5	12-Oct				16-Apr
6	22-Oct		26-Apr	22-Apr	22-Apr
7	3-Nov				22-Apr
8	12-Nov			26-Apr	22-Apr

A.3.8 CP 92-3 Expt. A

	Date of sowing	Avalon	Beaver	Rascal	Riband
Double ridge					
1	4-Sep	18-Jan	11-Feb	17-Nov	4-Feb
2	1-Oct	14-Mar	19-Mar	10-Mar	16-Mar
3	13-Nov	10-Apr	13-Apr	7-Apr	11-Apr
Terminal spikelet					
1	4-Sep	18-Mar	5-Apr	12-Feb	25-Mar
2	1-Oct	14-Apr	19-Apr	12-Apr	17-Apr
3	13-Nov	30-Apr	6-May	25-Apr	2-May
Flag leaf emergence					
1	4-Sep	21-May	1-Jun	17-May	27-May
2	1-Oct	2-Jun	8-Jun	26-May	8-Jun
3	13-Nov	9-Jun	15-Jun	8-Jun	14-Jun
Ear emergence					
1	4-Sep	14-Jun	18-Jun	7-Jun	16-Jun
2	1-Oct	20-Jun	21-Jun	16-Jun	21-Jun
3	13-Nov	24-Jun	1-Jul	21-Jun	28-Jun
Anthesis					
1	4-Sep	22-Jun	25-Jun	17-Jun	23-Jun
2	1-Oct	24-Jun	29-Jun	22-Jun	28-Jun
3	13-Nov	30-Jun	7-Jul	29-Jun	1-Jul

A.3.9 CP 91-2

	Double ridge	Terminal spikelet	Flag Leaf emergence	Ear emergence
Sowing 1 - 5 Sep 91				
Admiral	9-Mar	20-Apr	29-May	12-Jun
Apollo	3-Feb	10-Apr	24-May	8-Jun
Apostle	9-Mar	18-Apr	26-May	10-Jun
Aristocrat	10-Feb	14-Apr	23-May	9-Jun
Axona	24-Jan	10-Apr	22-May	4-Jun
Brigadier	10-Feb	15-Apr	26-May	10-Jun
Fortress	2-Mar	15-Apr	26-May	9-Jun
Galahad	10-Feb	15-Apr	25-May	9-Jun
Haven	5-Mar	13-Apr	28-May	10-Jun
Hereward	10-Feb	18-Apr	27-May	10-Jun
Hunter	21-Feb	14-Apr	25-May	9-Jun
Hussar	25-Feb	15-Apr	25-May	9-Jun
Mercia	8-Feb	10-Apr	23-May	8-Jun
Norman	29-Feb	9-Apr	25-May	8-Jun
Soisson	21-Feb	10-Apr	28-May	1-Jun
Spark	25-Feb	19-Apr	25-May	10-Jun
Tara	25-Feb	15-Apr	22-May	9-Jun
Torfrida	3-Mar	12-Apr	27-May	11-Jun
Urban	9-Mar	22-Apr	27-May	11-Jun
Sowing 2 - 12-Nov 91				
Admiral	13-Apr	8-May	3-Jun	18-Jun
Apollo	8-Apr	4-May	1-Jun	14-Jun
Apostle	15-Apr	7-May	1-Jun	16-Jun
Aristocrat	9-Apr	4-May	1-Jun	15-Jun
Axona	10-Apr	4-May	28-May	11-Jun
Brigadier	8-Apr	5-May	1-Jun	17-Jun
Fortress	9-Apr	7-May	1-Jun	15-Jun
Galahad	8-Apr	6-May	1-Jun	16-Jun
Haven	13-Apr	7-May	4-Jun	18-Jun
Hereward	10-Apr	8-May	2-Jun	15-Jun
Hunter	9-Apr	7-May	5-Jun	18-Jun
Hussar	13-Apr	6-May	1-Jun	15-Jun
Mercia	8-Apr	6-May	31-May	14-Jun
Norman	8-Apr	5-May	1-Jun	14-Jun
Soisson	4-Apr	30-Apr	27-May	8-Jun
Spark	16-Apr	8-May	1-Jun	16-Jun
Tara	10-Apr	6-May	2-Jun	17-Jun
Torfrida	7-Apr	6-May	1-Jun	17-Jun
Urban	17-Apr	8-May	2-Jun	16-Jun

A.3.10 CP 92-3 -(Expt. B)

	Double ridge	Terminal spikelet	Flag Leaf emergence	Ear emergence	Anthesis
Sowing 1 - 4 Sep 92					
Admiral	10-Feb	29-Mar	30-May	17-Jun	26-Jun
Brigadier	24-Jan	28-Mar	28-May	16-Jun	23-Jun
Buster	24-Jan	18-Mar	22-May	15-Jun	21-Jun
Cadenza	3-Dec	11-Feb	17-May	7-Jun	18-Jun
Estica	1-Feb	3-Apr	31-May	18-Jun	23-Jun
Haven	8-Feb	25-Mar	30-May	16-Jun	24-Jun
Hereward	10-Feb	1-Apr	30-May	16-Jun	23-Jun
Hunter	1-Feb	22-Mar	29-May	16-Jun	24-Jun
Hussar	10-Feb	26-Mar	22-May	14-Jun	23-Jun
Lynx	4-Feb	3-Apr	28-May	14-Jun	25-Jun
Mercia	26-Jan	25-Mar	22-May	15-Jun	20-Jun
Rialto	2-Feb	25-Mar	27-May	14-Jun	22-Jun
Soisson	10-Feb	15-Mar	16-May	5-Jun	17-Jun
Spark	3-Feb	27-Mar	30-May	15-Jun	23-Jun
Tara	5-Feb	26-Mar	31-May	17-Jun	27-Jun
Tonic	19-Nov	14-Feb	17-May	7-Jun	19-Jun
Torfrida	2-Feb	26-Mar	23-May	14-Jun	22-Jun
Zodiac	1-Feb	23-Mar	28-May	15-Jun	24-Jun
Sowing 2 - 13 Nov 92					
Admiral	17-Apr	4-May	11-Jun	23-Jun	3-Jul
Brigadier	12-Apr	29-Apr	12-Jun	28-Jun	4-Jul
Buster	9-Apr	28-Apr	10-Jun	27-Jun	2-Jul
Cadenza	8-Apr	25-Apr	9-Jun	21-Jun	30-Jun
Estica	14-Apr	6-May	12-Jun	29-Jun	4-Jul
Haven	12-Apr	30-Apr	11-Jun	24-Jun	7-Jul
Hereward	10-Apr	7-May	11-Jun	26-Jun	2-Jul
Hunter	12-Apr	2-May	12-Jun	25-Jun	5-Jul
Hussar	10-Apr	2-May	12-Jun	25-Jun	1-Jul
Lynx	10-Apr	5-May	12-Jun	24-Jun	3-Jul
Mercia	10-Apr	27-Apr	8-Jun	25-Jun	30-Jun
Rialto	10-Apr	2-May	10-Jun	24-Jun	1-Jul
Soisson	5-Apr	23-Apr	7-Jun	20-Jun	28-Jun
Spark	14-Apr	7-May	12-Jun	25-Jun	4-Jul
Tara	14-Apr	7-May	11-Jun	26-Jun	5-Jul
Tonic	7-Apr	26-Apr	8-Jun	21-Jun	30-Jun
Torfrida	9-Apr	28-Apr	12-Jun	25-Jun	1-Jul
Zodiac	15-Apr	4-May	12-Jun	29-Jun	1-Jul

Appendix table 4. Rosemaund and Arthur Rickwood curve fitting.

Parameters for the quadratic function (Eqn. 1) and the linear plus exponential function (Eqn. 2). The adjusted R^2 is also shown.

A.4.1 Rosemaund

Year	Variety	Quadratic				Linear + exponential				
		c	b	a	R^2	r	β	δ	α	R^2
1998-90	Riband	9.01	-0.0353	0.00015	74	0.932	0.0969	-0.0194	8.65	76
	Avalon	3.65	0.0992	-0.00092		0.932	-6.1220	-0.0184	7.30	
	Apollo	5.87	0.0486	-0.00050		0.932	-3.8161	-0.0179	8.03	
	Pastiche	5.37	0.0300	-0.00036		0.932	-2.4503	-0.0159	6.81	
1990-1	Riband	9.01	0.0563	-0.00051	18	0.041	-4.46*	0.0049	10.18	29
	Avalon	10.46	-0.0483	0.00057		0.041	-1.01*	-0.0019	9.74	
	Apollo	8.74	0.0362	-0.00040		0.041	-32.2*	-0.0025	9.56	
	Pastiche	7.93	0.0891	-0.00110		0.041	-6.16*	-0.0148	10.11	
1991-2	Riband	9.11	-0.0101	-0.00010	50	1.004	-12.2478	0.0364	21.36	49
	Beaver	7.20	0.0392	-0.00042		1.004	-48.0743	0.2211	55.29	
	Avalon	6.70	0.0402	-0.00047		1.004	-53.7698	0.2438	60.49	
	Rascal	6.15	0.0749	-0.00075		1.004	-87.0692	0.4049	93.24	
1992-3	Riband	5.91	0.1038	-0.00094	87	1.007	-25.4521	0.2828	31.43	86
	Beaver	5.09	0.0978	-0.00064		1.007	-17.8870	0.2251	23.00	
	Avalon	4.50	0.1139	-0.00096		1.007	-25.8447	0.2955	30.41	
	Rascal	2.88	0.1803	-0.00179		1.007	-49.3181	0.5299	52.28	

* x 10^{15}

A.4.2 Arthur Rickwood

Year	Variety	c	b	a	R^2	r	β	δ	α	R^2
1990-1	Riband	4.95	0.1464	-0.00132	68	1.061	-0.0349	0.0634	6.47	68
	Avalon	2.81	0.1889	-0.00172		1.061	-0.0434	0.0782	4.85	
	Apollo	6.88	0.0492	-0.00040		1.061	-0.0101	0.0232	7.36	
	Pastiche	5.13	0.1031	-0.00095		1.061	-0.0234	0.0413	6.28	
1991-2	Riband	6.75	0.0823	-0.00119	69	0.966	-9.4245	-0.1011	14.58	70
	Beaver	7.79	0.0585	-0.00092		0.966	-7.2833	-0.0834	13.85	
	Avalon	6.26	0.0688	-0.00096		0.966	-6.9736	-0.0739	12.18	
	Rascal	6.36	0.0322	-0.00031		0.966	-2.3522	-0.0145	8.34	
1992-3	Riband	8.79	0.0129	-0.00039	54	0.958	-2.4615	-0.0448	10.99	55
	Beaver	7.16	0.0494	-0.00050		0.958	-2.4967	-0.0174	9.49	
	Avalon	5.81	0.0635	-0.00080		0.958	-4.9211	-0.0542	10.23	
	Rascal	5.68	0.0938	-0.00115		0.958	-4.8467	-0.0511	10.36	