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Managing early-drilled winter wheat:
Seed rates, varieties and disease control

by

C Pillinger[1], E J Evans[1], J M Whaley[1], S M Knight[2]
& N Poole[2]

[1]School of Agriculture, Food and Rural Development,
University of Newcastle-upon-Tyne, NR1 7RU

[2] The Arable Group, Manor Farm, Daglingworth, Cirencester, GL7 7AH

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1 ABSTRACT

This project assessed the effects of varieties, seed rate and fungicide regimes on the performance of early September sown crops of winter wheat at five sites during four growing seasons. In the first year thirteen varieties, sown at three seed rates, were compared under a standard, three fungicide programme at four sites. In subsequent seasons the varieties Claire, Consort and Equinox were sown at two seed rates and subjected to five fungicide programmes to determine the need for adequate disease control over the longer growing season. These trials were carried out over five sites throughout England.

Seed rate effects : In general, across the five sites and four seasons, reducing seed rates led to reduced plant population, *Septoria tritici* and eyespot infection. Overall, however, there were consistent and significant increases in yield at the higher seed rate of between 0.3 and 0.4 t ha^{-1}. This was achieved through an increase in ears m^{-2}. Assuming a TGW of 44 g, and seed costs of £230 t^{-1} a cost-benefit analysis was made on the yield differences between seed rates of 100 and 200 or 250 seeds m^2. In the season where lodging occurred, increasing seed rate led to increasing costs, due to greater lodging at the higher seed rate. In subsequent years increasing seed rate generally led to benefits, of the order of £34 ha^{-1} at a feed wheat price of £70 t^{-1}.

Varietal effects : The three varieties included in trials for detailed evaluation, Claire, Consort and Equinox, were selected on the basis of their suitability for early sowing, especially standing power, disease resistance and tillering capacity. Claire gave the highest yields and Equinox the largest TGW, and these effects were consistent across sites and seasons. Consort and Equinox had higher levels of *Septoria tritici*, whereas Claire was more susceptible to mildew. These results reflect ratings given in HGCA recommended lists. In 1999/00, a wider range of varieties were included in the trials; there were statistically significant interactions but these were related to lodging resistance rather than any intrinsic developmental or growth characteristics.

Fungicide effects : During the duration of this project over five sites, covering a wide geographic area only small traces of mildew were recorded. The main disease encountered was *Septoria tritici*. In all seasons there were high levels of *S. tritici* early in the season on the lower leaves. In two seasons disease levels remained low as the year progressed; only in one season (2002/03) was there an appreciable increase in disease levels from June onwards at some sites. Additional spring fungicides only had lasting effects under conditions of high disease pressure and in the majority of site and season combinations resulted in only small yield benefits. Similarly, additional autumn fungicides had only transitory effects on disease levels and rarely led to economic yield increases. Effects of the different fungicide treatments were not influenced by seed rate whilst varietal response corresponded closely to resistance rankings to individual pathogens, but these were only seen in years of high disease pressure. Only at the Kent site in one season was there a significant economic benefit from the application of an additional spring fungicide.

2 SUMMARY

The predominance of winter cropping on large arable units has resulted in excessive work loads during the autumn leading to many growers adopting sowing dates for winter wheat earlier than the traditionally perceived optimum of mid-September to the middle of October. Increasing the length of the growing season has the advantage of increasing the yield potential as the optimum canopy size will be achieved sooner, thereby increasing the amount of intercepted radiation during the season. This yield advantage may not always be achieved in practice due to increased disease pressure, poor establishment and increased risk of lodging. This study aims to investigate the effects of varieties, seed rate and fungicide regimes on the performance of early September sown crops of winter wheat at five sites throughout England.

2.1 AIMS AND OBJECTIVES

This study aims to investigate a number of management practices that may influence the performance of winter wheat sown in early September at five sites during four growing seasons as follows :

1. The influence of seed rate on crop growth and yield of early sown crops.

2. The role of fungicide timing and rate of application on the development of foliar diseases.

3. The interaction between varieties, seed rate and fungicide application.

4. The effects of site and season.

2.2 MATERIALS AND METHODS

Field experiments were carried out at four TAG sites from Kent to East Yorkshire over four seasons and for two seasons at the University of Newcastle's Cockle Park Experimental Station (Table 2.2.1). All crops were sown as a first wheat after winter oilseed rape, with the exception of the Bainton site where vining peas was the preceding crop and Cockle Park, where the preceding crop was a grass ley.

Table 2.2.1 Site location and soil series for each site

Site	1999/00	2000/01	2001/02	2002/03
East Yorkshire	Bainton Panholes	Bainton Panholes	Bainton Panholes	Bainton Panholes
Kent	Braeborne Lees Combe2	Braeborne Lees Combe 2	Shottenden Batcombe	Shottenden Batcombe
Bedfordshire	Kettering Hounslow	Kettering Hounslow	Biggleswade Cannamore	Biggleswade Cannamore
Gloucestershire	Cirencester Elmton	Cirencester Elmton	Cirencester Elmton	Cirencester Elmton
Northumberland	*	*	Cockle Park Hallsworth	Cockle Park Hallsworth

2.2.1 Experimental Design

The experimental design was a split plot with three replicates with sowing date as the main plot, seed rate and variety were factorially combined and fully randomised as sub-plots. Each plot size was 2m by 12m. Where destructive sampling was employed an identical adjacent plot was sown for combine harvesting. At Cockle Park in 2002/3, sub-plot length was increased to 24m with a length of 10m retained for final yield determination.

Prior to sowing each site was ploughed and subject to secondary cultivation, dependent on site and season to produce a suitable seedbed. A prophylactic programme of pest and weed control was applied in all experiments, depending on local conditions. Plant growth regulators were applied in all seasons to minimise the incidence of lodging.

The aim was to drill experiments as early as possible in September, but practical difficulties at some sites resulted in the sowing date approaching mid September (Table 2.2.2).

Table 2.2.2 Sowing dates for all experiments

Site	1999/2000	2000/01	2001/02	2002/03
East Yorkshire	02 September	08 September	07 September	11 September
Kent	01 September	08 September	10 September	11 September
Bedfordshire	02 September	11 September	11 September	12 September
Gloucestershire	03 September	08 September	07 September	10 September
Northumberland	*	*	05 September	05 September

2.2.2 Experimental treatments

In the first year three different seed rates were applied at each site, low (100 seeds m^2), medium (200 – 250 seeds m^2) or high (350 – 400 seeds m^2). Thirteen varieties were included in the trial and a standard three fungicide regime adopted.

In the following years the same seed rates were used at all sites, 100 and 200 seeds m^2 and three varieties only were included, Claire, Consort and Equinox. From the second year onwards, five fungicide regimes were applied. The first was a standard fungicide regime, with a T1 being applied at the 3rd leaf stage, a T2 applied to coincide with flag leaf emergence, and a T3 ear wash. The second regime was as the standard fungicide but with an additional fungicide application in the autumn. The third was a standard regime with additional fungicide applied in early spring. The fourth was a standard fungicide with both additional autumn and spring applications. The fifth treatment in 2000/01 was the standard regime, but with the T1 treatment split between early T1, as leaf three was emerging, followed by another spray as leaf two was emerging. In the third and fourth years of the programme this was simplified to a single early application of the T1 fungicide. Spring and autumn fungicides applications were 0.25 l Opus and 1.0 l Bravo. T1, early T1 and T2 and were based on a mixture of 1.0 l Twist and 0.25 l Opus. Late T1 was a mixture of 1.0 l Bravo and 0.25 l Opus. At T3 0.25 l Opus was used throughout.

2.2.3 Measurements

Detailed growth measurements were taken at the East Yorkshire and Kent sites for the three growing seasons 2000/01, 2001/02 and 2002/03 to provide a greater understanding of the effects of the treatment variables on crop growth and performance. In the 2000/01 the crops were sampled on seven occasions and on four occasions in subsequent seasons. Biomass, Green Area Indices, fertile shoot populations and PAR interception were recorded together with disease assessments for eyespot, sharp eyespot, *Septoria tritici* and mildew.

Established plant populations, yield and yield components were recorded across all experiments. Additionally at harvest biomass and fertile shoot numbers were recorded for the three less intensively monitored sites.

2.3 RESULTS AND DISCUSSION

2.3.1 Plant populations

In the first year plant establishment was measured for all thirteen varieties at the Kent and East Yorkshire sites. The increase in plant establishment with increasing seed rate was similar at both sites, whilst percentage establishment was not affected by variety.

In subsequent trials the three varieties, Claire, Consort and Equinox were established at two seed rates, 100 and 200 seeds m^2. Establishment was generally good in most sites each year. However, taking the mean of the two seed rates, the percentage establishment varied between 54 and 95%. The East Yorkshire site consistently gave establishment levels in excess of 80%, compared to the Gloucester site where establishment varied between 54 and 75% (e.g. Table 2.3.1).

Table 2.3.1 Percentage establishment of three varieties at (a) Gloucestershire and (b) East Yorkshire in October 2001

a	Variety				b	Variety		
Seeds m^{-2}	Claire	Consort	Equinox	Mean	Claire	Consort	Equinox	Mean
100	64	52	53	**56**	79	83	86	**83**
200	52	50	53	**52**	78	81	81	**80**
Mean	**58**	**51**	**53**	**54**	**78**	**82**	**84**	**81**
		P-value	SED			P-value	SED	
Rate		0.002	1.44			0.211	2.04	
Variety		<0.001	1.77			0.119	2.5	
Rate * Variety		0.003	2.50	58 d.f.		0.778	3.53	58 d.f.

Varietal choice had little consistent effect across sites and seasons. Fungicide treatments did not influence plant population density or plant survival, although an attack of frit fly at Cockle Park in the autumn of 2001 reduced plant populations significantly.

2.3.2 Disease Measurements

Disease information was collected from the Gloucestershire and Bedfordshire sites in 2000. Significant varietal differences in *Septoria tritici* levels were recorded between varieties and seed rate at GS 75 at the Cirencester site. Disease levels generally fell progressively with increase in seed rate. At Bedford, *S. tritici* was again the main disease recorded with Chaucer, Madrigal and Marshall having significantly higher disease levels than the other varieties.

For other seasons detailed disease measurements were made at the East Yorkshire and Kent sites to encompass wildly differing climatic regions. Additional disease information was collected from the Northumberland site towards the end of the growing season.

There were two years of relatively high *Septoria tritici* incidence (1999/00 and 2001/02), a year where disease pressure was relatively low (2000/01) and a year of moderate disease pressure. Sowing at a higher seed rate tended to increase levels of disease, but not in all years and at all sites. Under low disease pressure, seed rate effects were not observed, and even at high disease pressure, effects of seed rate were not always maintained to the end of the season.

Where additional autumn fungicides had effects, these were only present early in the following spring. Additional spring fungicides had more lasting effects where they were applied under high disease pressure situations, and under these conditions significantly reduced disease on the upper leaves. At low disease pressure there were no effects. Additional autumn and spring fungicides behaved similarly to additional spring fungicides, whilst the early T1 treatment did not reduce disease levels. In fact in 2002/03 it significantly increased disease levels at two of the three sites where disease was measured.

Mildew levels were generally low, out of the two years where observations were made, only in one were there measurable disease symptoms. The very low levels of disease even in this year meant absolute treatment differences were small and the only consistent effect across sites was that the variety Claire was more susceptible than the other two varieties. At the East Yorkshire site there did appear to be more disease at the higher seed rate.

In most years, there was a tendency for sowing at the higher seed rate to increase eyespot and sharp eyespot, although not always significantly so. There were no consistent effects of fungicide treatment.

2.3.3 Fertile shoot numbers

Shoot numbers increased with increasing seed rate throughout the season at all sites and in all seasons. Consort generally produced the highest number of fertile tillers of the three varieties with Equinox having the lowest number. The effect of fungicide treatments were inconsistent although some site/season combinations responded positively to additional autumn and spring fungicides, but only rarely were these responses statistically significant.

2.3.4 Canopy growth and PAR interception

Radiation use efficiency was measured at the East Yorkshire and Kent sites from 2001 to 2003. Values ranged between 1.71 and 2.63 g MJ^{-1}. Varietal differences were not recorded, but there were no consistent or significant seed rate or fungicide treatment effects.

Increasing seed rate generally led to an increase in PAR interception, but these increases were generally small. Only at the Kent site in the 2000/01 season and the East Yorkshire site in 2002/03 were there a substantial increase in PAR interception at the higher seed rate. Fungicides effects were only recorded in the

2001/02 season where additional spring, and to a lesser extent additional autumn fungicides slightly increased PAR interception.

Increasing seed rate increased Green Area Index (GAI) early in the season, but generally these differences decreased as the season progressed. Fungicides only had a significant effect in the 2001/02 season in Kent where additional spring fungicides were applied, and then only at the end of the growing season.

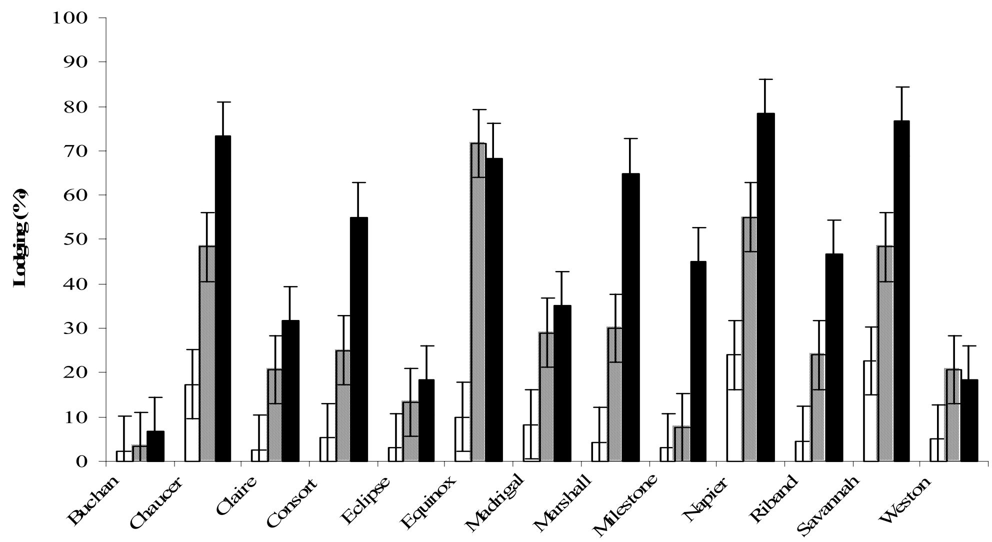
2.3.5 Biomass accumulation

Differences between seed rates tended to be greater early in the season, becoming smaller as the season progressed. Overall, increasing seed rate produced approximately 1 t ha^{-1} greater biomass at harvest. Consort tended to produce the lowest amount of biomass, and Claire the highest. Fungicide effects were small, although additional spring fungicides resulted in increased biomass in some instances. There were no consistent treatment interactions across sites or seasons.

2.3.6 Lodging

In the first year lodging increased significantly as seed rate increased at all sites. These increases were generally larger when comparing the lowest seed rate (100 seeds m^2) with the medium rate (200 or 250 seeds m^2) than when comparing the medium rate with the high rate (350 or 400 seeds m^2). Lodging was particularly severe at the East Yorkshire site, whilst at the other three sites lodging was consistent at between 29 and 35% overall. Significant differences were recorded between varieties (Figure 2.3.1). No lodging was recorded from any of the sites in subsequent seasons.

Figure 2.3.1 Percentage lodging in mid July in 13 different varieties at 100 (white bars), 250 (cross hatched bars) and 350 (black bars) seeds m-2, Kent 1999/2000. Error bars are SEDs for comparing seed rate/variety combinations (d.f. = 76)



2.3.7 Grain yield and yield components

Decreasing seed rate led to significant increases in yield at all sites in the first year (Table 2.3.2).

The highest yielding varieties were Claire, Eclipse, Buchan and Marshall, whereas Savannah, Napier, Equinox, Consort and Chaucer tended to yield the lowest. There were some differences in varietal response to seed rate, Claire and Buchan were relatively insensitive to seed rate, whilst Napier, Savannah and Chaucer showed strong response at most sites.

In subsequent seasons where Claire, Consort and Equinox were the selected varieties the result of decreasing seed rate was to reduce grain yield. The benefit of increasing seed rate was 1.2 t ha^{-1} at the Bedford site in 2000/01, but generally the increase was around 0.4 t ha^{-1}. At the Northumberland site in 2001/02 where frit fly damage was encountered the yield benefit from increasing the seed rate was 1.7 t ha^{-1}. Across all sites and seasons, Claire was the highest yielding variety.

Table 2.3.2 Combine yields (t ha^{-1}) at 85% dry weight 1999/2000 (Mean of thirteen varieties)

	Seeds m^2			
	100	250	400	Mean
East Yorkshire	10.49	9.77	8.64	9.63
		(SED 0.001)		
Kent	8.69	7.87	7.35	7.97
		(SED 0.097)		
Bedford	11.2	10.5	9.6	10.4
			(SED 0.1678)	
Gloucester	8.2	7.5	6.2	7.3
			(SED 0.1994)	

Efficacy of fungicide treatments varied widely across sites and years. In the 2000/01 season when low disease pressure was encountered fungicide treatments had no effect. In the 2001/02 season, additional spring fungicides, or additional autumn and spring fungicides significantly increased yield in three out of five sites. The extent of the response varied from site to site, with the Kent site showing a 1.6 t ha^{-1} response whilst other sites gave only a 0.3 t ha^{-1} increase. In 2002/03 response to additional spring and additional spring and autumn fungicides were more consistent across sites at around 0.3 t ha^{-1} at three out of five sites. The Bedfordshire and Northumberland sites showed no response to these fungicide treatments in either of these two seasons.

The economic benefits of applying additional or differently timed fungicides in terms of extra yield gained over that of the standard T1, T2, T3 regime is presented in Table 2.3.3. In general the benefits of the non-standard fungicide regimes were quite small, and in the case of the additional autumn fungicide and early T1 treatments, mostly negative. Overall, the benefits of an additional spring fungicide were around £10 ha^{-1}, although at the Kent site in 2001/02 the benefit was over £150 ha^{-1}.

Increasing seed rate generally led to decreased TGW, though decreases were generally small, and not always significant, particularly in comparing seed rate effects. Additional spring or additional autumn and spring fungicide significantly increased TGW in only one out of thirteen site/season combinations. Of the three varieties Equinox tended to produce the largest seed and Claire the smallest.

Grains per ear decreased significantly as seed rate increased in the majority of site/season combinations. Varietal effects were inconsistent, although Claire and Consort tended to have more grains ear^{-1} than Equinox, except in the 2002/03 season. Fungicides effects were small and showed no consistent trend across treatments

Table 2.3.3 Costs/benefits (£ ha^{-1}) compared to a standard T1, T2, T3fungicide programme for application of additional autumn or spring, or early T1 fungicides.

		Fungicide treatment			
Year	Site	Additional autumn	Additional spring	Additional autumn and spring	Early T1
2000/01	East Yorkshire	-5.33	-12.70	-4.89	-15.88
	Kent	1.31	22.39	9.83	36.38
	Bedfordshire	22.28	-32.61	-13.42	-11.51
	Gloucestershire	-1.98	7.58	10.17	14.88
	Mean	**4.07**	**-3.83**	**0.42**	**5.97**
2001/02	East Yorkshire	0.48	26.97	57.47	45.32
	Kent	-18.61	151.73	145.66	-14.55
	Bedfordshire	18.36	6.32	16.65	-3.07
	Gloucestershire	-7.56	30.75	19.02	-10.85
	Northumberland	9.36	-53.80	21.43	-48.77
	Mean	**-1.83**	**53.94**	**59.70**	**4.21**
2002/03	East Yorkshire	-3.68	-3.48	11.49	-5.61
	Kent	-7.47	18.11	23.33	-17.55
	Bedfordshire	12.02	11.25	2.08	0.83
	Gloucestershire	-8.67	12.16	19.71	-11.70
	Northumberland	-1.77	8.91	4.63	0.05
	Mean	**-1.91**	**9.39**	**12.25**	**-6.80**
Overall mean		**0.11**	**19.83**	**24.12**	**1.13**

Calculations based on the assumption that feed grain is priced at £100 t^{-1}. Costs of fungicides are Twist at £19 l^{-1}, Bravo at £3 l^{-1} and Opus at £29 l^{-1}. Figures for each site are averaged across seed rate and varietal treatments.

3 TECHNICAL DETAIL

3.1 INTRODUCTION

Winter wheat sown early, that is to say before mid-September, has become increasingly prevalent in the last few years in the UK. Sowing early increases the yield potential of the crop (Fielder, 1988), as the canopy will be able to achieve optimal size for maximum light interception sooner than a later sown crop. However, the potential for higher yield could be compromised by increased disease pressure (Fielder, 1988; Cook, Polley and Thomas, 1991, Polley and Thomas, 1991; Shaw and Royle, 1993), increased risk of lodging (Stapper and Fischer, 1990a and b; Berry *et al*., 2000) and poorer establishment due to drier conditions in early September. This study aimed to investigate ameliorating these effects through the use of different seed rates, modified fungicide regimes and different varieties in early September sown crops of winter wheat.

3.1.1 Seed rate effects and early sowing

Earlier sowing has been shown to result in increased lodging (Stapper and Fischer, 1990; Berry *et al*., 1998, 2000). Berry *et al*. (2000) found that early sown crops had increased height of centre of gravity and reduced stem strength, both factors that would increase a crops' vulnerability to lodging. Reducing the sowing rate from 500 to 250 seeds m^{-2} was found to increase anchorage of the plant, though this was partly counteracted by increasing shoot number per plant. Thus reducing sowing rate may reduce lodging risk, and will be especially appropriate in early sown crops, as work by Spink *et al*. (2000) showed that with a longer growing period, crops sown at lower seed rates had more time to compensate for lower plant populations than crops with shorter growing periods (i.e. later sown crops). However, in northern regions, higher seed rates may be needed than in southern regions because of the reduced thermal time from sowing to full vernalisation.

Spink *et al*. (2000) found that sowing in late September tended to increase percentage establishment (i.e. no. plants established as a percentage of seeds sown) compared to later sown crops. However, comparing sowing dates from early-September to mid-November, Kirby *et al*. (1998) found lower seedling emergence and plant establishment in early sowings due to low September rainfall and dry seed beds. To compensate for this, it may be necessary to sow at a higher seed rate; though as mentioned above, this may lead to greater lodging risk.

Sowing at higher seed rates has been shown to increase levels of *S. tritici* (Tompkins, Fowler and Wright, 1993) eyespot (Goulds and Fitt, 1991; Colbach *et al*., 1997; Colbach and Saur, 1998) and powdery mildew (Tompkins, Wright and Fowler, 1992). With increased disease pressure in early sown crops these effects could be exacerbated.

Sowing at lower seed rates should reduce effects of lodging and disease, but may lead to poor establishment. Increased understanding of the relative sensitivity of these variables to seed rate will be necessary to realise the yield potential of early sown crops. In addition, latitude at which crops are to be grown may affect decisions that are made.

3.1.2 Early sowing effects on disease

Shaw and Royle (1993) postulated that early sown crops were more at risk from *Septoria tritici*, as they produced more leaves to provide host material and subsequently more sources of inoculum, stem extension was slower meaning that infected and uninfected leaf layers were closer together for longer, and phyllocrons are longer allowing greater multiplication of inoculum within a leaf layer. However, Lovell *et al*. (1997) suggested that since development is faster in later sown crops, leaves emerge lower down the canopy, and therefore are closer to inoculum sources on the ground. Sowing date effects could therefore cancel each other out. Thus Polley and Thomas (1991) found in examining 11 years of field survey data that *Septoria* infections (either *tritici* or *nodorum*) that in only five years were symptoms increased in early sown crops, and were actually decreased in two years. However, although these surveys encompassed sowing dates from September to November, most sowing dates were in October, and only a few were in September. Other studies have found *S. tritici* infection to be more severe on early sown crops (Fielder, 1988). For eyespot and sharp eyespot, Polley and Thomas (1991) found that in the majority of years early sown crops suffered more than later sown crops. The consensus of work available therefore suggests that early sown crops are at higher risk from diseases, and new strategies must be sought to allow yield potential to be realised.

Thomas *et al*. (1989), in late September/early October sown crops found that applying fungicides as early as 1st October significantly controlled winter *S. tritici* levels, but by the end of the season yields were no different from where fungicide application had not started until the onset of stem extension. It is possible, however, that in early sown crops inoculum will be able to build up to such levels that applications of fungicides earlier than the third leaf stage may be necessary.

3.1.3 Varietal interactions

Kirby *et al*. (1998) found that varietal rankings in terms of yield were consistent across a range of sowing dates. However, slower developing varieties were thought to be a better choice for early sowings in order to avoid winter damage. Other varietal traits that may be useful with early sowings include lodging resistance and disease resistance and possibly a profuse tillering habit.

3.1.4 Project aims

The aims of this project are to investigate some practices for better management of early sown winter wheat including:

1) How early sowing affects seed rate decisions.
2) Whether changing fungicide amounts or timing of application will ameliorate the larger amounts of disease likely to be seen in early-sown crops.
3) Whether certain varieties are better at responding to different fungicide and seed rate treatments than others.
4) How changing seed rate will interact with disease, lodging and establishment variables, and the fungicide and variety treatments.
5) How the latitude crops are grown at will affect seed rate decisions.

3.2 MATERIALS AND METHODS

Experiments were conducted over four years, 1999/2000, 2000/01, 2001/02 and 2002/03. All data for 1999/2000 were collected by Arable Research Centre (now The Arable Group, TAG) staff. In the following years, all data except combine yield data were collected by staff at Newcastle University.

3.2.1 Experimental sites

Field experiments were undertaken at TAG sites around the country (Table 3.2.1). In 2001/02 and 2002/03 experiments were also conducted at Cockle Park in Northumberland.

Table 3.2.1 Site locations and approximate latitude/longitude data

Site	1999/00	2000/01	2001/02	2002/03
East Yorkshire	Bainton 53:57:23N 0:31.58W	Bainton 53:57:23N 0:31.58W	Bainton 53:57:23N 0:31.58W	Bainton 53:57:23N 0:31.58W
Kent	Braeborne Lees 51:08:15N 0:59:56E	Braeborne Lees 51:08:15N 0:59:56E	Shottenden 51:14:57N 0:54:19E	Shottenden 51:14:57N 0:54:19E
Bedfordshire	Kettering 52:25:33N 0:39:42W	Kettering 52:25:33N 0:39:42W	Biggleswade 52:02:50N 0:13:10W	Biggleswade 52:02:50N 0:13:10W
Gloucestershire	Cirencester 51:40:56N 1:56:51W	Cirencester 51:40:56N 1:56:51W	Cirencester 51:40:56N 1:56:51W	Cirencester 51:40:56N 1:56:51W
Northumberland	*	*	Cockle Park 55:12:46N 1:41:25W	Cockle Park 55:12:46N 1:41:25W

3.2.1.1 Soil types

Soil types at each of the sites are shown in Table 3.2.2.

Table 3.2.2 Soil types at the different experimental sites

Site	Soil Type	Soil Description
East Yorkshire	Panholes	Well drained calcareous silty soil over chalk
Kent Braeborne Lees	Combe 2	Chalk down wash silty soil over chalk. (Series 5 11g)
Kent Shottenden	Batcombe	Plateau drift and clay with flints
Bedfordshire Kettering	Hounslow	Chalky boulder clay
Bedfordshire Biggleswade	Cannamore	Deep calcareous clay loam
Gloucestershire	Elmton	Brash, clayey soil over limestone (no. 343a)
Northumberland	Hallsworth Series	Clay loam over clay

3.2.1.2 Previous crops

All crops were 1st winter wheats. Details of preceding crops are given in Table 3.2.3.

Table 3.2.3 Preceding crops for all site/season combinations

	1999/2000	2000/01	2001/02	2002/03
East Yorkshire	Vining peas	Vining peas	Vining peas	Vining peas
Kent	Winter oilseed rape	Winter oilseed rape	Winter oilseed rape	Winter oilseed rape
Bedfordshire	Winter oilseed rape	Winter oilseed rape	Winter oilseed rape	Winter oilseed rape
Gloucestershire	Winter oilseed rape	Spring linseed	Winter oilseed rape	Winter oilseed rape
Northumberland	*	*	Grass ley	Grass ley

3.2.1.3 Experimental Design

The experimental design was a split plot with three replicates. Sowing date was on the main plot; seed rate and variety were factorially combined and fully randomised on sub plots. Sub-plot length was 12 m. Where plots were to be used for destructive sampling (growth analysis), an identical, adjacent plot was sown for combining at harvest. At Cockle Park, in 2002/03, sub-plot length was 24 m, a length of 10 m was maintained until harvest for yield determination.

3.2.1.4 Site Management

The site was ploughed prior to sowing and was subject to secondary cultivations, dependent on the site and season, to produce a fine seedbed. An Oyjard drill was used to sow seeds, row width was dependent on site (Table 3.2.4). The Arable Group sites drilled 14 rows and 12 rows were drilled at Cockle Park. A prophylactic programme of pest and weed control was applied in all experiments, depending on prevalent problems and local conditions. Plant growth regulators were applied in all seasons to minimise the incidence of lodging in the experiments. See the appendix for specific site records.

Table 3.2.4 Row spacing at the different experimental sites

Site	Row Width (cm)
Northern	12
Southern	12
Eastern	12.5
Western	12
Cockle Park	12.3

3.2.2 Sowing dates

The aim was to drill the experiments as early as possible in September, but practical difficulties at some sites meant a mid-September sowing was the earliest that could be achieved (Table 3.2.5).

Table 3.2.5 Sowing dates for all experiments

Site	1999/2000	2000/01	2001/02	2002/03
East Yorkshire	02 September	08 September	07 September	11 September
Kent	01 September	08 September	10 September	11 September
Bedfordshire	02 September	11 September	11 September	12 September
Gloucestershire	03 September	08 September	07 September	10 September
Northumberland	*	*	05 September	05 September

3.2.3 Experimental treatments

3.2.3.1 Sowing rate

In the first year of experimentation (1999/2000), three different seed rates were applied at each site, with 100 seeds m^{-2}, then either 200 or 250 seeds m^{-2}, then a rate of either 350 or 400 seeds m^{-2}, depending on the site (Table 3.2.6). In following years, the same two seed rates were used at all sites, 100 and 200 seeds m^{-2}.

Table 3.2.6 Seed rates in 1999/2000 experiment

	Seed rate (seeds m^{-2})		
Site	Low	Medium	High
East Yorkshire	100	200	400
Kent	100	250	350
Bedfordshire	100	250	400
Gloucestershire	100	250	400

3.2.3.2 Variety

In the 1999/2000 experiment 13 different varieties were used at each site. These varieties were: Buchan, Chaucer, Claire, Conosrt, Eclipse, Equinox, Madrigal, Marshall, Milestone, Napier, Riband, Savannah and Weston. In the following year's experiments, the number of varieties used was reduced to three, Claire, Consort and Equinox.

3.2.3.3 Fungicide

No fungicide treatments were applied in the first year's experiments, other than the standard T1, T2, T3 regime (Table 3.2.7). In other years, in addition to standard fungicide treatments, additional fungicides or different times of fungicide application were used. There were five different fungicide regimes. The first was a standard fungicide regime, with a T1 being applied at the 3rd leaf stage, a T2 applied to co-incide with flag leaf emergence, and a T3 ear wash. The second regime was as the standard fungicide but with an additional fungicide application in the autumn. The third was a standard regime with additional fungicide applied in the early spring. The fourth was with both additional autumn and spring fungicides. The fifth treatment in 2000/01 was as the standard regime, but with T1 treatment split between an early T1, as leaf three was emerging, followed by another spray as leaf two was emerging. In 2001/02 and 2002/03 this was simplified to a single early application of the T1 fungicide, brought forward to the 4th leaf stage.

Table 3.2.7 Times of application and application rates of the different fungicide regimes; 2000-2003.

		Fungicide treatment						
Site	Year	Autumn	Spring	Early T1	Late T1	T1	T2	T3
East Yorkshire	2000/01	10/11/00	06/03/01	30/04/01	09/04/01	10/05/01	22/05/01	21/06/01
	2001/02	26/11/01	12/03/02	17/04/02	*	03/04/02	12/05/02	07/06/02
	2002/03	25/11/02	21/02/03	04/04/03	*	23/04/03	21/05/03	05/06/03
Kent	2000/01	16/11/00	06/03/01	10/05/01	23/04/01	22/05/01	30/05/01	19/06/01
	2001/02	28/11/01	26/03/02	05/04/02	*	16/04/02	16/05/02	13/06/02
	2002/03	28/11/02	13/03/03	11/04/03	*	23/04/03	14/05/03	13/06/03
Bedfordshire	2000/01	03/11/00	15/03/00	12/04/01	12/04/01	03/05/01	23/05/01	08/06/01
	2001/02	16/11/01	12/03/01	21/03/02	*	18/04/02	20/05/02	14/06/02
	2002/03	16/01/03	03/03/03	31/03/03	*	23/04/03	08/05/03	12/06/03
Gloucestershire	2000/01	07/11/00	14/03/01	30/04/01	11/05/01	11/05/01	23/05/01	21/06/01
	2001/02	14/11/01	22/03/02	03/04/02	*	15/04/02	15/05/02	19/06/02
	2002/03	24/01/03	19/03/03	09/04/03	*	16/04/03	30/05/03	26/06/03
Northumberland	2000/01	*	*	*	*	*	*	*
	2001/02	14/11/01	18/03/02	26/03/02	*	02/04/02	16/05/02	10/07/02
	2002/03	13/11/02	13/03/03	08/04/03	*	06/05/03	22/05/03	16/06/03

Fungicides in each treatment:
Autumn: 0.25 l Opus, 1.0 l Bravo
Spring: 0.25 l Opus, 1.0 l Bravo
Early T1: 1.0 l Twist, 0.25 l Opus
Late T1: 0.25 l Opus, 1.0 l Bravo
T1: 1.0 l Twist, 0.25 l Opus
T2: 1.0 l Twist, 0.25 l Opus
T3: 0.25 l Opus

3.2.4 Measurements

3.2.4.1 Weather data

Data for the East Yorkshire site was acquired monthly from the weather station at Bishop Burton College (53:50:53N, 0:30:14W) and for the Kent site from Imperial College at Wye (51:11:12N, 0:56:16E).

3.2.4.2 Plant Counts

At each site plant counts were performed pre-tillering. The number of plants were recorded for 4 rows at the top and bottom of each plot along a metre length. Plants m^{-2} were also measured at each of the growth analysis stages (see 3.2.4.3) to monitor changes in plant population through the season.

3.2.4.3 Growth analysis

Sampling took place from the central rows of the plot to avoid edge effects (Austin and Blackwell, 1980). Sample areas were positioned at least 0.5 m from each other. Plants from an area of 8 rows by 0.3 m, at the top and bottom of plots (in case disease was localised within the plot) were sampled at each growth analysis. Dates of growth analyses are given in Table 3.2.8.

Table 3.2.8 Dates of growth analyses and combine harvest dates for each site/year combination. * indicates no samples taken at these points.

Site	Year	Dates of growth analysis							Harvest	
East Yorkshire	1999/2000	*	*	*	*	*	*	*	Preharvest	29/08/00
	2000/01	31-Oct	7-Feb	27-Mar	1-May	21-May	19-Jun	10-Jul	Preharvest	15/08/01
	2001/02	*	*	4-Mar	22-Apr	20-May	18-Jun	*	Preharvest	16/08/02
	2002/03	*	*	17-Mar	14-Apr	20-May	16-Jun	*	Preharvest	07/08/03
Kent	1999/2000	*	*	*	*	*	*	*	Preharvest	07/08/00
	2000/01	20-Nov	13-Feb	3-Apr	7-May	28-May	11-Jun	2-Jul	Preharvest	03/08/01
	2001/02	*	*	11-Mar	15-Apr	13-May	10-Jun	*	Preharvest	23/08/02
	2002/03			24-Mar	7-Apr	12-May	10-Jun	*	Preharvest	12/08/03
Bedfordshire	1999/2000	*	*	*	*	*	*	*	Preharvest	23/08/00
	2000/01	*	*	*	*	*	*	*	Preharvest	21/08/01
	2001/02	*	*	*	*	*	*	*	Preharvest	13/08/02
	2002/03	*	*	*	*	*	*	*	Preharvest	03/08/03
Gloucestershire	1999/2000	*	*	*	*	*	*	*	Preharvest	21/08/00
	2000/01	*	*	*	*	*	*	*	Preharvest	16/08/01
	2001/02	*	*	*	*	*	*	*	Preharvest	14/08/02
	2002/03	*	*	*	*	*	*	*	Preharvest	03/08/03
Northumberland	1999/2000	*	*	*	*	*	*	*	*	*
	2000/01	*	*	*	*	*	*	*	*	*
	2001/02	*	8-Jan	*	*	*	*	*	Preharvest	28/08/02
	2002/03	*	*	*	*	*	*	*	Preharvest	19/08/03

Growth analysis was carried out to ascertain plant and shoot density, dry weight and green area index (GAI) of leaves and stems. Plants were sampled intact, so that plant counts could be performed and so the main stem could be identified for disease assessment.

Post-winter plant establishment numbers were determined by separating all plants in the laboratory and counting them. A sub-sample of approximately 20% was removed from the main sample for growth analysis (SS1). The remainder of the sample was used for disease analysis. After the disease assessment the roots were cut off at ground level and the fresh weight recorded, this weight was added to the fresh weight of the sub-sample, to record the total fresh weight of the sample. Approximately 20% of the sample used for disease assessments was removed (SS2); its fresh weight and dry weight recorded to determine the overall dry weight of the sample. Early in the season, because of low sample weights, all plant matter minus the SS1 was used for overall dry weight determination.

The shoots on SS1 were split into two categories, potentially fertile shoots and dead and dying shoots. A shoot was considered to be dying when its emerging leaf had begun to turn yellow at the tip (Thorne and Wood, 1987), or showed symptoms of gout fly. The number of shoots in each category was recorded. The potentially fertile shoots were then further separated into green lamina, green stem and dead material. The fresh weight of each component and the projected area of the green components were recorded using an image analyser (Delta T Devices, Cambridgeshire). The dry weights for each component were then recorded after drying to constant weight.

3.2.4.4 Disease assessment

At each biomass sampling, 20 plants were selected at random from plants left over after the SS1 had been taken from the biomass samples. For each plant the following was recorded:

1) Total number of shoots.
2) Number of shoots with:
    a. Penetrating eyespot or sharp eyespot lesions i.e. where the last live leaf sheath has been penetrated and there is a lesion present on the next leaf layer.
    b. Non-penetrating eyespot lesions.
3) On the mainshoot, the following were assessed on all fully emerged, non-senescent leaves:
    a. Percentage area infected with *Septoria tritici*.
    b. Percentage area infected with mildew.

At mid-grainfill all plots were examined at Kent, East Yorkshire and Northumbria in harvest years 2000-2003. Ten shoots were selected at random from each plot and the flag leaf, leaf two and leaf three assessed for percentage area infected with *S. tritici* and mildew, and also percentage senescent area.

3.2.4.5 Harvest Assessments

3.2.4.5.1 Combine Analysis

A 10 m length of plot was combined by a plot harvester. The weight of grain harvested was recorded, and a sub-sample of grain, of approximately 2 kg was taken from the combine sample on selected plots. The moisture content was assessed using a Sinar AgrTech G3 moisture meter. The thousand grain weight of the selected combine harvested samples was determined by recording the fresh weight of approximately 60 g, drying it until constant weight, recording the dry weight, and then counting the number of grains in the sub-sample (mechanically).

3.2.4.5.2 Pre-harvest Quadrat Analysis

To determine final ear population density, grain, chaff and straw weight and harvest index, a final growth analysis was performed on all plots just before harvesting each growing season. An area 7 rows by 1 metre (6 rows at Cockle Park) was sampled and total fresh weight recorded. A sub-sample of 20% was randomly selected on the basis of fresh weight, weighed and the number of fertile ears recorded. The ears were then removed and the ear and straw dried in an oven, until constant weight. The dry ears were threshed to separate the grain and the chaff and the grain weighed. The thousand grain weight was determined by counting the number of grains (mechanically) in a sub-sample of approximately 50g.

3.2.4.6 Radiation interception

3.2.4.6.1 Total Incident Radiation

The number of sunshine hours incident on the crop was recorded daily at local Agro-Meteorological Stations. This was then converted to total incident radiation using a model designed to take into account time of year and latitude (Berry, 1964). The amount of photosynthetically active radiation (PAR) incident was then calculated as 50% of total radiation.

3.2.4.7 PAR Absorption by Crop

PAR absorption was measured for each plot at the same time as sampling for growth analysis, using ceptometers (Sunfleck Meters) between 11:00 and 14:00. The ceptometers sensed wavelengths between 0.4 and 0.7 μm. Firstly the percentage PAR transmitted through the crop was recorded. The ceptometer was placed above the crop, and a measurement taken, it was then placed below the crop, across the rows at and measurements taken at five different locations. The ceptometer was then placed above the crop again, and a measurement taken. The percentage PAR reflected by the crop was then measured by holding an inverted ceptometer above the crop (again, across the rows) and taking five readings. Finally, the ceptometer was then placed above the crop again, and a measurement taken. The percentage PAR absorbed by the crop was then calculated (Equation 1). This information was then used to calculate the extinction coefficient, k_{PAR}, using Equation 2. f refers to the fractional absorption of incident light by the crop (Equation 1). t is the fraction of light transmitted to the base of the canopy and r the fraction of light reflected from the top of the crop.

Equation 1

$$f = 1 - t - r$$

Equation 2

$$k = -\ln\left(\frac{I}{Io}\right) \Big/ L$$

This equation was defined by the Monsi and Saeki equation (1953; cited by Saeki, 1960) where L is the green leaf area, I is radiation transmitted through the canopy and I_o is incident radiation above the canopy.

3.2.5 Statistical analysis

GENSTAT 3.2 (Lawes Agricultural Trust) was used for all statistical analyses. Standard ANOVAs were performed to determine statistically significant differences between the treatments. In all analyses, a probability value of 0.05 or less was deemed to be statistically significant.