

## Results from experiments on winter barley measuring the effects of amount and timing of nitrogen and some other factors on the yield and nitrogen content of the grain

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### SUMMARY

Seven experiments on winter barley, made during 1979–81, measured the effects of several amounts of nitrogen, applied at different times in spring, on grain yield and nitrogen content. All of these experiments also tested a growth regulator applied in spring, and five of them tested fungicide sprays. In 1980 the experiment at Rothamsted also tested sowing dates, and an eighth experiment, also at Rothamsted in 1980, tested sowing dates and mildew fungicides applied in autumn or spring. In all the experiments treatments were tested in factorial combination.

N applied in February was less effective than N applied in March and both were less effective, in terms of grain yield, than N applied in April. Divided dressings were best applied in February and April or March and April; effects on % N in grain followed the same pattern and so, therefore, did the efficiency of uptake of fertilizer N. The growth regulator consistently reduced the length of the straw and diminished lodging; it increased yields in five of the seven experiments in which it was tested.

Responses to fungicides were inconsistent from year to year. Sowing in September rather than in October 1979 increased yield in both of the experiments at Rothamsted in 1980, especially of the 6-row variety Hoppel.

### INTRODUCTION

Much more spring than winter barley was grown in the United Kingdom until the mid-1970s, but since then the area of winter barley has increased, and by 1979 it occupied 31% of the barley area in England and Wales (Anon. 1984). Although we had experimented much with nitrogen and fungicides on spring barley (e.g. Widdowson, Jenkyn & Penny, 1976, 1982) we had no comparable data for winter barley, nor was much available elsewhere, though lodging was recognized as a serious restraint. Accordingly we decided to make experiments to determine when best to apply nitrogen in spring, recognizing that winter barley ripened 3–4 weeks before winter wheat and so might be expected to need N earlier. These tests were always made in factorial combination with a growth regulator, which we hoped would limit lodging and so enhance responses to nitrogen. Additional factors were tested in some of the experiments, including fungicides intended to control leaf diseases, especially powdery mildew (*Erysiphe graminis*), and eyespot (*Pseudocercospora herpotrichoides*). These factors were

included to extend our information on nitrogen × fungicide interactions which we had previously studied in spring barley. Because there was a trend towards September sowing of winter barley, especially in the Cotswolds, two of the experiments compared sowing in September with sowing at the more usual time in October. Eight experiments were made during 1979–81; three followed either beans or potatoes at Rothamsted, two were in fields long used to grow cereals on a chalkland farm at Barton Hill in Bedfordshire and three followed cereals at our Saxmundham field station in east Suffolk.

### EXPERIMENTAL DETAILS

#### *Soils*

At Rothamsted the soil is a flinty clay loam (Batcombe series), at Barton Hill a light chalky loam (Swaffham Prior series), and at Saxmundham a sandy clay loam (Beccles series).

#### *Materials*

The nitrogen fertilizer was 'Nitro-Chalk', 26% N, a mixture of ammonium nitrate and calcium

Table 1. *Variety, previous crop and calendar of operations in each experiment*

Year ...	Rothamsted			Barton Hill			Saxmundham		
	1979	1980 (a)	1980 (b)	1979	1980	1979	1980	1981	
Variety ...	Athene	Sonja	Hoppel	Maris Otter	Maris Otter	Sonja	Sonja	Igri	
Previous crop ...	Winter beans	Potatoes	Potatoes	Winter wheat	Spring barley	Spring barley	Winter barley	Winter wheat	
Seed sown ...	6 Oct. (1978)	18 Sept. and 16 Oct. (1979)	14 Sept. and 9 Oct. (1979)	16 Oct. (1978)	28 Sept. (1979)	26 Sept. (1978)	26 Sept. (1979)	24 Sept. (1980)	
Intended months of N application*									
1 Feb.	27 Feb.	1 Feb.	—	5 Mar.	13 Feb.	6 Mar.	12 Feb.	19 Feb.	
2 Mar.	2 Apr.	7 Mar.	—	2 Apr.	21 Mar.	10 Apr.	25 Mar.	—	
3 Apr.	25 Apr.	8 Apr.	9 Apr.†	26 Apr.	10 Apr.	2 May	23 Apr.	14 Apr.	
Sprays applied									
Growth regulator	25 May	22 Apr. (early sown) and 7 May (later sown)	—	14 May	25 Apr.	16 May	23 Apr.	30 Apr.	
Eyespot fungicide (carbendazim)	—	—	—	14 May	25 Apr.	15 May	23 Apr.	—	
Mildew fungicide (tridemorph)	—	—	24 Oct. (early sown) 13 Nov. (later sown)	14 May	25 Apr. and 16 May	15 May	23 Apr. and 14 May	—	
Combined disease and aphid control	—	—	11 Apr. 19 May	—	—	—	—	14 Apr. and 20 May	
Combine-harvested	6 Aug.	30 July	30 July	15 Aug.	1 Aug.	8 Aug.	29 July	27 July	

\* Planned dates of applying N-fertilizer in 1979 were not achieved because of wet weather (see *Treatments*).  
 † Basal dressing.

carbonate. 'Bavistin' (a.i. carbendazim) at 0.51 kg/ha was sprayed to control eyespot (*Pseudocercospora herpotrichoides*) and 'Calixin' (a.i. tridemorph) at 0.71/ha to control powdery mildew (*Erysiphe graminis*). 'Milstem' (a.i. ethirimol) was used as a seed treatment to control mildew. Combined disease and aphid control in 1981 (Table 1) consisted of 'Bavistin' plus 'Calixin' in April and 'Calixin' plus 'Calirus' (a.i. benodanil) at 2.2 kg/ha plus 'Aphox' (a.i. pirimicarb) at 280 g/ha in May. The growth regulator was 'Terpal' (mepiquat chloride plus 2-chloroethylphosphonic acid) at 2.5 l/ha.

#### Treatments

In 1979 we intended to apply nitrogen at monthly intervals from February to April. This was not possible because of wet weather; the actual dates achieved are in Table 1. For uniformity of presentation with subsequent years the intended months of application are used in the text and tables.

#### At Rothamsted

In 1979 nitrogen was applied early as either a divided (February, March) or as a single (March) dressing to supply either 60 or 90 kg N/ha. The 60 kg dressing was divided 30 plus 30, the 90 kg dressing 30 plus 60. These treatments were applied in combination with none or 30 kg N/ha in April or 30 kg N/ha in April plus 'Terpal' in May. There were three blocks, each containing these 12 treatments.

In 1980 experiment (a) tested four factors at two levels and one at three, in all combinations in a single replicate. They were: (1) sowing date, September v. October; (2) N in February, none v. 35 kg/ha; (3) N in spring, 75 v. 110 kg/ha; (4) timing of N in spring, March v. April v. half in March plus half in April; and (5) growth regulator, none v. 'Terpal'. In addition to these 48 plots there was one September-sown and one October-sown plot given neither N nor the growth regulator.

Experiment (b) tested three factors at two levels and one at three levels, in all combinations. They were: (1) sowing date, September v. October; (2) mildew fungicides in autumn, none v. 'Milstem' seed treatment v. 'Calixin' spray; (3) mildew fungicide in April, none v. 'Calixin'; and (4) mildew fungicide in May, none v. 'Calixin'. There were two replicates of these 24 treatments.

#### At Barton Hill

In 1979 six factors, each at two levels, were tested in all combinations in a single replicate containing 64 subplots, using a split-plot design. These were: (1) N early, 80 v. 120 kg/ha; (2) timing of early N,

40 kg/ha in February and remainder in March v. all in March; (3) N in April, none v. 40 kg/ha; (4) mildew fungicide, none v. 'Calixin'; (5) eyespot fungicide, none v. 'Bavistin'; and (6) growth regulator, none v. 'Terpal'.

In 1980 four factors, each at two levels, and one at three were tested in all combinations in a single replicate containing 48 subplots, again using a split-plot design. These were: (1) N early, 105 v. 140 kg/ha; (2) timing of early N, 35 kg/ha in February and remainder in March v. all in March; (3) N in April, none v. 35 kg/ha v. 35 kg/ha plus 'Terpal'; (4) mildew fungicide, none v. 'Calixin'; and (5) eyespot fungicide, none v. 'Bavistin'.

#### At Saxmundham

In both 1979 and 1980 the treatments and design were the same as those at Barton Hill in the respective years.

In 1981 four factors, each at two levels, were tested in all combinations. They were: (1) N in spring, 120 v. 160 kg/ha; (2) timing of N in spring, 40 kg/ha in February and the remainder in April v. all in April; (3) growth regulator, none v. 'Terpal'; and (4) combined disease and aphid control, none v. fungicides and aphicide (see *Materials*). There were two blocks, each containing these 16 treatments, plus two plots not given any of them and two given disease and aphid control only.

#### Methods

Individual plot dimensions (m) were: at Rothamsted in 1979, 2.1 × 9.1 and, in 1980, 2.7 × 13.9 (experiment a) and 2.1 × 6.1 (experiment b); at Barton Hill 2.4 × 17.4; at Saxmundham in 1979 and 1980, 2.7 × 20.1 and in 1981 3.0 × 6.4. The barley was sown in rows 18 cm apart at Rothamsted and Barton Hill and 15 cm apart at Saxmundham. All the barley was given basal P and K fertilizer and in experiment (b) at Rothamsted in 1980, basal N also.

In the seven experiments testing N the 'Nitro-Chalk' was spread by hand. All experimental sprays were applied in 280 l/ha of water using a motorized knapsack sprayer, except at Rothamsted in 1980, where in experiment (b) the 'Calixin' was applied in 340 l/ha of water, using a self-propelled small-plot sprayer.

In 1979 each of the experiments was sampled in June to estimate the severity of leaf diseases on 10 randomly selected shoots/plot. Percentage leaf areas affected were estimated using standard area diagrams (Anon. 1976). For statistical analyses a mean percentage ( $P\%$ ) was calculated for each plot and a logit transformation used (namely,  $0.5 \ln [(P\% + 0.05)/(100.05 - P\%)]$ ), a formula which

avoids problems arising from  $P\%$  values of 0 or 100%). The quoted percentage values were obtained by back transformation.

The height of the barley was measured in seven of the experiments; six measurements were made per plot. Ear counts in experiment (a) at Rothamsted in 1980 were made in two areas, each 0.1 m<sup>2</sup>, per plot. At maturity a central cut was made by a combine-harvester along each plot. The grain was weighed and then sampled to determine percentages of dry matter in all experiments and of N in the dry matter in all except experiment (b) at Rothamsted in 1980. The weight of 1000 grains was determined on the dry samples.

## RESULTS

### *The Rothamsted experiments*

#### *Crop height and lodging*

In 1979. Measurements on 29 June showed that where the early N was applied as a divided dressing in February and March the barley was 6 cm taller with 90 than with 60 kg N/ha. By contrast there was only a small effect of extra N on crop height (+2 cm) where it was applied as a single dressing in March. Additional N applied at 30 kg/ha on 25 April also had only a small effect on crop height (+2 cm) but the growth regulator (Table 2) decreased crop height by 13 cm.

In early August, average plot areas affected by lodging were increased from 7 to 18% by applying early N at 90 instead of 60 kg/ha and from 7 to 26% by applying extra N in April. The growth regulator decreased lodging from 26 to 4%.

In 1980 (*Expt a*). On 13 June, barley sown on 16 October 1979 was 4 cm taller than barley sown on 18 September, and that given nitrogen in February at 35 kg/ha was 5 cm taller than that

given none. The growth regulator (Table 2) decreased crop height by 14 cm.

#### *Leaf diseases*

In 1979. The experiment was sampled to assess leaf diseases on 29 June, at growth stage Za 75 (Zadoks, Chang & Konzak, 1974). Leaf blotch (*Rhynchosporium secalis*) was the most prevalent disease (averaging 1.6 and 4.4% on the second and third youngest leaves respectively) but was little affected by any of the treatments. Mildew (*Erysiphe graminis* f.sp. *hordei*) was slight but significantly increased by applying extra N in April (from 0.3 to 0.5% on the third youngest leaves). Yellow rust (*Puccinia striiformis*) and net blotch (*Pyrenophora teres*) also occurred but were very slight.

#### *Yields of grain*

In 1979. Appendix Table 1 shows how mean yields were affected by each of the factors tested, and Table 3 shows detailed yields when comparing amount and timing of N. Yield was larger with single dressings of nitrogen applied in March than with dressings divided between February and March. Giving an extra 30 kg N/ha in April was beneficial except where 90 kg N/ha had been applied in March, which gave the largest yield. The growth regulator increased yield significantly (Appendix Table 1); it increased yield slightly more where N had been applied in March, rather than divided between February and March.

In 1980 (*Expt a*). Appendix Table 1 again shows mean yield from each factor. Sowing in September instead of October increased yield by only 0.21 t/ha, and did not interact with any of the other factors. Although N applied in February did not change mean yield overall (Appendix Table 1), it did increase yield when the whole of the spring dressing was withheld until April (Table 4). There was a significant mean increase of 0.44 t/ha from applying the whole of the spring dressing in April instead of March, and Table 4 shows that this benefit occurred whether or not N was applied in February. Dividing the N between March and April gave an intermediate yield.

The growth regulator decreased the height of the straw (Table 2) and increased yield by more than any other factor (Appendix Table 1). Its effects were consistently significant and were about twice as large when tested with than without N applied in February (1.04 v. 0.58 t/ha), and larger with the larger than with the smaller amount of N in spring (0.89 v. 0.75) and with the spring N applied in April rather than in March (1.09 v. 0.71). Thus the greater the effect of N on growth and yield the greater the benefit from the growth regulator.

Counts made before harvest showed that the mean number of ears was greatly increased by

Table 2. The mean height (cm) of the barley straw from ground level to base of the ear, without and with growth regulator ('Terpal')

	Growth regulator		S.E.
	Without	With	
Rothamsted			
1979	110	97	0.7
1980 (a)	101	87	0.9
Barton Hill			
1979	94	88	1.3
1980	67	59	1.1
Saxmundham			
1979	102	88	1.1
1980	102	90	0.8
1981	84	78	0.8

Table 3. Yields and N contents of winter barley given different amounts of N-fertilizer at three times at Rothamsted in 1979

N applied early (kg/ha) ...	60		90	
Division of early N				
February ...	30	0	30	0
March ...	30	60	60	90
N applied in April (kg/ha)	Yields of grain (t/ha at 85% D.M.)			
0	7.58	7.97	8.23	8.92
30	8.45	8.42	8.80	8.88
S.E.	0.206			
	% N in dry grain			
0	1.48	1.43	1.52	1.53
30	1.52	1.57	1.56	1.64
S.E.	0.034			
	N (kg/ha) in grain			
0	95	97	106	116
30	109	113	117	124
S.E.	3.2			

Table 4. Yields and N contents of winter barley given different amounts of N-fertilizer at three times in Expt (a) at Rothamsted in 1980

N (kg/ha) applied in		Timing of N in spring (March–April)		
January	Spring	All March	½ March; ½ April	All April
		Yields of grain (t/ha at 85% D.M.)		
0	75	7.93	8.16	8.07
35	75	7.89	7.95	8.38
0	110	8.22	8.29	8.53
35	110	7.99	8.48	8.80
	S.E.	0.247		
		% N in dry grain		
0	75	2.03	1.92	2.00
35	75	2.03	2.03	2.08
0	110	2.10	2.05	2.07
35	110	2.17	2.08	2.14
	S.E.	0.031		
		N (kg/ha) in grain		
0	75	137	133	138
35	75	136	137	148
0	110	147	144	150
35	110	148	150	160
	S.E.	4.8		

sowing in September instead of in October (993 v. 648/m<sup>2</sup>), but was not significantly changed by any other factor. Differences in the number of ears due to sowing date were diminished, but not eliminated, by applying N in February and by giving the larger of the two spring top-dressings. The number of

grains/m<sup>2</sup> (thousands) was significantly larger with September than October sowing (17.2 v. 15.0), and with the growth regulator rather than without (16.9 v. 15.3), and with 110 rather than 75 kg N/ha in spring (16.5 v. 15.7). In contrast to these benefits the weight (g) of 1000 dry grains was much smaller

Table 5. Yields of winter barley given by sowing in either September or October and by mildew fungicides applied in April or May in Expt (b) at Rothamsted in 1980

Tridemorph spray		Yields of grain (t/ha at 85% D.M.)	
		Sown September	Sown October
April	Without	10.91	8.83
	With	10.69	9.06
May	Without	11.24	10.05
	With	11.15	9.50
S.E.		0.303	

where the barley was sown in September rather than in October (41.2 v. 46.0), thus explaining, in part, the small increase in yield from the earlier sowing; the weight of 1000 grains was unaffected by any other factor.

In 1980 (Expt b), Appendix Table 1 gives mean yields at each level of each factor. Mean yield was much larger with September than with October sowing (11.00 v. 9.36 t/ha) and Table 5 shows that this effect was always significant. Of the fungicide treatments, only tridemorph sprays applied on 11 April had any significant effect, increasing average yield from 9.87 to 10.49 t/ha. The unusually large yields in this experiment may be partly because the whole of each plot was harvested, disregarding the edge effects of the surrounding paths (Widdowson, 1973).

Plants and ears were counted and the weight of 1000 dry grains determined. The number of plants established was similar in plots sown on either 14 September or 9 October 1979, but there were subsequently 16% fewer ears in the October-sown barley than in the September-sown. However, grain from the October-sown barley, with a 1000-grain weight of 43.6 g, was 10% heavier than that from the September-sown. Ethirimol, applied to the seed, decreased the number of plants by 10%, but this was probably because it affected the flow of seed through the corn-drill. It had no effect on the number of ears. However, tridemorph sprays applied on 11 April or 19 May significantly increased the number of ears by 7 and 6%, respectively.

#### Nitrogen contents of grain

In 1979, Table 3 shows that although %N differed little with division of fertilizer N, provided equivalent amounts were given, it was largest with 90 kg N/ha in March plus 30 kg N/ha in April. Amounts of N taken up in the grain were always

larger with single than with divided N dressings, because yields were larger, and were largest when N was applied in April. The growth regulator did not affect % N but, by increasing yield, consistently increased the amount removed in the grain, although not significantly.

In 1980 (Expt a), Percentage N in the grain was slightly larger with September than with October sowing (2.11 v. 2.01) and the amount of N removed significantly larger (149 v. 139 kg/ha). Table 4 shows that % N was always increased by extra fertilizer N, whether applied in February, March or April. Uptakes of N by the grain were smaller when N applied in February was supplemented by N applied in March than when supplemented by the same amount of N in April. Presumably this was because the N applied in early February or in early March mainly enhanced vegetative growth, whereas the N applied in April was largely used for grain production. The growth regulator made no difference to % N but significantly increased the amount of N removed in the grain, again because yield was increased.

#### The Barton Hill experiments

##### Crop height

In 1979, On average, increasing the amount of early N (i.e. that applied in February and March, or all in March) by 40 kg/ha increased the mean height of the barley by 5 cm. The same amount applied in April increased it by 6 cm. The growth regulator (Table 2) decreased mean crop height by 6 cm.

##### Leaf diseases

In 1979, The experiment was sampled on 14 June when growth stages differed between plots, but none was beyond Za 58, and there was little disease on the flag leaves. Mildew and brown rust (*Puccinia hordei*) were both very slight. In contrast, leaf blotch and Septoria (*S. nodorum*) were common, but because symptoms of the two diseases were sometimes difficult to distinguish they were assessed together. They were unaffected by tridemorph, but on the third-youngest leaves were decreased by carbendazim from 2.6 to 1.2%. Symptoms were more severe where early N was applied at 120 instead of 80 kg/ha (2.3 and 1.3%, respectively) and also where all of that N was applied in March instead of as a divided dressing in February and March (2.3 and 1.4%, respectively).

##### Yields of grain

Appendix Table 2 shows mean yield with each factor, and Table 6 shows in more detail how they were affected by amounts and timings of N. In both years there were large and significant increases

Table 6. Yields and N contents of winter barley given by different amounts of N-fertilizer applied at three times at Barton Hill in 1979 and 1980

Year ...	1979				1980			
	80		120		105		140	
N applied early (kg/ha) ...								
Division of early N								
February ...	40	0	40	0	35	0	35	0
March ...	40	80	80	120	70	105	105	140
N applied in April (kg/ha)	Yields of grain (t/ha at 85% D.M.)							
0	4.53	5.03	5.59	5.67	5.57	5.85	6.33	6.58
40*	5.55	5.82	6.04	6.20	6.37	6.71	6.83	7.07
s.e.	0.146				0.070			
	% N in dry grain							
0	1.45	1.52	1.59	1.64	1.53	1.76	1.71	1.71
40*	1.57	1.63	1.72	1.79	1.75	1.76	1.87	1.92
s.e.	0.032				0.028			
	N (kg/ha) in grain							
0	56	65	76	79	73	76	95	96
40*	74	81	89	95	95	100	108	115
s.e.	2.8				2.4			

\* 35 kg N/ha in 1980.

from applying the larger instead of the smaller amounts of N during February and March. Yield was always larger when these early dressings were applied as a single dose in March rather than divided between February and March. Additional N in April was also beneficial, and more so where the smaller rather than the larger amount of N had previously been applied. However, the largest yield was obtained where the larger of the early dressings of N had been applied as a single dose in March and then supplemented with a further though smaller top-dressing in April (Table 6). The growth regulator had little effect on yield at this site, in either year.

Appendix Table 2 shows that in 1979 carbendazim significantly increased mean yield, and Table 7 shows that its benefit was smallest (0.32 t/ha) with least, and largest (0.55 t/ha) with most N. In 1980 carbendazim again increased yield, but the benefit was small (from 0.03 to 0.16 t/ha). Tridemorph did not significantly increase yield in either year.

*Nitrogen contents of grain*

Table 6 shows that % N in the grain was nearly always significantly larger when N was applied in March instead of February and March, and also when extra N was applied in April, well illustrating the difficulty of enhancing yield without also increasing % N in grain, which is undesirable in a

crop intended for malting. Because both the yield of grain and % N increased as the application of N was delayed in spring so also did nitrogen uptake (Table 6). In both years the absolute differences between the largest and smallest uptakes by the grain were similar (39 kg N/ha in 1979 and 42 kg in 1980), but apparent percentage recoveries of the

Table 7. Yields of winter barley given different amounts of N-fertilizer in the absence and presence of carbendazim at Barton Hill and Saxmundham in 1979

N applied in April (kg/ha) ...	N applied early (kg/ha)			
	80		120	
	0	40	0	40
	Yields of grain (t/ha at 85% D.M.)			
	Barton Hill			
Without	4.62	5.52	5.41	5.85
With	4.94	5.85	5.85	6.40
s.e.	0.130			
	Saxmundham			
Without	5.82	6.57	6.35	6.85
With	6.02	6.71	6.98	7.11
s.e.	0.180			

Table 8. *Yields and N contents of winter barley given by different amounts of N-fertilizer applied at three times at Saxmundham in 1979 and 1980*

Year ...	1979				1980			
N applied early (kg/ha) ...	80		120		105		140	
Division of early N								
February ...	40	0	40	0	35	0	35	0
March ...	40	80	80	120	70	105	105	140
N applied in April (kg/ha)	Yields of grain (t/ha at 85% D.M.)							
0	5.95	5.90	6.90	6.43	7.81	7.78	8.19	8.48
40*	6.56	6.72	7.17	6.79	8.31	8.64	8.43	8.64
S.E.	0.215				0.059			
	% N in dry grain							
0	1.89	1.90	2.03	2.05	1.84	1.84	2.00	2.05
40*	2.03	2.06	2.14	2.18	2.01	2.02	2.19	2.17
S.E.	0.036				0.021			
	N (kg/ha) in grain							
0	96	95	119	112	122	122	139	148
40*	112	118	130	125	142	148	157	159
S.E.	3.2				2.1			

\* 35 kg N/ha in 1980.

extra N applied (80 kg/ha in 1979, 70 kg in 1980) were very different (48% in 1979 and 60% in 1980).

#### *The Saxmundham experiments*

##### *Crop height*

*In 1979.* As at Barton Hill, the height of the barley was increased by applying an extra 40 kg N/ha either early (+4 cm) or in April (+5 cm in plots that had not been sprayed with the growth regulator). The barley was also taller (+3 cm) where the early N was applied as a divided dressing in February and March than where it was applied as a single dressing in March. The growth regulator (Table 2) decreased crop height by 14 cm.

*In 1980.* The height of the barley was slightly increased (+3 cm) by applying the early N at 140 instead of 105 kg/ha but was not significantly affected by applying 35 kg N/ha in April. It was decreased by 12 cm by the growth regulator (Table 2).

*In 1981.* The height of the barley was little affected by amount of N but was increased (+5 cm) by applying it partly in February and partly in April, instead of all in April. It was decreased by 6 cm by the growth regulator (Table 2).

##### *Leaf diseases*

*In 1979.* The Saxmundham experiment was sampled on 13 June, one day earlier than the Barton Hill experiment, but growth was much

more advanced (Za 71-73). Mildew was only slight but was decreased by tridemorph (from 0.6 to 0.1% on second-youngest leaves) and, to a lesser extent, by carbendazim (from 0.4 to 0.2%). It was most severe (1.4%) where most N, but no fungicide, had been applied. Brown rust was even less severe, averaging only 0.1% on second youngest leaves. There was, however, much leaf necrosis that could not be attributed to any one pathogen and seemed to be caused by a complex of species, some possibly encouraged by pollen that had fallen on to the leaves from the ears. Limited observations showed that the species present included *Pyrenophora teres*, *Septoria nodorum* and *Botrytis* sp. Total areas affected by these symptoms, which on second-youngest leaves averaged 1.8%, were not affected by either of the fungicide treatments. Although diseases on the uppermost leaves were not severe, both fungicides greatly increased survival of green tissue. Thus on third-youngest leaves green leaf areas were increased from 21.9 to 31.9% by carbendazim and from 17.1 to 38.8% by tridemorph.

##### *Yields of grain*

*In 1979 and 1980.* Appendix Table 2 gives mean yield with each factor. Table 8 shows that the larger amount of early N increased yield each year. Timing of the early N gave contrasting results in the 2 years. In 1979 there was a response to dividing the early N where the larger amount was

Table 9. Yields and N contents of winter barley given different amounts of N-fertilizer applied at different times in the absence and presence of disease and aphid control at Saxmundham in 1981

	N applied (kg/ha)				
	0	40	0	40	0
In February ...	0	40	0	40	0
In April ...	0	80	120	120	160
Disease and aphid control	Yields of grain (t/ha at 85% D.M.)				
Without	3.18	5.87	5.72	6.84	6.18
With	3.54	6.54	6.51	7.09	6.63
S.E.	0.327	0.231			
	% N in dry grain				
Without	1.34	1.52	1.59	1.70	1.72
With	1.32	1.58	1.59	1.69	1.69
S.E.	0.042	0.030			
	N (kg/ha) in grain				
Without	36.4	76.1	77.0	98.7	90.2
With	39.9	87.8	88.1	101.7	95.2
S.E.	4.38	3.10			

given, and yield was further increased by giving an additional 40 kg N/ha in April (to 7.17 t/ha). In 1980, by contrast, the early N was best withheld until March and either amount then plus the additional N in April gave the largest yield (8.64 t/ha).

The growth regulator again decreased the height of the barley straw (Table 2) and increased yield, significantly so in 1980 (Appendix Table 2). In 1979 its effect was greater when the early N was applied as a single rather than as a divided dressing (0.35 v. 0.06 t/ha) and in 1980 was greater with the larger than with the smaller amount of early N (0.39 v. 0.07 t).

Appendix Table 2 shows that in 1979 carbendazim increased yield by 0.30 t/ha, and Table 7 shows that its effect was larger with the larger amount of early N; in 1980 it had no effect on grain yield. In both years tridemorph increased mean yield only slightly but interacted with N amount. Thus it substantially increased yield when the larger amount of early N was followed by further N in April (by 0.36 t/ha in 1979 and by 0.44 t in 1980).

In 1981, Appendix Table 1 shows that fewer factors were tested than previously. Mean yield was larger where the N was divided between February and April rather than where it was given as a single dressing in April, but the benefit occurred only when the larger amount of N was tested (Table 9).

The growth regulator again decreased the height of the barley straw (Table 2) but, in contrast to the previous 2 years, it unexpectedly decreased grain yield (Appendix Table 1) and especially of barley grown with the larger amount of N.

Appendix Table 1 also shows that there was a mean increase of more than 0.5 t/ha from combined disease and aphid control but, unexpectedly, the benefit from this treatment was greater with the smaller than with the larger amount of N (Table 9).

#### Nitrogen contents of grain

In 1979 and 1980, Table 8 shows that % N in grain increased as the amount of N applied was increased, and also as the time of application was delayed in spring. Because division of N affected yield more than it did % N, uptakes of N followed the same pattern as yields. As at Barton Hill, the absolute differences between the largest and smallest uptakes were similar in the 2 years (34 kg N/ha in 1979 and 37 kg in 1980). The apparent percentage recovery by the grain of the extra N applied was 43% in 1979 and 54% in 1980.

In 1981, Table 9 shows that percentages of N differed little with division of applied N or with disease and aphid control. Uptake of N, however, was greater when the larger amount of N was divided, and also with disease and aphid control, because these treatments increased grain yield.

#### DISCUSSION

By 1978, when these experiments began, winter barley had already replaced much of the spring barley in some areas, mainly because it usually gave a much larger yield, particularly when wet weather delayed sowing of the spring crop. The

principal object of these experiments was to determine the time in spring when nitrogen fertilizer was best applied to winter barley. However, winter barley is more susceptible to lodging than is spring barley, so we also examined the benefits of a growth regulator, both through its effects on straw length and lodging and its effects on the components of yield.

Early-sown winter barley tillers freely during autumn and winter and in early spring its foliage often becomes yellow, a symptom associated with severe nitrogen deficiency. Furthermore, winter barley ripens 3–4 weeks earlier than winter wheat sown at the same time, so it seemed possible that winter barley would require nitrogen much earlier in spring than does winter wheat. Measurements of the concentration of  $\text{NO}_3\text{-N}$  in sap, expressed from the shoots of young barley plants sampled from our experiments during February, confirmed that those exhibiting the characteristic yellow symptoms were suffering from nitrogen deficiency. Plants on plots given 40 kg N/ha during February soon became green, and were evidently no longer restrained by shortage of nitrogen, while those on untreated plots remained yellow. It therefore seemed that some nitrogen was needed early in these circumstances. However, the design of most of the experiments allowed comparisons to be made between the same amount of nitrogen applied at one, two or three times in spring, and, in spite of yellowing and low sap- $\text{NO}_3$  concentrations in February, N applied in April was usually more effective in terms of increasing grain yield and N recovery than N applied in either February or March. Thus our results suggest that although a small dose of N may be justified during February the bulk of the N is not justified until late March or, as for wheat, is best withheld until early April. This result is in broad agreement with that of Whitear (1982), who found that the time at which N was applied during March and April was not critical, but that earlier dressings of N, although they increased leaf growth, seldom gave a larger grain yield.

The growth regulator was applied at the beginning of stem extension, i.e. at the 1- to 2-node stage in spring (Za 31–32). It demonstrably reduced the height of the crop and reduced the severity of lodging. However, the increases in grain yield which it gave could not always be ascribed to decreased lodging, so evidently there was some other cause. Apparently the growth regulator, by shortening the internodal length of the straw, not only increased the standing ability of the crop but also changed the distribution of photosynthate within the plant. Thus at Rothamsted in 1980 it increased the number of grains per ear, without changing the weight of individual grains, and so increased yield

by increasing the number of grains harvested per unit area.

In the one year when it was tested (1980), sowing in September rather than October enhanced yield, but less strikingly in the experiment with the 2-row variety Sonja than the relative growth of the two sowings had suggested. The two experiments (a) and (b) in the same field suggested that the benefit of early sowing was greater for the higher-yielding 6-row variety Hoppel, a result that we cannot explain but which agrees with those of Knopp (1985). Green, Furnston & Ivins (1985), who found that the yield of the 2-row variety Igri was greatest when sown in mid-September during 1981–3, showed that the increased yield was related to a larger number of grains per unit area, as was ours at Rothamsted in 1980.

The one experiment at Rothamsted which tested fungicides used the variety Hoppel, which is especially susceptible to powdery mildew. Although detailed disease data are not available for that experiment, mildew was prevalent during the winter months, but by mid-April had become difficult to find. In spite of this, a single spray of tridemorph on 11 April increased grain yield by 0.62 t/ha. Responses to tridemorph at Barton Hill were small in both 1979 and 1980. Although Maris Otter, the variety used in both experiments, is susceptible to mildew, the disease was only slight in 1979, so the small response to tridemorph in that year was not unexpected. However, Maris Otter is also very susceptible to leaf blotch, which was not controlled by tridemorph, and this may also help to explain the poor responses. By contrast, carbendazim did increase yield, and especially in 1979. In that year carbendazim was applied on 14 May, which was probably too late to be most effective against eyespot. However, it did decrease leaf blotch in that year and this probably explains, in part, the yield increases that were obtained. At Saxmundham the variety used in 1979 and 1980 was Sonja, which is less susceptible than Maris Otter to both mildew and leaf blotch. Yields were increased by tridemorph in both of these experiments, but only where most N was applied, a result that correlates with the observed effects of N on mildew in 1979. Furthermore, although mildew in 1979 was only slight, effects of tridemorph on survival of green tissue on the lower leaves were relatively large. Carbendazim similarly increased green leaf area in 1979, and this probably contributed to the yield response to this fungicide that was obtained in that year.

The experiments described in this paper served the preliminary purpose of defining the relative importance of several agronomic practices in determining the yield of winter barley. They produced yields larger than those commonly obtained with

spring barley, but smaller than those obtained with winter wheat in multidisciplinary experiments at Rothamsted (Prew *et al.* 1983). The results obtained from both sets of experiments were subsequently used to determine which factors should be tested in multidisciplinary experiments with winter barley which followed (Widdowson *et al.* 1986).

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Appendix Table 1. Mean yields of grain (t/ha at 85% D.M.) at each level of each factor at Rothamsted in 1979 and 1980 and at Saxmundham in 1981

Year ...	Rothamsted			1980 (b)			Saxmundham		
	1979	1980 (a)		1980 (b)			1981		
N applied early (kg/ha)		Sowing date		Sowing date		N applied in spring (kg/ha)			
60	8-38	18 Sept.	8-33	14 Sept.	11-00	120	6-16		
90	8-82	16 Oct.	8-12	9 Oct.	9-36	160	6-68		
S.E.	0-084	S.E.	0-100	S.E.	0-151	S.E.	0-115		
Timing of early N		N applied in February (kg/ha)		Mildew fungicide in autumn		Timing of spring N			
February-March	8-49	0	8-20	None	10-21	February-April	6-59		
All in March	8-72	35	8-25	Ethirimol to seed	10-03	All in April	6-26		
S.E.	0-084	S.E.	0-100	Tridemorph spray	10-29	S.E.	0-115		
				S.E.	0-185				
N applied in April (kg/ha)		N applied in spring (kg/ha)		Mildew fungicide in April		Growth regulator ('Terpal')			
0	8-17	75	8-06	None	9-87	Without	6-49		
30	8-64	110	8-39	Tridemorph	10-49	With	6-36		
S.E.	0-103	S.E.	0-100	S.E.	0-151	S.E.	0-115		
Growth regulator ('Terpal')		Timing of spring N		Mildew fungicide in May		Disease and aphid control			
Without	8-64	All in March	8-01	None	10-26	Without	6-15		
With	8-99	‡ March; † April	8-22	Tridemorph	10-10	With	6-69		
S.E.	0-103	All in April	8-45	S.E.	0-123	S.E.	0-115		
		Growth regulator ('Terpal')							
		Without	7-82						
		With	8-63						
		S.E.	0-100						

Appendix Table 2. *Mean yields of grain (t/ha at 85% D.M.) at each level of each factor at Barton Hill and Saxmundham in 1979 and 1980*

Year ...	Barton Hill		Saxmundham		
	1979	1980	1979	1980	
<b>N applied early (kg/ha)</b>					
1979	1980				
80	105	5.23	6.27	6.28	8.27
120	140	5.87	6.80	6.82	8.50
s.e.		0.053	0.028	0.050	0.024
<b>Timing of early N</b>					
February–March		5.43	6.40	6.64	8.34
All in March		5.68	6.67	6.46	8.53
s.e.		0.053	0.028	0.050	0.024
<b>N applied in April (kg/ha)</b>					
1979	1980				
0	0	5.20	6.08	6.29	8.06
40	35	5.90	6.75	6.81	8.51
s.e.		0.075	0.035	0.141	0.030
<b>Growth regulator ('Terpal')</b>					
Without		5.50	6.75	6.45	8.51
With		5.61	6.78	6.65	8.74
s.e.		0.075	0.035	0.141	0.030
<b>Eyespot fungicide (carbendazim)</b>					
Without		5.35	6.49	6.40	8.41
With		5.76	6.58	6.70	8.46
s.e.		0.070	0.052	0.087	0.064
<b>Mildew fungicide (tridemorph)</b>					
Without		5.53	6.50	6.53	8.38
With		5.58	6.57	6.57	8.49
s.e.		0.070	0.028	0.087	0.024