ROTHAMSTED RESEARCH

Report for 1981 - Part 1

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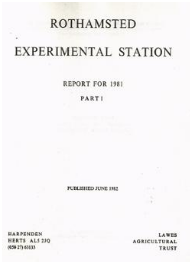
ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1981

PART 1

Report on Multidisciplinary Activities

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MULTIDISCIPLINARY ACTIVITIES

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Factors limiting yield of winter wheat

The multifactorial experiment reported here is the third in the series, located on a new site (Little Hoos), following early potatoes to minimise soil-borne disease and to release the site for early sowing. The same eight factors (Table 1) were tested as in 1979–80 (*Rothamsted Report for 1980*, Part 1, 17–23) and in addition this year an experiment was done at Woburn following those done in 1976 and 1979 (*Rothamsted Report for 1976*, Part 1, 32–33, and *for 1979*, Part 1, 22–25), aimed at improving our understanding of the causes of yield differences between Rothamsted and Woburn soils. The Rothamsted site was on clay with flints and the Woburn on light sandy loam.

(a) Rothamsted site

Yield at maturity. Grain yields were slightly smaller than in the 2 previous years. The mean over all plots was 8·3 t ha^{-1} and only five plots exceeded 10 t ha^{-1}. The largest increase in yield was caused by applying fungicide (Table 1). The benefit was even greater with earlier sowing, the larger amount of nitrogen, later application of nitrogen (at the high rate) and with the autumn pesticide (on early-sown plots). With the most sensitive combination of treatments, fungicide increased yield by one-third, 2·7 t ha^{-1}. Most of the effect of fungicide was on grain size, with a 5% increase in number of grains per spikelet and also a small increase in ear number when nitrogen was applied late. Aldicarb increased the yield of the early-sown crop by 0·6 t ha^{-1} but only when fungicide was also applied. Pirimicarb had no effect. Earlier sowing increased yield by 0·9 t ha^{-1} when fungal leaf diseases and barley yellow dwarf virus (BYDV) were controlled: it increased grain size but decreased ear number. Grain yield was decreased by the larger amount of nitrogen in the absence of fungicide but unaffected in its presence. Additional nitrogen always increased ear number and decreased grain size. Altering the date or number of nitrogen applications had some small inconsistent effects on grain yield and its components. Irrigation decreased yield by decreasing grain size and increased straw

TABLE 1

Factors tested and their effects on grain yield (t ha^{-1}) of Hustler winter wheat. Means over all other factors

Level 1	Yield	Level 2	Yield
(1) Sown early (E), 15 September	8·38	Sown later (L), 30 October	8·19
(2) Nitrogen rate, 80 kg ha^{-1}	8·45	Nitrogen rate 2, 150 kg ha^{-1}	8·12
(3) Nitrogen single application	8·28	Nitrogen split application, 40 kg early, 20 kg late, remainder at time of single application	8·29
(4) Timing of single nitrogen Ear initiation early-sown (19 March)	8·21	Timing of single nitrogen Ear initiation later-sown (23 April)	8·36
(5) Irrigation (125 mm) Soil moisture deficit limited to 37 mm	8·09	None	8·49
(6) Autumn pesticide—aldicarb Applied to seedbed 5 kg ha^{-1}	8·39	None	8·19
(7) Summer aphicide—pirimicarb	8·26	None	8·31
(8) Fungicides 'Cosmic'* + 'Sanspor'†) 4 kg ha^{-1} + 2·0 l ha^{-1} (13 May, 10 June, 30 June)	9·12	None	7·45

* 'Cosmic', a.i. maneb + tridemorph + carbendazim
† 'Sanspor', a.i. captafol

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weight by an equivalent amount. Straw weight was also increased by fungicide, earlier sowing and additional nitrogen. The results of individual sponsors' sampling are reported below. (Thorne, Botany Department; Dewar, Entomology Department; Williams, Nematology Department; Lacey, Plumb and Prew, Plant Pathology Department; Penny, Soils and Plant Nutrition Department, and Church and Todd, Statistics Department)

Growth and development. The experiment was sampled seven times (Table 2). The number of plants established in both sowings was 240 m^{-2}. The effects of sowing date on tillering, development and growth were similar to those in the previous year (*Rothamsted Report for 1980*, Part 1, 18–19) except that maximum shoot numbers were smaller and tiller survival better.

TABLE 2

Change with time in total dry weight ($g\ m^{-2}$), leaf area index, number of shoots m^{-2} and Zadoks growth stage of winter wheat sown on 15 September (E) or 30 October (L). Means over all other treatments

	Sowing date	8 December	16 March	22 April	6 May (E) 20 May (L)	16 June (E) 29 June (L)	6 August (E) 13 August (L)	21 August
Total dry weight	E	38	148	420	441	1140	1609	1740
	L	2	29	185	368	1021	1505	1620
Leaf area index	E	0·57	1·9	5·0	5·7	9·3	1·9	0
	L	0·02	0·5	2·7	6·6	8·2	1·1	0
Number of shoots	E	846	1283	899	766	587	527	526
	L	269	892	1066	786	574	540	546
Growth stage (GS)	E	15/22	18/24*	32	32	64	86	92
	L	11	14/23	30*	33	66	86	92

* 'Double ridge' (ear initiation stage)

The effects of fungicide were first evident at anthesis, when dry weight and leaf area were increased by up to 15%, especially with the later application of nitrogen. After anthesis, fungicide delayed leaf senescence and greatly increased the growth of ears and stems, especially on plots sown early and given the larger amount of nitrogen. Aldicarb applied to the seed bed increased the dry weight and leaf area of the early-sown crop at the first four samplings by between 12 and 24%. No such effect was detected again until maturity when total dry weight of the early-sown crop was 4% greater with than without aldicarb. The crop sown later was never affected by aldicarb. Pirimicarb never affected growth.

The effects of the nitrogen treatments can be understood by examining them in the crops that received fungicide. Increasing the amount of nitrogen applied from 80 to 150 kg N ha^{-1} increased shoot number, dry weight and leaf area in May by between 9 and 22%. Thereafter the difference decreased to give a small increase in ear number and straw dry weight at maturity. Applying the nitrogen early instead of late gave more shoots and greater dry weight and leaf area up to anthesis. Later, the difference in shoot number disappeared and that in dry weight reversed so that the dry weight at maturity was 0·8 t ha^{-1} greater with later than with early nitrogen. Immediately after the first application of the divided nitrogen treatment, crops grew faster than those that had not yet received nitrogen. Any difference between crops given the divided and single applications of nitrogen disappeared soon after the main application.

Irrigation (125 mm) was applied between 25 June and 21 July. The maximum deficit

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reached on the unirrigated plots was only 85 mm. Irrigation delayed leaf senescence, though less than did fungicide or more nitrogen, did not affect total dry weight, but increased the proportion retained in the stem. (Thorne and Taylor, Botany Department)

Nitrogen contents

***Early* v. *later sowing*.** On 8 December early-sown wheat contained 4·24% N, the later-sown 3·58%; by 16 March respective values had increased to 4·77 and 5·73% but afterwards declined. N concentration continued to be larger in the later-sown until May, but by anthesis differences were small and the grain of the early- and later-sown wheat contained 1·88 and 1·85% N respectively. On 2 February the early-sown wheat contained 830 ppm of NO_3-N in the sap of the lower parts of the stems, the later-sown 650 ppm. On 16 March, in wheat yet to be given N, values had decreased to 760 ppm in the early-sown but had increased to 990 ppm in the later-sown; on 22 April respective values had dropped to 120 and 180 ppm, and on 20 May, without N fertiliser, neither sowing contained NO_3-N. Uptakes of N by the early-sown in March (71 kg ha^{-1}) were four times larger than by the later sown and in April (129 kg) 80% larger: by anthesis uptakes were 183 and 156 kg ha^{-1} and by early August, 200 and 183 kg respectively. On 21 August grain plus straw contained about the same amount of N as the whole crop did in early August and the combine-harvested grain of the early- and later-sown plots contained 133 and 129 kg N ha^{-1} respectively.

***Split* v. *single and early* v. *late N*.** Application of 40 kg N ha^{-1} on 2 February significantly increased %N and N uptake on 16 March (from 65 to 86 kg ha^{-1}) by the early-sown wheat but did not affect the later-sown. Application of 40 kg N on 19 March significantly increased %N in both sowings on 22 April and increased N uptake from 97 to 114 kg ha^{-1} by the early-sown and from 48 to 65 kg ha^{-1} by the later-sown. At this stage %N and N uptake were larger from a single N dressing (on 19 March) than from two parts of the split dressing (2 February and 19 March) but significantly so only for the later sowing. In May, neither %N nor uptake of N differed with division of N fertiliser even though the last part of the split application had still to be given. At the same time %N tended to be larger with N applied late but uptakes were larger with N applied early because yields were larger. On 20 May there was still much NO_3-N in the stem sap of wheat given N. From anthesis, when single and split amounts were comparable, neither %N nor uptake of N by the early-sown wheat differed with division of N fertiliser. In the later-sown, both values were significantly larger at anthesis with a single N dressing but, by August, division of N fertiliser made no difference. Neither at anthesis nor in early August did time of applying N significantly affect %N or uptake of N (by either sowing) but, in the mature grain, %N tended to be larger and uptakes of N were significantly larger with N applied late.

Nitrogen rates. At anthesis and later, %N and N uptake were always significantly larger with 150 than with 80 kg N ha^{-1}. By early August the early-sown wheat had taken up 215 and 185 kg ha^{-1} respectively with the two amounts of N, and the later-sown 210 and 156 kg; corresponding uptakes by the combine-harvested grain were about 70% as large. The significant interaction between fungicides and amounts of N on grain yield was reflected in N uptakes (Table 3). (Penny, Widdowson, Darby and Hewitt, Soils and Plant Nutrition Department)

Nematodes. Soil samples were taken on three occasions (Table 4) and in June root samples also, for nematode estimations. Numbers in roots were small and therefore estimates of soil populations only are given.

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TABLE 3

Effects of amounts of N and fungicides (F with, −without) on amount of N taken up by winter wheat grain

	80 kg N ha^{-1}		150 kg N ha^{-1}	
	−	F	−	F
	N uptake, kg ha^{-1}, by grain			
Sown early	119	135	123	154
Sown late	118	130	122	145

SE of a difference ± 2·8

Fungicides used, *see* footnote to Table 1

TABLE 4

Effects of aldicarb (A with, −without) on plant parasitic nematodes (numbers per litre of soil). Means over all other treatments

Date sampled	*Pratylenchus* spp.		*Tylenchus* spp.		*Tylenchorhynchus* spp.		*Helicotylenchus/Rotylenchus* spp.		Total spear-bearing nematodes	
8 September 1980	400		425		250		1200		2350	
	A	−	A	−	A	−	A	−	A	−
1 June 1981	103	256	291	513	241	756	388	1078	1303	3203
28 August 1981	188	603	569	674	438	1206	1319	3966	2750	6803

Species most commonly occurring were *Pratylenchus neglectus*, *Tylenchorhynchus dubius*, *Helicotylenchus vulgaris* and *H. varicaudatus*. Cereal cyst nematodes (*Heterodera avenae*), *Longidorus* spp. and *Xiphinema* spp. were not found.

Aldicarb significantly decreased numbers of the principal parasitic genera until June but by harvest numbers had mostly reached or exceeded those before treatment. In untreated plots, numbers of some genera increased considerably, those of *Helicotylenchus* and *Pratylenchus* spp. achieving the largest numbers encountered in these experiments. There were indications that plant establishment and spring growth of the early-sown crop were improved by aldicarb suggesting that nematodes were involved. Because aldicarb controlled barley yellow dwarf virus (BYDV) as well as decreasing nematode numbers, apportionment of the yield increase from the treatment between the two is not possible, but in the light of present knowledge it seems probable that control of BYDV (see next section) accounts for most of the increase. However, the increase occurred only in early-sown plots which also received fungicide (Table 5). (Williams and Beane, Nematology Department)

TABLE 5

The effect of sowing date, aldicarb (A with, −without) and fungicide treatments on yield (t ha^{-1}) of winter wheat

	Sowing date	−	A	% difference	SED
No fungicide	15 September	7·34	7·28	−0·8	0·135
	30 October	7·50	7·69	+2·5	
Fungicides	15 September	9·16	9·74	+6·3	0·135
	30 October	8·76	8·82	+0·7	

Fungicides used, *see* footnote to Table 1

Barley yellow dwarf virus (BYDV). In autumn 1980 *Rhopalosiphum* spp. were common and 7·4% transmitted BYDV to test plants; for the first time a few infective *Sitobion* spp.

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were also caught. It was expected, therefore, that infection by BYDV, especially on early-sown plots, would be more widespread than in previous years. The mild winter probably aided aphid survival and virus spread and although not as common as at Woburn (see p. 10) more BYDV was seen at Rothamsted in 1981 than for many years. Symptoms appeared in mid-May and by the end of June reached 10% in some plots with patches up to several metres across, but with little stunting. On 23 June there was three times as much infection on early- as on late-sown plots but it was apparent that infection had spread from early-sown plots to adjacent ones sown later.

No accurate assessment of virus symptoms was possible after June. The often poor and inconspicuous expression of symptoms of BYDV in wheat coupled with the 3–4 week interval between infection and appearance of symptoms, suggests that final virus incidence may have been twice that recorded in June. However, the absence of any effect of the aphicide pirimicarb (applied on 23 June) suggests that there was little damaging virus spread after this date.

Aldicarb was very effective in controlling BYDV in early-sown plots, even in those adjacent to untreated ones with up to 10% infection, but had no significant effect on infection in plots sown late.

Tests of the vector specificity of the BYDV isolates in both early- and late-sown plots showed that the most efficient vector was *S. avenae: Metopolophium dirhodum* and *M. festucae* transmitted the virus relatively efficiently and *R. padi* was the least efficient. It is interesting that 1980 was the first year that infective *S. avenae* had been detected in the autumn. While difficult to interpret, these results do suggest that although all aphid species commonly found in cereal crops could transmit the prevalent virus isolate, the species usually most common in summer, *S. avenae* and *M. dirhodum*, were the most likely to have spread BYDV in 1981 and had their numbers not declined rapidly after mid-May (see next section) virus damage could have been more serious. (Plumb and Lennon, Plant Pathology Department)

Aphids. Migrations of *R. padi* and *S. avenae* were larger than normal in September of 1980, but unfavourable weather in October resulted in only small numbers of *R. padi* and no *S. avenae* being caught in the suction trap at Rothamsted after the 2 October. During the winter, aphids were present only in early-sown plots not treated with aldicarb. Vacuum samples showed that total numbers (3 m^{-2} on 3 November; 1·5 m^{-2} on 9 December) were about the same as in the previous autumn but this year *S. avenae* outnumbered *R. padi*. Numbers remained relatively stable until the onset of mild weather, when they increased dramatically up to 10 m^{-2} on 13 January and 12 m^{-2} on 11 February when *R. padi* was the most abundant species and small numbers of *M. festucae* were also recorded. Numbers continued to increase in the early-sown plots through the spring (16 m^{-2} on 16 March; 89 m^{-2} on 13 April), with *S. avenae* and *M. festucae* becoming the dominant species and *R. padi* declining.

In early May alates of *S. avenae* and *M. festucae* were present in the late-sown crops also. Numbers of aphids peaked in mid-May and then declined markedly, so that when pirimicarb was applied on 23 June there were few aphids in any of the plots and pirimicarb had no effect on grain yield. This decline was caused by a combination of parasitism and *Entomophthora* infection in the aphid colonies. (Dewar, Entomology Department)

Weeds. The spring herbicide ('Brittox' (a.i. bromoxynil+ioxynil+mecoprop) at 3·5 litres ha^{-1}) in a tank mix with a growth regulator (chlormequat chloride as '5C Cycocel' at 3·5 litres ha^{-1}) was applied to the early- and late-sown crops at growth stage 30 (3 April, 1 May respectively). The main weed was cleavers (*Galium aparine*) which was

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well controlled in the early-sown crop but in the later-sown, control differed with nitrogen treatments (Table 6).

TABLE 6

Effects of amounts and timing of nitrogen on the control of cleavers (Galium aparine) *in the later-sown crop*

		Early N				Later N			
kg N ha^{-1} applied	2 February	40	—	40	—				
	19 March	90	150	20	80	40	—	40	—
	23 April	20	—	20	—	90	150	20	80
Cleavers infestation*		3·3	2·9	1·3	2·4	0·9	0·1	1·4	0·3

* Visual score: 0=none, 10=very severe

Fungal diseases. Early in the season, mildew was prevalent on the lower leaves and more so on the later- than the early-sown (4·8 and 0·9% area infected leaf two on 13 April). The infection never became severe, the maximum on the topmost leaf being 2%. The larger rate of N increased mildew and crops with N applied early had more mildew in April and May but less in June and July than those with N applied later. As in previous years, *Septoria* was the most damaging pathogen and was prevalent on the flag leaf from early July onwards, though fungicide sprays contained the infection well (Table 7). Early sowing and the larger rate of N both increased the incidence of *Septoria* and also of yellow rust, which was present in small amounts late in the season. One focus of black stem rust was also found. Eyespot was the only foot rot present in significant amounts and was increased by early sowing and the lower rate of N; the fungicide sprays, although not timed for eyespot control, greatly decreased infection (Table 7). (Prew, Plant Pathology Department)

TABLE 7

The effect of sowing date, nitrogen rate and fungicide on the incidence of fungal diseases on winter wheat

		Septoria (% leaf area infected) 8 June leaf 3	8 July leaf 1	20 July leaf 1	4 August leaf 1	Eyespot (% straws infected) 8 August
Sown	early	6·6	2·4	14·7	40·9	26
	later	0·3	0·1	0·6	11·9	14
Nitrogen (kg ha^{-1})	80	2·8	0·7	5·6	23·9	25
	150	4·1	1·7	9·7	29·0	14
Fungicides	full	2·9	0·3	1·1	1·5	10
	none	3·9	2·1	14·3	51·4	30

Fungicides used, *see* footnote to Table 1

Microflora of developing ears. Pink and white yeasts together with the yeast-like fungi, *Aureobasidium pullulans* and *Hyalodendron* sp., were the dominant fungal flora up to GS 75 after which filamentous fungi became predominant (Table 8). The major fungi in this group were *Cladosporium* spp., *Verticillium lecanii*, *Alternaria alternata*, *Fusarium culmorum* and *Acremoniella atra*. Other fungi isolated included *Epicoccum purpurascens*, *Arthrinium*, *Botrytis*, *Trichoderma* spp. and *F. avenaceum*. At harvest, *Cladosporium* was isolated from 70% of plated grains, *Alternaria* from 69%, *F. culmorum* 26%, *Acremoniella* 19% and *Arthrinium* 18%. Storage fungi were represented by *Penicillium* spp. (mainly *P. cyclopium* and *P. brevicompactum*) on 14% of grains and *Aspergillus* spp. on fewer than 1%.

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TABLE 8

The effect of fungicide (F with, – without) on the microflora of developing ears of winter wheat assessed by dilution plating. Means over 16 plots

Growth stage (GS)	12 June 57		26 June 69		2 July 70		17 July 75		31 July 83		14 August 92	
	–	F	–	F	–	F	–	F	–	F	–	F
	(No. of colonies, g^{-1} fresh weight × 10^4)											
Yeasts	0·49	0·14	9·56	2·06	19·70	6·58	90·69	43·24	30·12	19·41	47·0	12·4
Yeast-like fungi	0·17	0·09	1·61	0·75	1·93	0·94	20·24	12·66	16·11	16·32	45·8	36·5
Filamentous fungi	0·06	0·04	0·33	0·44	1·31	0·36	32·35	11·50	35·71	27·52	152·3	238·5
Bacteria	2978	2368	344	8198	352	311	1507	510	336	109	16708	21116

Fungicides used, *see* footnote to Table 1

The late application of fungicide at GS 57 caused a significant decrease in fungal populations for 3 weeks, until the second late fungicide was applied at GS 70, after which 4 weeks elapsed before fungal populations reached numbers similar to those found on untreated plots. These decreases were mainly due to the significant effect of fungicides on yeasts, yeast-like fungi and *Cladosporium* spp.: *Alternaria alternata* and *Verticillium lecanii* were unaffected. (Magan and Lacey, Plant Pathology Department)

(b) Growth and yield of winter wheat on contrasting soils: Rothamsted and Woburn

Thirty-two plots of an experiment on Butt Close at Woburn were given the same treatments, in a half replicate of a 2^6 design, as the 32 plots of the Factors Limiting Yield of Winter Wheat experiment at Rothamsted that received both fungicide and summer aphicide treatment (Table 1, Treatments 1–6), except that the rates of nitrogen fertiliser were increased by 70 kg ha^{-1} to span the optimum application rate for the lighter soil. Six extra plots sown on each of the two sowing dates were given a range of N dressings from 0 to 255 kg ha^{-1} to confirm the optimum rates. Eight extra plots sown in September were used to test urea equivalent to 40 kg N ha^{-1} and dicyandiamide nitrification inhibitor given in all combinations on 10 December 1980 or 3 February 1981. Four extra plots sown in October were used in conjunction with two early-sown N-scale plots to study root growth and activity of the crop with high inputs of other factors. The Woburn experiment was sown with cv. Hustler on 16 September or 31 October, the days following the corresponding sowings at Rothamsted. Operations thereafter were carried out essentially in the same way and at the same times as for the Rothamsted experiment. The samplings and observations made on the crop and soil closely paralleled those on the Rothamsted experiment, except that after April the crop was sampled when it reached the appropriate stage of growth, which was in some instances a few days earlier than at Rothamsted. Irrigation was based on long-term estimates of water loss from crops, modified in the light of measurements of actual soil water content with neutron moderation meters. It was first given on 10 June, when the measured soil water deficit was approximately 35 mm. On unirrigated plots the deficit was 69 mm on 19 June and 82 mm on 25 June, about the time of anthesis for September and October sown wheat respectively. On this soil such deficits were expected to begin to affect growth. It then increased to a maximum of 115 mm on 16 July and remained near that level until 30 July. The deficit on irrigated plots was kept below 40 mm by frequent water applications of not more than 10 mm.

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Yields at maturity. Generally Woburn results are compared with those from all the fungicide-treated plots at Rothamsted, where summer aphicide, which was applied basally at Woburn, had no significant effect. The mean Woburn yields of September and October sown wheat were 9·4 and 7·8 t ha^{-1} respectively, compared with 9·5 and 8·8 t ha^{-1} at Rothamsted. At Woburn aldicarb and irrigation had the largest main effects and with these treatments combined, September-sown crop averaged 10·4 t ha^{-1}. With this sowing the later timing of N application also gave an advantage: the mean yield of plots with aldicarb given this treatment was 10·5 t ha^{-1}. The best yields at Rothamsted from this sowing with aldicarb and no irrigation (which had a negative effect) averaged 9·9 t ha^{-1} (eight plots), or 10·1 t ha^{-1} if only the later time of N application is considered. This was the first time that winter wheat yields as good as the heaviest at Rothamsted had been produced on the light land at Woburn.

TABLE 9

The effect of six factors on grain yield (t ha^{-1}) of Hustler winter wheat at Rothamsted and Woburn in 1981. Means over all other treatments. Differences in parentheses

Factor tested	Farm: Rothamsted	Farm: Woburn
(1) Sowing date		
15/16 September	9·45	9·40
30/31 October	8·79 (−0·66)	7·84 (−1·56)
(2) Total N kg ha^{-1}		
(R) 80 (W) 150	9·15	8·43
(R)150 (W) 220	9·09 (−0·06)	8·81 (+0·38)
(3) N Division		
Single	9·18	8·38
Divided	9·07 (−0·11)	8·86 (+0·48)
(4) N Time		
Early	9·03	8·70
Late	9·21 (+0·18)	8·54 (−0·16)
(5) Irrigation		
None	9·28	8·25
Full	8·96 (−0·32)	8·99 (+0·74)
(6) Aldicarb (5 kg ha^{-1}) to seedbed		
Without	8·96	8·23
With	9·28 (+0·32)	9·01 (+0·78)

Note: Rothamsted means are for plots with fungicides (cf. Table 1)

Table 9 shows the yield of grain from each of the six two-level factors tested on the two soils, meaned over all other factors. Sowing the wheat in September eliminated most of the difference between the soils except for responses to irrigation and aldicarb but the October sowing demonstrated a real difference between them: comparisons of the effect of each factor on the two soils shows that the effect of every one was greater at Woburn than at Rothamsted.

Data presented by the Soils and Plant Nutrition Department (p. 250) show that there was much less N available to the Woburn crop during winter and spring probably as a result of leaching. This explains why N given in December or February increased growth and tiller production at Woburn but not at Rothamsted and why more fertiliser N was required at Woburn to achieve the same level of yield.

Aldicarb increased yield, especially of the September sowing, more at Woburn than at Rothamsted, probably reflecting the more severe attack of barley yellow dwarf virus at Woburn: the response was greater with later N and in the absence of irrigation. Grain yield was decreased by irrigation at Rothamsted but, as expected in view of the small

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water-holding capacity of the soil, it was increased at Woburn though the mean effect was no greater than that of aldicarb. Details of water usage by the two crops is given in the Soils and Plant Nutrition Department report (p. 248).

Components of yield. Components of grain yield results showed that the greater yield of September- than October-sown wheat came from more ears m^{-2}: a smaller number of spikelets per ear was offset by more grains per spikelet. The effect of irrigation was mainly on 1000 grain weight (increased from 38·9 to 41·3 g). Aldicarb increased 1000 grain weight from 39·0 to 41·2 g and grains per spikelet from 2·2 to 2·3.

Growth of the crop. The crop was a little denser than that at Rothamsted but not significantly so, 249 and 295 plants m^{-2} in autumn from early and late sowings respectively, compared with 240 m^{-2} for both sowings at Rothamsted. By 10 December, September-sown crop had 1071 shoots m^{-2}, compared with 846 at Rothamsted, shoot dry matter (DM) of 48·8 g m^{-2}, compared with 37·5, and leaf area index (LAI) of 0·59, compared with 0·57. October-sown crop with 2·5 g m^{-2} shoot dry matter and LAI of 0·022 was very similar to that at Rothamsted. During winter, growth and tillering were less than at Rothamsted and indeed some tillers seem to have died before the application of the first instalment of divided N dressings in early February. When sampled on 12 March the September sowing yielded 72 g DM from 915 shoots m^{-2} with a LAI of 0·81; corresponding Rothamsted values were 148 g, 1283 shoots and LAI 1·92. The October sowing at Woburn had 20 g DM m^{-2} with 652 shoots m^{-2} and LAI 0·37; Rothamsted values were 29 g, 892 shoots and LAI 0·52. However, 40 kg N as urea given in December increased the yield of Woburn September-sown wheat to 123 g DM m^{-2} with 1177 shoots m^{-2} and LAI 1·52, suggesting that inadequate N supply from the soil was a major cause of poorer winter growth on that soil. This is also suggested by large responses at Woburn at both this and the next sampling to initial 40 kg N ha^{-1} instalments of divided N fertiliser dressings given 6 weeks previously, compared with the relatively smaller responses at Rothamsted.

At sampling on 21 April the differences in DM yield, shoot number and LAI between Woburn and Rothamsted wheat had not increased on plots given their main N dressing in March, although Woburn wheat had suffered further where the main N dressing had still not been given. By the following sampling, 5 May for September-sown, 19 May for October-sown crop, differences in DM yield between Woburn and Rothamsted were small where the main N was applied in March and this was also true for shoot numbers and LAI when the N was given as a single dressing. However, where the main N was applied in late April DM yields at Woburn averaged 244 g m^{-2} compared with 385 g at Rothamsted and the difference was greater with the single application. Similar differences occurred in shoot numbers and LAI, all supporting the conclusion that poor ability of the Woburn soil to supply mineral N was a major cause of inferior crop development during the vegetative stage of growth.

At anthesis the effects of site difference on DM yield of crop given later N dressings persisted (981 g m^{-2} at Woburn cf. 1097 g), although little difference remained with earlier N timing (1078 g m^{-2} cf. 1097 g). Shoot numbers from September sowings were 586 m^{-2} on both sites, but the October sowing had only 475 m^{-2} at Woburn compared with 570 at Rothamsted. LAI averaged 8·0 at Woburn (9·1 at Rothamsted) and was less at Woburn for most treatment combinations, but still above the level of 6 or 7 needed for full use of the incident radiation, apart from some October-sown plots given inferior aldicarb, irrigation or N fertiliser treatments. At this stage aldicarb greatly increased LAI at Woburn, which was otherwise affected by barley yellow dwarf virus. This had also begun to affect dry matter yield of September-sown crop. Irrigation at a soil moisture

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deficit of 35 mm started at Woburn on 10 June and just significantly increased yield from 1005 to 1054 g DM m^{-2} at anthesis.

It is interesting that at this stage of growth extra plots given urea averaged 636 shoots m^{-2}, yielding 1213 g DM and with LAI 10·3. These were comparable with the best factorial treatment combinations and the urea-treated plots at Rothamsted. (Welbank and Taylor, Botany Department, and Widdowson, Penny, Darby and Hewitt, Soils and Plant Nutrition Department)

Nitrogen taken up by the wheat. Dry matter yields were obtained and N uptake calculated on six occasions. At Woburn, early-sown wheat always removed more N than late-sown, so that on 10 December there was 15·6 kg N ha^{-1} in tops and 1·9 in surface roots compared with only 2·6 and 1·1 respectively in the later-sown. At anthesis uptakes were 155 (early) and 115 (late) and at harvest 178 and 139. Thus early-sown wheat made better use of both soil N in autumn and fertiliser N in spring. Aldicarb increased N uptake by 14 and irrigation by 29 kg N ha^{-1} and late N was used more efficiently than early.

Comparisons between Rothamsted and Woburn show that uptakes of N (kg ha^{-1}) in December were similar but that by mid-March those at Rothamsted were very much larger, 70·8 *v.* 26·8 for the September and 16·4 *v.* 9·1 for the October sowings. Comparable uptakes at anthesis on the two soils were 183 *v.* 155 for the early and 156 *v.* 115 for the later sowings. These differences were maintained until harvest when the early-sown Rothamsted crop removed 198 and that at Woburn 178. Comparable values from the October sowings were 181 and 139. Thus early sowing diminished differences in uptake, but the wheat at Rothamsted still removed more, presumably because the soil was richer in N, even though mean yields of grain were the same and more fertiliser N was applied at Woburn. (Widdowson, Penny, Darby and Hewitt, Soils and Plant Nutrition Department)

NO_3-N in wheat stems. As at Rothamsted, NO_3-N content of stems (ppm of DM) was determined each time soils were sampled for N content and subsequently to measure effects of soil and fertiliser N. On 12 December, September-sown wheat at Woburn contained 536 ppm NO_3-N and at Rothamsted, 880. By 2 February the paucity of NO_3-N in Woburn soil was reflected by the crop content of 292 ppm (833 ppm at Rothamsted) and on 22 April the figures were 33 and 121 respectively. October-sown wheat contained 521 ppm on 2 February, declining to 304 on 13 March and to nil on 22 April at Woburn. Comparable figures for Rothamsted were 646, 986 and 177 ppm. Additions of fertiliser N greatly increased NO_3-N contents of the wheat at both sites. (Widdowson, Williams and Darby, Soils and Plant Nutrition Department)

Barley yellow dwarf virus (BYDV). Infection, which was more widespread and severe than at Rothamsted, was assessed on 2 and 22 June. On the latter date symptoms were more difficult to score but there had been little increase in disease from the previous sampling except in late-sown plots not treated with aldicarb.

Plots sown early had much more infection (mean 9%) than those sown late (mean 2%), but the biggest effect was given by aldicarb. Whether sown early or late, plots treated with aldicarb had negligible infection ($<0·2$%) whereas early- and late-sown untreated plots had 33 and 5% infection respectively, much of the latter resulting from spread from contiguous early-sown plots.

Meaned over all other treatments aldicarb increased yield by 0·78 t ha^{-1} (9·5%) but more on early sown plots (1·25 t ha^{-1}, 14·3%), than on those sown late (0·32 t ha^{-1}, 4·2%). It is not certain that these increases were due solely to virus control, as aldicarb will also have restricted nematode damage. However, as approximately a third of the

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early-sown crop was infected and BYDV can cause up to 50% loss of yield in wheat, it seems likely that most of the yield increase was indeed due to virus control.

Aphid transmission tests of virus isolates from both early- and late-sown plots showed that, as at Rothamsted, *S. avenae* was the most efficient vector but *R. padi*, *M. dirhodum* and *M. festucae* were also vectors. (Plumb, Plant Pathology Department)

Factors limiting yield of winter barley

The experiment on winter barley, reported last year (*Rothamsted Report for 1980*, Part 1, 23–24) was repeated, with additional tests of autumn pesticide (aldicarb *v.* none) and of fungicides applied either in autumn ('Baytan' seed treatment, a.i. triadimenol+fuberidazole *v.* none) or in spring and summer ('Sportak' sprays, a.i. prochloraz *v.* none), in all combinations with the four previous tests in 1980, viz. sowing date (17 September *v.* 30 October); amounts of nitrogen (90 *v.* 140 kg ha^{-1}); timings of nitrogen (18 March *v.* 13 April); and growth regulator ('Terpal', a.i. mepiquat chloride+ethephon *v.* none). The seven factors were tested in factorial combination (2^7) using a half-replicate design of 64 plots, arranged in two blocks of 32 plots. There were two extra plots which did not receive any treatment.

The barley, cv. Igri, followed early potatoes and so the soil was rich in NO_3-N. On 3 October (emergence of the first sowing) there were 124 kg N ha^{-1} to 90 cm (NO_3-N) and on 26 November (emergence of the second sowing) 96 kg N ha^{-1}. Soil N declined steadily under the barley sown in September until none was measurable on 13 April. By contrast soil N increased slightly under the later sown barley until 4 March (116 kg N ha^{-1}) and then decreased rapidly until 13 April (36 kg N ha^{-1}), when sampling ceased. Of this 36 kg N, 29 kg was present in the 60–90 cm soil horizon, reflecting the shallower root system of the later-sown crop. (Widdowson, Darby and Bird, Soils and Plant Nutrition Department)

Growth and development. On 14 October there were 221 plants m^{-2} on early-sown and on 15 December 203 plants m^{-2} on the late-sown plots, Aldicarb slightly increased and seed treatment slightly decreased plant numbers. On 15 December typical plants from the early sowing had five to six fully expanded main-stem leaves and four to five tillers; the apex was at the late double ridge stage. The later sowing had no tillers and two to three leaves.

Subsequently, destructive samples were taken for dry weight and plant and shoot number estimates on four occasions (Table 10). After winter, there were slightly fewer

TABLE 10

Changes with time in total dry weight (g m^{-2}), numbers of plants and shoots (m^{-2}), of winter barley sown on 17 September (E) or 30 October (L). Means over all other treatments

		Sampling date				
		14 October (E) 15 December (L)	4 March	13 April	18 May (E) 1 June (L)	1 August
Total dry weight	E	—	100	303	784	1294
	L	—	16	102	717	1142
Number of plants	E	221	194	193	—	—
	L	203	199	162	—	—
Number of shoots	E	—	1442	1614	1009	—
	L	—	398	1269	733	—

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plants from both sowings, but the early-sown had tillered more (7·4 *v.* 2·1 shoots per plant). Aldicarb slightly increased and seed treatment slightly decreased shoot number, especially of the later sowing. At ear emergence there were many more ear-bearing shoots from the September than from the October sowing. Relative to this, other factors had only small effects on ear number. However, fungicide sprays, increased N, and April rather than March N, all increased ear numbers in October-sown barley.

On 3 June the growth regulator applied at GS 31 on 15 April for the early sowing and 7 May for the later sowing had decreased straw length (to base of ear) from 104 to 100 cm and from 95 to 92 cm, respectively. The barley lodged before harvest and some of the September-sown plots were attacked by sparrows and grain lost. (Widdowson, Penny, Darby and Hewitt, Soils and Plant Nutrition Department)

Yields at harvest. The data in Table 11 have been adjusted to allow for sparrow damage. However, they show that four of the factors had positive and one had negative effects, on both September and October sowings, so that comparisons between sowing dates appear to be valid. Effects were usually larger on the September-sown crop. All treatments except seed treatment increased yields on both sowings and so the factors tested were demonstrably limiting yield. However, only aldicarb, fungicide sprays and April N increased yield significantly and only of the September sowing. (Widdowson, Soils and Plant Nutrition Department; Jenkyn and Plumb, Plant Pathology Department; Lawlor, Botany Department, and Ross, Statistics Department)

TABLE 11

The effects of six factors on grain yield (t ha⁻¹) of Igri winter barley, sown on 17 September or 30 October 1980. Means over all other treatments. (Unadjusted yields in parentheses)

	Sowing date	
	17 September	30 October
(1) Aldicarb (5 kg ha^{-1}) to seedbed		
Without	7·27 (6·87)	6·92 (7·39)
With	7·92 (7·40)	7·10 (7·55)
(2) Seed treatment ('Baytan')*		
Without	7·79 (7·57)	7·08 (7·54)
With	7·40 (6·70)	6·94 (7·40)
(3) Fungicide sprays ('Sportak')† in spring and summer		
Without	7·31 (6·82)	6·91 (7·36)
With	7·88 (7·45)	7·12 (7·58)
(4) Growth regulator (Terpal')‡		
Without	7·49 (6·93)	6·85 (7·30)
With	7·69 (7·34)	7·18 (7·64)
(5) Nitrogen amount (kg ha^{-1})		
90	7·56 (7·05)	7·09 (7·56)
140	7·63 (7·22)	6·94 (7·38)
(6) Nitrogen timing		
18 March	7·22 (6·90)	6·89 (7·34)
13 April	7·97 (7·37)	7·14 (7·60)

* 'Baytan', a.i. triadimenol + fuberidazole
† 'Sportak', a.i. prochloraz
‡ 'Terpal', a.i. mepiquat chloride + ethephon

Fungal leaf disease. The principal leaf disease in this experiment was powdery mildew (*Erysiphe graminis* f.sp. *hordei*). Early-sown plants were infected soon after they emerged and by 24 October areas affected on first seedling leaves from plots which had not received 'Baytan' seed treatment averaged 3·9%. In treated plots the disease was decreased to 0·1%. Conditions continued to favour mildew after seedlings in the late-sown plots

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had emerged so that by early February they also were severely diseased where not protected by seed treatment (40·9 and 34·0% on second youngest leaves from early- and late-sown plots, respectively). There was very much less mildew in all treated plots but significantly more in early-sown than in late-sown (1·0 and 0·1%, respectively, on second youngest leaves). In early April, mildew seemed little affected by sowing date but was decreased similarly by seed treatment and by one spray of prochloraz applied on 16 February (from 4.9 in untreated plots to 1·0 and 1·3%, respectively, on second youngest leaves). By contrast, mildew in mid-May was much less severe in early-sown plots than in late-sown (0·1 and 2·2%, respectively, on second youngest leaves from plots given no fungicide). It was also increased by applying more nitrogen. Seed treatment was still providing some control of mildew in the late-sown plots but seemed no longer effective in the early-sown. Leaf diseases were finally assessed at about GS 75–77 (23 and 29 June, respectively, for early- and late-sown plots). On these dates also mildew was less severe in early-sown plots than in late-sown but 'Baytan' was no longer having any detectable effect. The disease was, however, decreased by the prochloraz sprays; from 10·9 to 3·9% on second youngest leaves from early-sown plots and from 23·7 to 10·1% on those from late-sown plots. It was increased by extra nitrogen and by later N.

Net blotch (*Pyrenophora teres*) was also common but never severe. The early-sown barley showed symptoms soon after emergence, averaging 0·5% on first seedling leaves on 24 October, when disease seemed to be decreased by 'Baytan'. However this may have reflected slightly delayed growth in treated plots, especially as there was no measurable effect of seed treatment in early February. At this time the disease was more severe in early-sown plots than in late-sown (1·9 and 0·2%, respectively, on second youngest leaves) but this difference had disappeared by early April. The one prochloraz spray, that had been applied by that date decreased disease from 0·8 to 0·2% on second youngest leaves. By mid-May, net blotch was even less severe but there was then less on the early-sown barley than on the late-sown and at the final assessment in late June areas affected on second youngest leaves from early- and late-sown plots not sprayed with prochloraz averaged 1·5 and 4·3%, respectively. On this date the disease was decreased by prochloraz but increased by extra nitrogen. It was also increased by 'Baytan', the average areas affected on second youngest leaves sampled from all untreated and 'Baytan'-treated plots being 0·8 and 2·8%, respectively. Corresponding values from plots not sprayed with prochloraz were 1·3 and 4·8%, respectively.

Leaf blotch (*Rhynchosporium secalis*) also occurred but never became severe. Brown rust (*Puccinia hordei*), which developed during June, was apparently increased by the prochloraz sprays but this may reflect the increased areas of susceptible tissue available for infection as a result of mildew control.

(The data reported in this section were analysed using a logit transformation and the quoted percentage values were obtained by back transformation.) (Jenkyn, Plant Pathology Department)

Aphids. Vacuum samples showed that aphids, including *S. avenae*, *R. padi* and a few *M. festucae*, were abundant at the beginning of November in early-sown plots not treated with aldicarb (Table 12). A few that were present in treated plots had disappeared by 9 December. Numbers remained large on early-sown untreated plots during November and December but declined in January and February, in contrast to those in wheat, possibly as a result of winter-kill of the outer leaves of the barley plants on which many of the aphids may have been feeding. By March numbers had declined still further. Only one or two aphids were recorded in the late-sown plots throughout the winter. These occurred only on untreated plots and probably originated from the adjacent early-sown plots. (Dewar, Entomology Department)

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TABLE 12

The effect of sowing date and aldicarb (A with, – without) on aphid numbers m^{-2} on winter barley. Means over all other treatments

Sowing Date	September		October	
Sampling date	–	A	–	A
3 November	5·8	1·2	–	–
9 December	3·0	0	–	–
13 January	4·1	–	–	–
11 February	3·7	–	0·05	–
16 March	1·0	–	0	–

Barley yellow dwarf virus (BYDV). Symptoms of BYDV first appeared in April and subsequently patches of infected crop developed. There was much more infection in early- than in late-sown crops when assessed on 12 May and where aldicarb had been used infection was negligible. However, by June while early-sown plots still had much more infection (mean 4%) than those sown late (<0·2%) the difference between aldicarb treated (1·3%) and untreated (2·8%) was less. Aldicarb approximately halved infection on both early-sown (5·4–2·5%) and late-sown (0·2–0·07%) plots. There was an almost ten-fold increase in virus incidence from 12 May to 23 June, much of it probably due to the development of symptoms in plants infected in the autumn or early winter. However, some virus may have been spread in spring by aphids that survived the winter in the crop. The aphids *R. padi* and *S. avenae* were seen on the crop but numbers were small.

Tests of aphid transmission of virus isolates from the experiment showed that, as at other sites at Rothamsted and Woburn this year, *S. avenae*, *R. padi*, *M. dirhodum* and *M. festucae* were all vectors but *S. avenae* was the most efficient.

When meaned over all other treatments aldicarb increased yield by 0·41 t ha^{-1} (5·8%) but it had a much greater effect on early-sown plots (+0·65 t ha^{-1} or 8·9%) than on those sown late (+0·18 t ha^{-1} or 2·6%). It is not certain that these increases were due solely to control of BYDV but yield increases of this order are certainly compatible with virus control, although they would suggest that virus infection had been underestimated; lodging and fungal leaf diseases later in growth may have masked later-developing symptoms. (Plumb, Plant Pathology Department)

Winter and spring field beans (*Vicia faba L.*): effects of pests and pathogens

Last year we reported the start of a series of simple experiments on spring beans designed to assess the contribution of pests and pathogens to seasonal variation of yields (*Rothamsted Report for 1980*, Part 1, 26–29). This series was continued on a new site and a further series was started on winter beans.

As in 1980 we compared standard practice with sets of treatments likely to give economic responses and with sets of treatments expected to give the best available control. The sets differed according to the crop.

For winter beans standard practice was foliar sprays of benomyl (0·56 kg ha^{-1}) on 5 May and 3 June plus pirimicarb (0·14 kg ha^{-1}) on 29 June. 'Economic' control included these sprays plus a seed treatment of benomyl and thiram (at 2·0 g of each per kg of seed), a foliar spray of fosetyl-Al (3·3 kg ha^{-1}) on 16 December and carbofuran (2·2 kg ha^{-1}) as granules on 6 April. 'Full' control included all these treatments plus aldicarb (10 kg ha^{-1}) worked into the seedbed and additional foliar sprays of fosetyl-Al (3·3 kg ha^{-1}) on 17 February and benomyl (0·56 kg ha^{-1}) on 16 December, 3 February, 27 March and 29 June. The treatments were arranged in six blocks of three plots.

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For spring beans standard practice was foliar sprays of pirimicarb (0·14 kg ha^{-1}) on 3 June and 28 July. 'Economic' control included these sprays plus phorate (2·2 kg ha^{-1}) combine drilled with the seed and a foliar spray of benomyl (0·56 kg ha^{-1}) on 11 August. 'Full' control included the foliar sprays of the other treatments plus aldicarb (10 kg ha^{-1}) worked into the seedbed, a foliar spray of fosetyl-Al (2·2 kg ha^{-1}) on 23 April and an additional benomyl spray (0·56 kg ha^{-1}) on 28 July. A test of irrigation was also included, to lessen soil moisture deficits of 50–25 mm before pod set, and 80–55 mm thereafter. The treatments were arranged in four blocks of two plots, for irrigation, split into three subplots for chemical treatments.

TABLE 13

Effects of irrigation and control of pests and pathogens on grain yield of beans (t ha^{-1})

	Pest and pathogen control		
	'Standard'	'Economic'	'Full'
Spring beans			
Unirrigated	3·9	4·5	4·6
Irrigated	4·7	5·0	5·0
SED ±0·12 (±0·10 within a level of irrigation)			
Winter beans			
Unirrigated	2·9	4·5	4·8
SED ±0·20			

Grain yields (Table 13) of both winter and spring beans were significantly increased by 'economic' control but were not further increased by 'full' control. Irrigation increased spring bean yields on average by 0·5 t ha^{-1}. (Bardner and Fletcher, Entomology Department; McEwen and Yeoman, Field Experiments Section; Webb, Nematology Department; W. Day, Physics Department, and Bainbridge, Cockbain and Salt, Plant Pathology Department)

Results from sponsors' sampling are reported briefly below.

The season and plant growth. Both experiments were sown at Rothamsted; the winter bean cv. Throws M.S. on 30 September 1980, the spring bean cv. Minden on 20 February 1981. They were harvested on 1 September and 8 September respectively. From October until the end of February the weather was generally drier, warmer and sunnier than average. March and April were wet and warm; above average rainfall continued in May, with a brief dry period in June and early July, but both temperature and sunshine were below average in this period. August started wet and warm but became dry, warm and sunny in the second half of the month.

Winter bean establishment was considerably improved by the benomyl+thiram seed treatment which increased plant population in mid-December from 27 to about 40 m^{-2}. Severe chocolate spot damage occurred in late February and early March on plots not given the seed treatment and many plants were destroyed; 'economic' control, given the seed treatment only by this time, survived despite some damage, 'full' control which had by this time received two sprays of benomyl in addition to the seed treatment was little damaged. By harvest stem counts from 'standard', 'economic' and 'full' were 12, 35 and 47 m^{-2} respectively. Both 'economic' and 'full' treatments lodged in July after strong winds. Total above-ground dry matter, measured on 27 July, was 7·1 t ha^{-1} from 'standard', and was increased by 4·8 and 7·3 t by 'economic' and 'full' respectively.

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Spring beans established well with a plant count in mid-April of 44 m^{-2} without significant effects of treatment. Irrigation was required only in the first half of July when a total of 50 mm was applied. Total above-ground dry matter, measured on 17 August, was 7·6 t ha^{-1} from the unirrigated 'standard' treatment. The mean effect of irrigation was an increase of 1·4 t and the mean effects of 'economic' and 'full' were increases of 0·1 and 1·8 t respectively. (McEwen and Yeoman, Field Experiments Section)

Weevils (*Sitona lineatus*). Leaf notching (adult feeding damage) was assessed on winter beans on 13 May and showed 8·5 notches per leaflet on 'standard' control, lessened to 0·1 notches for both 'economic' and 'full'. On 8 July numbers of weevil larvae on the roots were 20, 0·9 and 0·3 for 'standard' 'economic' and 'full' respectively.

Spring beans had 4·1 notches per leaflet on 'standard' on 1 June, lessened to 0·4 by 'economic' and 1·3 by 'full' control. On 7 July 'standard' plots had a mean larval count of 5·8 per root lessened to 0·1 by 'economic' and 4·5 by 'full'. (Bardner and Fletcher, Entomology Department)

Viruses and vectors. The pea aphid, *Acyrthosiphon pisum*, was rare on both winter and spring beans before and during flowering. At the end of flowering of winter bean the incidence of bean leaf roll virus ranged from 0·5 to 2·0% for 'standard' and 0·0 to 0·5% for 'economic' and 'full'; corresponding results for pea enation mosaic virus were 1·0–3·0% and 0·0–0·5% respectively. The incidence of aphid-borne viruses in spring beans after flowering was less than 0·5% with no treatment effects. Although the parent spring bean crop in 1980 had 30% infection with the nematode- and seed-borne pea early browning virus none was found this year. (Cockbain, Plant Pathology Department)

Foliar fungi. On winter beans chocolate spot (*Botrytis fabae*) became aggressive on 'standard' plots during late February and by mid-April, on surviving plants, 81% of the lower leaf area was affected by spreading lesions (Table 14). At this date the seed treatment had still afforded some protection and 'economic' plots had only 49% of lower leaf area affected by spreading lesions; benomyl sprays applied to 'full' plots had further lessened this to 17%. Thereafter conditions were less favourable to the spread of this disease and by 1 June only 1% of the area of the lowermost leaves of 'standard' plots had spreading lesions. This was less than in the other treatments probably because the fewer plants on 'standard' allowed better penetration both of the benomyl spray on 5 May and of wind, leading to decreased humidity and hence less favourable conditions for disease development. (Bainbridge, Plant Pathology Department)

TABLE 14

Effects of control of pests and pathogens on percentage of lower leaf area of winter beans affected by aggressive chocolate spot lesions

	Pest and pathogen control			
Assessment date	'Standard'	'Economic'	'Full'	SED
11 February	8	2	6	± 3·0
23 March	72	42	43	±11·0
14 April	81	49	17	± 9·1
11 May	6	6	4	± 1·7
1 June	1	5	9	± 1·2

On each date the stem length which still retained leaves was divided into upper, middle and lower thirds. Figures presented are from the lower third

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On spring beans chocolate spot although prevalent did not become aggressive. Rust (*Uromyces fabae*) developed rapidly in August: it was not controlled by benomyl and by the end of August all plots were almost completely defoliated. It is generally believed that late rust infections are unimportant but this may not be true for crops with an increased yield potential as a result of controlling pests and other pathogens. (Salt, Plant Pathology Department)

Root fungi. In mid-February winter bean roots were very healthy, white and well branched; disease rating averaged less than 2% for tap root and laterals. Early in June the disease rating of lateral roots had reached 24% in 'standard' plots and was decreased by 'economic' and 'full' to 15 and 10% respectively. Disease ratings on tap roots were similar. By the end of July roots were still only moderately discoloured and the disease rating for laterals was 56% for 'standard', 48% for 'economic' and 42% for 'full' control, with tap-roots about 10% less. Root discolouration was associated with the presence of *Fusarium* spp. (*F. oxysporum*, *F. solani*). *Phytophthora megasperma* and *Aphanomyces euteiches* were not found and *Pythium* spp. were not prevalent so the reductions in disease ratings were unlikely to be due to fosetyl-Al sprays applied in autumn and spring but may have resulted indirectly from the use of benomyl+thiram seed treatment and its control of aggressive chocolate spot.

The amounts of root-rot on 'standard' plots of spring beans in early June and late July were very similar to the amounts on winter beans in this treatment but 'economic' and 'full' treatments had no effect. Thus, the mean disease ratings on lateral roots in the 'standard', 'economic' and 'full' treatments were 29, 30 and 25% respectively early in June and 56, 51 and 53% late in July, irrigation having no effect.

Spring bean seed was not treated and chocolate spot was not serious, so these results tend to support the suggestion that seed treatment of winter beans reduced root-rot indirectly, through control of aggressive chocolate spot. (Salt, Plant Pathology Department)

Nematodes. Plant parasitic nematodes were numerous on both winter and spring beans. *Pratylenchus* spp. predominated and reached 163 g^{-1} of fresh root weight on winter beans in February with a preponderance (57%) of the very damaging *P. penetrans*, a species not previously recorded at Rothamsted. The other two species found on winter beans, *P. neglectus* (31%) and *P. crenatus* (12%) cause little damage. Numbers of *Pratylenchus* were not significantly lessened by the aldicarb in 'full' control, although numbers of non-parasitic nematodes were.

On spring beans numbers of *Pratylenchus* reached 148 g^{-1} of fresh root weight in June, mainly *P. neglectus* (63%) with smaller numbers of the more damaging species *P. thornei* (19%) and *P. pinguicaudatus* (18%). Unlike previous years, aldicarb did not control these nematodes, probably because the material was leached by the unusually heavy spring rainfall. Phorate on 'economic' plots lessened total numbers of *Pratylenchus* in June to 55 g^{-1} of fresh root weight. (Webb, Nematology Department)

Effects of irrigation on spring beans. The dry spell in June and early July led to a maximum potential soil moisture deficit of 103 mm. Irrigation, totalling 50 mm, gave an extra 0·5 t ha^{-1} grain, with no significant interaction with pest and pathogen control. French and Legg (*Journal of Agricultural Science, Cambridge* (1979), **92**, 15–37) have reported that the limiting deficit for spring beans at Rothamsted is about 80 mm, and from their results we calculate that a maximum deficit 23 mm greater than the limiting deficit would give a yield loss of about 9%—comparing well with the observed 11% loss this year. (W. Day, Physics Department)

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Economics of treatments. The 'economic' treatment on winter beans gave a yield increase over 'standard' of 1·6 t ha^{-1} (worth £240 at current prices) but had an increased materials cost of £245. Our results suggest that the extra yield was a result of controlling early chocolate spot by the benomyl + thiram seed treatment (cost £20 ha^{-1}) and *Sitona* larvae by carbofuran granules (£110 ha^{-1}). If ancillary experiments show that, as for spring beans, the much cheaper phorate granules (£18 ha^{-1}) are almost as effective as carbofuran, the combination of seed treatment and granules would be very profitable. The 'full' treatment cost a further £700 ha^{-1}, largely for aldicarb, but despite giving a substantial increase in total dry matter in July, it did not significantly increase grain yield, probably because relatively more was lost from lodging.

The 'economic' treatment on spring beans cost £36 ha^{-1} and gave an increased yield over 'standard' of 0·6 t ha^{-1} (worth £90) on the unirrigated crop and 0·3 t ha^{-1} (worth £45) on the irrigated crop. Because viruses were rare and effects of treatments on root-rots were slight the benefits of 'economic' are attributed to the control of *Sitona* larvae and *Pratylenchus* spp. achieved by the phorate and the improved leaf efficiency from the single spray of benomyl. 'Full' control cost £615 ha^{-1} more than 'economic' but gave no further yield increase. Aldicarb, which hitherto has given excellent pest control, this year failed to control both *Sitona* larvae and *Pratylenchus* spp.—probably because of leaching associated with much early rain. A computer simulation (Briggs, CLU and Nicholls, Insecticides and Fungicides Department) suggested that by the end of March all the phorate would have remained in the top 10 cm of soil whereas none of the aldicarb would have been in this layer, most being below 20 cm. It is therefore surprising that 'full' control gave yields equal to 'economic': possible explanations are control of unrecognised seedling pests by aldicarb before leaching and greater leaf efficiency from the two benomyl sprays included in this treatment. The severity of the attack by rust, irrespective of treatment may have contributed to yields smaller than those in previous experiments.

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