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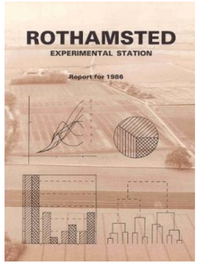
Full Table of Content



Multidisciplinary Agronomy

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MULTIDISCIPLINARY AGRONOMY

Multidisciplinary field experiments were continued on winter barley, winter oilseed rape, winter wheat and potatoes. On barley and rape the experiments were designed to study the effects and interactions of a wide range of factors on growth and yield. One of the wheat experiments tested sowing dates and times of applying nitrogen, the others continued investigations into straw incorporation. The experiment on intensive potato growing began a sequence of three years' test cropping following four preparatory years. The work on straw incorporation was extended to an off-station site in a new experiment, initially in winter barley, which has heavier, wetter soil than is available on our farms.

Factors limiting yield of winter barley

The second series of experiments, begun in 1984 (*Rothamsted Report for 1984*, 28–32), was concluded with an experiment on a new site which again allowed comparisons between three crop sequences, (1) barley–barley–barley, (2) barley–oats–barley, and (3) barley–fallow–barley. In the first sequence, the seven factors shown in Table 1 were tested in factorial combinations (2^7) using a half replicate design. Additional plots allowed the second and third cropping sequences to be compared with the first, over a restricted set of treatments; all were sown with a two-row winter barley (Panda). Further additional plots, in sequences (1) and (2) only, were sown with a six-row winter barley (Pirate). These 80 plots, plus four of Panda that did not receive any nitrogen fertilizer, were arranged in two blocks of 42 plots.

Nitrogen in the soil. The experiment was in a field which had grown arable crops every year since 1974, following eight years of grass. On 21 October, soon after crop emergence, the soil after cereals contained 88 kg NO_3-N ha^{-1} to a depth of 90 cm. By 16 December, most of this NO_3-N had been removed, leaving only 28 kg ha^{-1} in plots that had not been given 'winter' N. During the same time the amount in the top 30 cm declined from 59 to 10 kg ha^{-1}, presumably reflecting uptake by the barley. By 4 February the amount of NO_3-N had declined to only 18 kg ha^{-1} in the whole profile; most of the loss was from the 30 to 60 cm horizon.

'Winter' N, as urea, was applied at 30 kg ha^{-1} on 27 November and again on 10 March. Effects were monitored by measuring NO_3-N concentrations in stem sap at fortnightly intervals. On 14 November there were 625 μg NO_3-N ml^{-1} in the sap. By 12 December the concentration was unchanged where urea had not been applied but had increased to 917 μg ml^{-1} where it had. Thereafter concentrations rose to a maximum of 1000 μg NO_3-N ml^{-1} on 23 December in plots with urea and 875 μg ml^{-1} on 13 January in those without. Although concentrations subsequently declined, they were always larger where urea had been applied than where it had not and on 11 April, just before the spring N was applied, averaged 133 and 4 μg ml^{-1}, respectively. Applying 'winter' N delayed the date when the nitrogen deficiency threshold of 200 μg ml^{-1} was reached, from 19 March to 25 March. (Darby and Widdowson, Soils and Plant Nutrition)

Development and tillering. Seed supply was delayed and the experiment was not sown until 2 October 1985, about two weeks later than in the previous two years. Dry weather further delayed germination and hence development. Thus the double-ridge stage was not reached until about mid-January, approximately six weeks later than in the previous two years. The maximum spikelet/awn primordium stage was reached on 24 April (14 and 23 days later than in 1984 and 1985, respectively) and anthesis on 13 June (21 and 12 days later, respectively). Most treatments had little effect on development but Panda grown after oats or after fallow matured four days later than Panda after barley.

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TABLE 1

The effects of seven factors on the number of ears on 2 June and on the grain yield (t ha^{-1}) of Panda winter barley

	Ears m^{-2}	Grain yield
(1) Seeds sown m^{-2}		
300	1025	5·90
450	1113	5·98
(2) Seed treatment ('Baytan')*		
Without	1068	5·80
With	1069	6·08
(3) Winter nitrogen (60 kg N ha^{-1} as urea)		
Without	1109	6·02
With	1028	5·86
(4) Early growth regulator†		
Without	1047	5.94
With	1091	5.94
(5) Fungicide sprays‡ in spring and summer		
Without	1065	5.51
With	1072	6.37
(6) Spring nitrogen (kg N ha^{-1}) on 11 April		
100	1063	5·89
160	1074	5·99
(7) Insecticide ('Ambush C')§		
Without	1060	5·96
With	1077	5·91
SED	29.6	0·120

*'Baytan' a.i. triadimenol + fuberidazole.
†Chlormequat as 'Cycocel 5C' at 0·8 litre ha^{-1} on 12 December, 11 March and 17 April.
‡'Sportak Alpha' a.i. prochloraz + carbendazim on 30 April; 'Cosmic' a.i. maneb + tridemorph + carbendazim on 16 May; 'Bayleton CF' a.i. triadimefon + captafol on 30 May.
§'Ambush C' a.i. cypermethrin on 25 November.

Numbers of shoots were counted frequently in measured row-lengths in selected plots and these data showed that tillering, which began in mid-November, proceeded rapidly during mild weather in December but was very slow between mid-January and mid-March. Maximum shoot number was not reached until early April (mid-February in 1984 and early February in 1985). In plots of Panda without 'winter' N, maximum shoot number was greater than in either of the previous two years (1405, 959 and 1542 m^{-2}, respectively, in 1984–86) but in plots given 'winter' N, maximum shoot number was increased to 1743 m^{-2}, similar to that in 1984 (1723 m^{-2}) but still greater than that in 1985 (1272 m^{-2}). (Mullen and Rainbow, Physiology and Environmental Physics)

Growth and yield in the first crop sequence. Dry weather in the autumn delayed germination of shed grain so that, despite relatively late sowing, there were many volunteers.

Samples were taken on three occasions to measure shoot number, dry weight and leaf area index. Sowing at the larger seed rate increased the number of shoots on 10 March (1612 vs. 1260 m^{-2}) but not on 9 April (1853 vs. 1844 m^{-2}). In contrast, 'winter' N had no effect in March but increased the number of shoots in April (2006 vs. 1691 m^{-2}). Dry weights showed similar effects, being increased most by seed rate in March (76 vs. 62 g m^{-2}) and by 'winter' N in April (133 vs. 109 g m^{-2}), but leaf area index was increased only in April, by 'winter' N. There was little effect of other treatments on either date.

On 2 June the number of ear-bearing stems was increased by sowing at the larger seed rate

https://doi.org/10.23637/ERADOC-1-27

(Table 1), despite the large numbers of volunteers, but decreased by 'winter' N; other treatments had little effect. In contrast, dry weight was increased most by fungicide sprays in spring and summer (721 vs. 675 g m^{-2}) and by extra N in spring (712 vs. 684 g m^{-2}), both of which also increased leaf area index.

At harvest on 1 August (Table 1) grain yield was increased most by fungicide sprays (+ 0·86 t ha^{-1}) mainly because they increased grain size (28·4 vs. 26·3 mg per grain). Grain yield was also increased by triadimenol + fuberidazole ('Baytan') (+ 0·28 t ha^{-1}) which increased the mean number of grains per ear (21·3 vs. 20·8) but not grain size. The increase in ear number achieved with the larger seed rate was offset by a decrease in the mean number of grains per ear so grain yield was unaffected. The decrease in ear number that resulted from applying 'winter' N was accompanied by an increase in the mean number of grains per ear but a decrease in grain size and neither it nor extra N in spring significantly affected grain yield.

Growth and yield in all three crop sequences. Volunteers in plots after barley were all of cv. Panda so differences between the two cultivars sown in these plots must be interpreted with caution. However, there were many fewer volunteers in plots following oats. In these, cv. Panda and cv. Pirate had similar numbers of shoots in April but in June there were more ear-bearing stems in plots of the two-row Panda than in those of the six-row Pirate (Table 2).

TABLE 2

The effects of previous cropping and cultivar on the number of ears on 2 June and on the grain yield (t ha^{-1}) of winter barley

	Ears m^{-2}	Grain yield
Two-row barley (Panda)		
Previous crop		
Fallow	956	8·04
Barley	1053	6·26
Oats	889	7·88
Six-row barley (Pirate)		
Previous crop		
Barley	1042	6·59
Oats	729	8·26
SED	78·9	0·385

As last year (*Rothamsted Report for 1985*, 26) seedlings grown after oats were much smaller than those grown after barley. Measurements on the samples taken for disease assessments in November showed that the largest seedlings were those of Panda after fallow (68·8 mg per plant) but seedlings of Panda and Pirate after oats were, on average, 37% smaller than those after barley (29·3 and 46·5 mg per plant, respectively) despite less competition from volunteers in plots following oats. Similar differences were apparent in December in both mean dry weights (77·3 vs. 47·0 mg per plant after barley and oats, respectively) and numbers of shoots (2·1 vs. 1·5 shoots per plant). The samples taken in March and April also had many fewer shoots, and smaller dry weights, per m^2 after oats than after barley but these differences may, in part, reflect differences in numbers of volunteers. Numbers of ear-bearing stems in June were similarly smaller in barley after oats than after barley (809 vs. 1048 m^{-2}) but differences in dry weight per m^2 were much smaller. However, despite fewer ears, there was a mean benefit of 1·65 t ha^{-1} from growing barley after oats (Table 2) because there were more grains per ear and grains were 14% larger. (Widdowson and Darby, Soils and Plant Nutrition; Gutteridge, Jenkyn and Plumb, Plant Pathology; Mullen, Physiology and Environmental Physics; Carter, Entomology; Kerry, Nematology; Ross, Statistics)

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Fungal diseases. Powdery mildew (*Erysiphe graminis* f.sp. *hordei*) was always very slight but in December was more common in plots of Panda after fallow than after barley or oats. No leaf blotch (*Rhynchosporium secalis*) was seen in November or December but it was relatively common by mid-March when areas affected on the youngest leaves were decreased by 'Baytan' (0·9 vs. 2·0%). It was less severe in plots after oats than barley (0·2 vs. 1·4%). Subsequently the disease was most affected by fungicide sprays which decreased areas affected on fourth youngest leaves in May (1·8 vs. 7·6%) and on second youngest leaves in June (1·2 vs. 7·6%). In June, it was increased by extra nitrogen applied in either 'winter' or spring (8·6 vs. 6·6 and 9·5 vs. 6·0%, respectively, on second youngest leaves from plots not given fungicide sprays).

As expected, take-all (*Gaeumannomyces graminis* var. *tritici*) was again more prevalent after barley than after oats or fallow (take-all ratings in mid-June of 136, 30 and 29 respectively). The proportion of plants showing symptoms was less at the larger seed rate in November (1·2 vs. 3·2%) and December (10·8 vs. 24·6%) but thereafter seed rate had little effect. The effect of 'Baytan' in decreasing the disease was less clear than in the previous two years, perhaps because of numerous untreated volunteers or because the experiment was later-sown. Thus in plots after barley, the fungicide decreased numbers of plants affected in November (1.4 vs. 2·5%), December (13·6 vs. 20·0%) and March (53·7 vs. 63·5%) but none of these effects was significant. The only significant effect was on the average number of 'take-all' infected roots per plant in March which 'Baytan' decreased from 1·2 to 0·9. Differences in the take-all rating in June were negligible (139 and 134, respectively for plots without and with 'Baytan'). Take-all was unaffected by 'winter' N.

Eyespot (*Pseudocercosporella herpotrichoides*) in June was well controlled by the fungicide sprays which decreased numbers of straws with moderate or severe symptoms from 7·2 to 0·2%. It was increased by sowing at the larger seed rate (8·6 vs. 5·9% in plots not given fungicide sprays) but decreased by applying extra N in spring (4·7 vs. 10·7% in plots not given fungicide sprays).

Sharp eyespot (*Rhizoctonia cerealis*) and brown foot rot (*Fusarium* spp.) were negligible. (Jenkyn, Gutteridge and Feekins, Plant Pathology)

Aphids and barley yellow dwarf virus (BYDV). The numbers of *Rhopalosiphum padi* migrating in autumn were larger than recorded in any previous year and their infectivity with BYDV was greater than in any year since 1982. As the migration continued into November the barley was colonized by *R. padi* and *Sitobion avenae*, despite being relatively late-sown, but numbers were small and the crop avoided most of the potential infection by BYDV of earlier-sown crops. Unusually cold weather later in November apparently killed most of these aphids and none were found by vacuum sampling in December or by crop inspection in April. (Carter, Entomology; Plumb, Plant Pathology)

Factors limiting yield of winter oilseed rape

The second of a series of experiments on winter oilseed rape following winter barley continued on a site adjacent to that used in 1985. The same seven factors (Table 4) were tested on cv. Bienvenu in factorial combinations (2^7) in a half replicate design of 64 plots. Thirty-two extra plots were included to test an extended range of nitrogen applications and a seedbed nematicide, and for detailed physiological study, root growth measurements and studies on uptake of nitrogen, micronutrients and sulphur applied as foliar sprays.

Growth and development. Early-sown (E) plots emerged within ten days and established well. Prolonged dry weather in September delayed the emergence of the later-sown (L) plots and hence delayed the application of post-emergence herbicide on these. This led to much

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TABLE 3

Changes with time in total dry weight (g m^{-2}), number of plants m^{-2} and leaf area index of Bienvenu winter oilseed rape sown early (E, 20 August) or later (L, 6 September)

	Dry weight		Number of plants		Leaf area index	
	E	L	E	L	E	L
3 December	100	32	120	51	0·8	0·3
5 March	120	52	112	40	1·0	0·5
6 May	518	285	106	40	4·3	2·4
16 June	1131	938	94	36	(4·9	4·4)*
23 July	1318	1324	81	29	—	—

(* Data from extra plots only, others from main factorial)

competition from volunteer barley and poorer, patchier establishment than on E (72 vs. 136 plants m^{-2}). Plants were lost during the winter but the difference in plant population was maintained throughout the season (Table 3). The effect of sowing date on plant population was the reverse of that in 1985. Growth was slow on both sowings in the dry, cold autumn. Dry matter and leaf area, measured in December, were less than half the amounts in 1985. Freezing conditions in January and February, when temperatures reached −18°C, halted growth and killed some small plants, particularly on L plots, partly restored by some late germination in spring on these plots. Increasing temperatures and light during March and April caused rapid growth but the differences in dry matter and leaf area on E and L plots were maintained until May. The fewer plants on L plots developed more secondary branches (6·6 vs. 4·9 per plant). Unlike 1985 E and L plots flowered together, on about 10 May. Most plots had finished flowering by 15 June, but L plots, particularly those without growth regulator, continued longer. The larger number of branches per plant on L plots eventually compensated for the smaller number of plants after mid-June, when total dry matter of branches exceeded that on E plots. By 23 July plants on L plots had more fertile pods on both terminal and secondary branches (254 vs. 100 per plant), more dry weight of seed per plant (15·1 vs. 4·6 g) and greater harvest index (30·2 vs. 26·8), although the total number of pods per unit area was smaller than on E plots (6750 vs. 7719 m^{-2}). (Leach, Mullen and Rainbow, Physiology and Environmental Physics)

Seed and oil yield. Yields (Table 4) were estimated by combine and, nine days earlier, by hand (0·85 m^2 per plot, 2·2% of the combine harvest area). Unlike 1985, when much seed was lost from shedding before combine harvesting, yields from hand harvesting were only slightly greater (means of 3·72 vs. 4·17 t ha^{-1} respectively). Like 1985, there was benefit from the later sowing date, despite large differences in plant population on E and L plots. The application of 275 kg N ha^{-1} and spring plus summer fungicides significantly increased combine harvest yields. In combination these treatments were additive, yielding 3·93 t ha^{-1}. Most benefit from the larger amount of nitrogen occurred on E plots and that from the fungicides on L plots. Autumn fungicide tended to increase yield most on E plots and on those given a single application of spring nitrogen. Insecticide and growth regulator had little effect on yield because pest numbers were low and wet weather prevented timely application of growth regulator. Sowing date had little effect on oil content of seed, but the larger amount of nitrogen significantly decreased it from 44·9 to 44·1% at 90% DM. However, this effect was offset by a significant increase in oil yield (1623 vs. 1691 kg oil ha^{-1}). Spring and summer fungicides did not affect oil content but significantly increased oil yield from 1614 to 1699 kg oil ha^{-1}. (Rawlinson, Plant Pathology; Darby, Soils and Plant Nutrition; Leach,

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TABLE 4

Factors tested and their effects on seed yield (t ha^{-1} at 90% DM) of Bienvenu winter oilseed rape

	Hand harvest 23 July	Combine harvest 2 August
(1) Sowing date		
20 August	3·93	3·69
6 September	4·42	3·75
(2) Spring nitrogen rate (kg N ha^{-1})		
175	4·18	3·61
275	4·16	3·83
(3) Spring nitrogen timing		
All on 11 March	4·14	3·70
One-third on 11 March, two-thirds on 1 April	4·21	3·75
(4) Insecticide*		
Without	4·20	3·74
With	4·14	3·71
(5) Autumn fungicide†		
Without	4·06	3·67
With	4·28	3·77
(6) Spring and summer fungicide‡		
Without	4·08	3·63
With	4·27	3·81
(7) Growth regulator§		
Without	4·26	3·72
With	4·09	3·72
SED	0·188	0·063

* 'Decis' a.i. deltamethrin on 12 November + 'Hostathion' a.i. triazophos on 24 June.
† 'Sportak' a.i. prochloraz on 26 November
‡ 'Sportak' a.i. prochloraz on 28 April + 'Rovral Flo' a.i. iprodione on 23 June
§ 'Cerone' a.i. 2-chloroethylphosphonic acid on 12 June.

Physiology and Environmental Physics; Digby, Statistics; Evans, Nematology; Williams, Entomology; Yeoman, Field Experiments)

Nitrogen in soil. Dry soil conditions and the presence of many stones prevented measurement of NO_3- and NH_4-N beyond a depth of 30 cm in September and October. Wetter soil in spring permitted normal sampling to a depth of 90 cm. On 10 September soil contained 50 kg NO_3-N ha^{-1} increased by seedbed N to 114 kg ha^{-1}. By 4 October the latter value had declined to 32 and 104 kg ha^{-1} on E and L plots respectively. On 3 February amounts on E and L were 3 and 5 kg ha^{-1} respectively.

Nitrogen content in plants. The percentage of N in dry matter in December was larger in L plants (4·41 vs. 3·50%) but the greater growth and larger plant population on E plots gave larger N uptake (34 vs. 14 kg N ha^{-1}). On 5 March the percentage of N remained greater in L plants (4·29 vs. 3·87%) and N uptake greater from E plots (46 vs. 22 kg N ha^{-1}). The larger spring N dressing and the divided application of N both increased percentage of N on 6 May (3·90 vs. 3·67% and 3·89 vs. 3·68% respectively). Dry matter in E plants on 6 May remained greater than in L plants so N uptake was larger (192 vs. 109 kg N ha^{-1}).

Nitrogen in plant sap. During mid-October to late November the concentration of NO_3-N in the petiole of the youngest expanded leaves of E plants was only 120 μg ml^{-1} and plants

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showed stress symptoms. The concentration in L plants also declined but not as much. In early December concentrations increased rapidly to between 900 and 1000 μg ml^{-1} as the soil became moist and lower temperatures slowed growth. After 13 January concentrations declined steadily to zero by 1 April on both sowings. Nitrogen fertilizer applied in March caused a rapid increase to 1000 μg ml^{-1} before declining again as crop growth increased in April. (Darby and Hewitt, Soils and Plant Nutrition)

Root growth. The roots of the many barley volunteers, particularly in L plots, could not be unequivocally distinguished from those of rape and this precluded root measurements. (Weir, Soils and Plant Nutrition)

Foliar nutrients. Six L plots, all given 275 kg N ha^{-1} and full fungicides and insecticides, were sprayed additionally with ammonium nitrate and urea (1), or with a commercial formulation containing the same nitrogen plus Mg, Mn, Cu, Fe, B, Zn and Mo (2), or with the latter plus micronized elemental sulphur (3). Mean combine harvest yield of (1) was 4·05, of (2) 3·74 and of (3) 4·19 t ha^{-1}. As expected on Rothamsted soil, there was no benefit from micronutrients and little effect from sulphur because atmospheric deposition of sulphur in this region is adequate. Oil content in seed of (1) was 44·6%, of (2) 44·5% and of (3) 44·0%. Effects on nitrogen and trace element contents of seed await analyses. (McGrath, Soils and Plant Nutrition)

Insect pests. In autumn adult cabbage stem flea beetles (*Psylliodes chrysocephala*) were few and subsequent larval damage was much less than in 1985. Larval damage was again commoner on E than L plots (62 vs. 13% plants and 31 vs. 4% petioles damaged on 25 November). By 24 January the numbers on E and L were little changed but damage was decreased by insecticide (65 vs. 24% plants and 31 vs. 7% petioles damaged). On 5 March there were more larvae per plant on E plots (3·1 vs. 1·9 without insecticide; 0·6 vs. 0·05 with) and more damage (87 vs. 75% plants and 65 vs. 27% petioles damaged, without and with insecticide respectively). In April and May numbers of pollen beetles (*Meligethes aeneus*) did not exceed 0·5 per plant. In June numbers of seed weevils (*Ceutorhynchus assimilis*) did not exceed 0.06 per plant and on 18 July few pods contained seed weevil or pod midge (*Dasineura brassicae*) larvae. On E plots triazophos had no effect on larval numbers (2·7% pods with seed weevil, 1·3% with pod midge larvae). On L plots triazophos slightly decreased them (5 vs. 2·2% and 2·2 vs. 1·7% pods with seed weevil and pod midge larvae respectively). (Williams and Martin, Entomology; Stevenson and Smart, Insecticides and Fungicides)

Insecticide resistance. Since autumn 1984 samples of *Myzus persicae* have been collected (before the application of deltamethrin) to examine changes in insecticide resistance in overwintering populations. An immunoassay was used to quantify the activity of the enzyme (E4) responsible for conferring insecticide resistance. This showed substantial increase in the frequency of highly resistant (R_2) aphids, from 0·02 in 1984 to 0·5 in 1985. (ffrench-Constant (Entomology); Devonshire, Insecticides and Fungicides)

Nematodes. Four extra plots tested oxamyl applied to the seedbed. This decreased numbers of *Pratylenchus* spp. in May (48 vs. 80 per g of root, 1320 vs. 2670 per litre of soil). Total ectoparasitic nematode numbers were also decreased slightly (10 540 vs. 11 700 per litre of soil). There were more *Pratylenchus* in roots of E than L plots (100 vs. 55 per g of root) but as in 1985 no species was present in numbers likely to cause damage and oxamyl did not affect yield. No cyst nematodes were detected. (Evans, Nematology)

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Diseases. The main fungal diseases were downy mildew (*Peronospora parasitica*), light leaf spot (*Pyrenopeziza brassicae*) and grey mould (*Botrytis cinerea*) but as in 1985 none was severe. Incidence was usually greater on E than on L plots. Up to 1% of plants had *Phoma* leaf spot and stem canker lesions (*Leptosphaeria maculans*), dark leaf spot (*Alternaria* spp.) and stem rot (*Sclerotinia sclerotiorum*). On 25 November L plots had downy mildew (9% plants and 2% leaves infected) but none was found on E plots. On 24 January downy mildew, light leaf spot and grey mould were more prevalent on E than L (24 vs. 10% plants and 4 vs. 2% leaves, 6 vs. 1% plants and 1 vs. 0·2% leaves, 22 vs. 7% plants and 4 vs. 1% leaves infected respectively). Autumn fungicide decreased grey mould (24 vs. 6% plants and 4 vs. 1% leaves infected) and prevented light leaf spot. On 23 April downy mildew, light leaf spot and grey mould remained more prevalent on E plots (51 vs. 22% plants and 8 vs. 2% leaves, 18 vs. 2% plants and 3 vs. 0·1% leaves, 27 vs. 25% plants and 3 vs. 2% leaves infected respectively). On this date grey mould was unaffected by autumn fungicide but light leaf spot was decreased (17 vs. 2% plants and 3 vs. 0·4% leaves infected). By 6 May downy mildew had increased, unaffected by sowing date (90% plants and 26% leaves infected). There was more grey mould on L plots (20 vs. 9% plants and 3 vs. 1% leaves infected) but it remained unaffected by either autumn or spring fungicide. Light leaf spot had decreased, also unaffected by sowing date (6% plants and 0·7% leaves infected), but was decreased by autumn and spring fungicide (15% plants infected on untreated plots vs. 2, 7 and 1% on plots given autumn, spring or both sprays respectively). Mean incidence of beet western yellows virus (p. 115), detected by enzyme-linked immunosorbent assay (ELISA) and immuno-specific electron microscopy (ISEM), was 25% plants infected; this was unaffected by sowing date but halved on plots given autumn insecticide. Cauliflower mosaic and turnip mosaic viruses were not detected. On 17 June downy mildew was greater on L plots (75 vs. 43% plants and 31 vs. 15% leaves infected). Grey mould was unaffected by sowing date and fungicides (60% plants and 21% leaves infected). Light leaf spot was greater on E than L (54 vs. 17% plants, 14 vs. 3% leaves and 18 vs. 3% plants with pods infected). Both fungicide treatments decreased plant infection (18 vs. 52% and 29 vs. 42% autumn and spring fungicide respectively) and leaf infection (2 vs. 15% and 5 vs. 12% respectively) with least on plants given fungicide on both occasions (56 vs. 27 vs. 49 vs. 9% for none, autumn, spring and both sprays respectively). Infection on stems and pods was controlled more effectively by autumn (14 vs. 47% stems and 2 vs. 20% plants with pods infected) than by spring fungicide (28 vs. 33% and 8 vs. 13%) with least infection on both tissues when both sprays were given. On 16 July light leaf spot on pods and stems and grey mould on stems were greater on E than L plots. Light leaf spot, but not grey mould, was decreased by autumn fungicide; spring and summer fungicide had little effect on either disease although infection was least on plots given all three sprays. (Rawlinson, Church, Ford and Jones, Plant Pathology)

The superficial microflora of leaves and pods. Microbial colonization of leaves and pods was generally less than in 1985. Bacterial populations on overwintered leaves reached a maximum of 10^{10} colony-forming units (CFU) g^{-1} of tissue in late April but on uppermost main leaves were always less than 10^9 g^{-1}. Numbers on pods increased from 10^4 to 10^7 CFU g^{-1} during development and ripening. Yeasts numbered up to 10^7 CFU g^{-1} on leaves and up to 10^6 g^{-1} on pods, with white colony types again usually more numerous than pink *Sporobolomyces* spp. *Aureobasidium pullulans* was isolated from few leaf samples before late May, and then only in small numbers, but 10^3 to 10^5 CFU g^{-1} pods were found at harvest. Filamentous fungi, mostly species of *Cladosporium* and *Phoma* with smaller numbers of *Alternaria* and *Botrytis* gave maximum counts of 10^6 CFU g^{-1} on leaves and 3×10^5 g^{-1} on pods. Unusually, numbers on pods decreased through June before increasing to a maximum at harvest. Although numbers of filamentous fungi were usually smaller on fungicide-treated

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plots than on untreated, the differences were small. Unlike 1985, few *Alternaria* were isolated from surface-sterilized seed at harvest; only 1·3% of fungicide-treated and 7% of untreated seed yielded colonies. No *Alternaria* was isolated from seed more than two weeks before harvest. (Lacey and Nabb, Plant Pathology)

Winter wheat: sowing dates and times of nitrogen application

In the previous two series of multidisciplinary experiments wheat sown in mid-September instead of mid-October gave larger yields in the first series but not in the second. Possible causes of this difference were the presence of large N residues from previous potatoes grown in the first series in contrast to smaller residues from previous cereals in the second, and the change in variety from Hustler to Avalon. In these experiments delaying N application generally resulted in greater uptake of N, a larger concentration in the grain, a larger yield of grain and a smaller yield of straw. The experiment this year examined the response of Avalon to sowing date with differing N residues from previous crops, and to a range of timings of N including some applied later than previously tested or generally recommended to farmers. Six factors were tested in a partial factorial design: (1) previous crop: spring oats or spring oilseed rape, (2) sowing date: 20 September or 18 October, (3) winter N: none or 50 kg ha^{-1} applied on 27 November, (4) spring N (200 kg ha^{-1}): single or divided, (5) spring N timing: early (single 200 on 25 April, divided as 50 kg on 6 March, 1 April, 25 April and 19 May) or late (single 200 on 19 May, divided as 50 kg on 1 April, 25 April, 19 May and 9 June), (6) summer N: none or 50 kg ha^{-1} applied on 9 June (flag leaf emergence of early-sown wheat) following early spring N or 25 June following late spring N. The late timing of spring N was tested only on early-sown plots. Spring and summer N applications were made at the intended growth stages which were reached at later dates than expected because of exceptionally slow development (see below).

Yield at maturity. The mean of all plots was 9·27 t ha^{-1}. Early sowing increased yield by 0·48 t ha^{-1} and did not interact with any other treatment. The increase was due to slightly more ears and slightly larger grains. There were no other significant effects on grain yield but some components were changed. Wheat given single spring N late had less straw and fewer ears than treatments which included some N applied earlier. The smaller number of ears was offset by larger grains and more grains per spikelet. This resulted in the unusually large value of 54% for harvest index (grain as percentage of above-ground dry weight). (Thorne, Physiology and Environmental Physics; Prew, Field Experiments; Penny and Darby, Soils and Plant Nutrition; Todd, Statistics)

Growth and development. Emergence of plants from the first sowing and the appearance of the first few leaves and tillers was delayed by drought (p. 47). Subsequently the development of both sowings was exceptionally slow because of cold weather. Mean dates when wheat sown in September (E) and October (L) reached particular stages were: double ridges E 4 April, L 16 April; terminal spikelet E 6 May, L 16 May; anthesis E 22 June, L 26 June; zero green area E 9 August, L 10 August; grain hard E and L 13 August. These dates were unaffected by previous crop or N fertilizer with the exception of terminal spikelet stage of later-sown wheat which was four days earlier after rape than after oats. The number of plants established was 257 (E) and 317 (L) m^{-2}. Maximum shoot number was reached at the end of April with all treatments and never exceeded 1200 shoots m^{-2}. Crop dry weight and leaf area were also exceptionally small until anthesis. Dry weight, leaf area and shoot number during the winter and spring were increased by earlier sowing, by rape instead of oats as a previous crop and by winter N. By maturity early sowing still showed an advantage, increasing total

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dry weight from 15·2 to 16·0 t ha^{-1}; the benefit from a previous crop of rape was only 0·4 t ha^{-1} and that from winter N had gone by anthesis. These three factors did not interact.

When spring N was applied early there was a benefit in April and May from dividing the application into four which had gone by anthesis. The late single application gave consistently smaller dry weights, leaf areas and shoot numbers at anthesis than did the other three treatment combinations. However after anthesis the upper leaves senesced more slowly with late single N than with other treatments (p. 46) and by maturity the difference in dry weight was seen only in straw. Summer N had no significant effects. (Thorne, Mullen, Rainbow and Stevenson, Physiology and Environmental Physics)

Nitrate-N in the soil. Only the soil under the early-sown wheat was sampled. On 7 October 1985 it contained 77 kg NO_3-N ha^{-1} after rape and 26 kg after oats to 90 cm depth. This difference determined the choice of 50 kg ha^{-1} of fertilizer N as the winter N treatment. On 4 February amounts of NO_3-N had fallen to 27 and 22 kg ha^{-1} after rape and oats respectively.

Nitrate-N in wheat shoots. Without fertilizer N the sap of the lower parts of the wheat shoots sampled on 27 November, 12 December and 23 December contained, after rape and oats respectively, 670 vs. 620, 790 vs. 500 and 870 vs. 830 μg ml^{-1} NO_3-N. Thereafter concentrations did not differ consistently with previous crop, e.g. after rape and oats respectively, 790 vs. 920 μg NO_3-N on 13 January, 500 vs. 540 on 4 February, 750 vs. 670 on 6 March, 620 vs. 540 on 19 March. After rape, the concentration fell to less than 200 μg NO_3-N ml^{-1} on 20 April and to nil on 12 May; after oats the concentration did not fall to less than 200 μg ml^{-1} until 30 April but then fell quickly to nil on 6 May. Winter N always increased the concentration of NO_3-N, especially after oats; values were at a maximum on 13 January (920 μg ml^{-1} after rape, 1000 after oats). From mid-April concentrations fell rapidly so that although winter N delayed the initial fall to less than 200 μg ml^{-1} by a few days it did not delay the subsequent fall to nil.

Nitrogen contents of crops. Data are available only from the first four dates of sampling.

Spring and summer N applied at normal time. Percentage of N in the dry matter differed with previous crop only in May when it was larger after oats than after rape (4·47 vs. 4·18). Because of the larger crop after rape, uptake of N was always larger than after oats (16 vs. 12 kg N ha^{-1} in March, 121 vs. 110 in May) but the difference was not significant at anthesis in June (222 vs. 213).

Sowing date also affected percentage of N only in May (early 4·13 vs. later 4·53) but early sowing doubled N uptake in March and April, and much increased it in May, after both previous crops (mean values 18 vs. 9, 29 vs. 15 and 134 vs. 97 kg N ha^{-1} respectively). By June the effect of early sowing was less marked (228 vs. 207).

Winter N usually increased percentage of N, but not appreciably until June (2·30 vs. 2·02). It affected uptake of N little in March and April. In May winter N increased uptake of N after oats (104 vs. 116) and after rape (116 vs. 127). The identical uptakes after oats with, and rape without, winter N supported the method of determining the rate of winter N. Increases in June were similar to those in May (197 vs. 229 after oats; 205 vs. 239 after rape).

In March, 16 days after applying 50 kg ha^{-1} of spring N, only the percentage of N after oats was increased and there was little effect on N uptake. In April, divided spring N (100 kg ha^{-1} now applied) increased percentage of N after both crops but uptake only after oats. In May before applying the final 50 kg ha^{-1} of the divided dressing, the percentage of N was larger with the single application but uptakes did not differ consistently. In June, division of spring N affected neither percentage nor uptake of N.

In June, 16 days after application, the summer N had increased both percentage and

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uptake of N slightly more after rape than after oats and slightly more with single than divided spring N (mean values, 2·21 vs. 2·11 %N and 224 vs. 211 kg N ha^{-1}).

Spring N applied late. On the early-sown plots given spring N later than normal the single dressing had not been applied by the May sampling date; winter N then increased both percentage and uptake of N. Where the divided N had been delayed (100 kg ha^{-1} then applied) winter N increased percentage of N but not uptake. In June, giving spring N later than normal had little effect on percentage of N but slightly decreased uptake (205 vs. 218 kg ha^{-1}). (Penny, Widdowson, Darby, Hewitt and Bird, Soils and Plant Nutrition)

Diseases. Eyespot was slight in March, with less than 20% of plants infected and this was well controlled by fungicides. Take-all was virtually absent. Septoria was present in small amounts on the lower leaves in May, never more than 5% of the third youngest leaf infected. In July mildew and Septoria were present on the flag leaf but very slight, both less than 1% of the leaf area infected. None of these infections was considered severe enough to affect yield. (Prew, Field Experiments)

Conclusions. In contrast to previous experiments there were no interactions between N residues from previous crops and sowing date, but the conditions experienced in the previous experiments were not repeated. In those, the good use made of N residues by early-sown wheat resulted in crop weights in spring that were six times those of later-sown wheat when the previous crop was potatoes; the benefit decreased to threefold when the previous crop was oats. Crop weight in the spring of 1986 was only doubled by early sowing, following poor growth in the previous autumn, and the benefit was no greater after rape than after oats.

The absence of differences in grain yield with such a wide range of timings of spring N supports the conclusions drawn from the previous multidisciplinary experiments (*Rothamsted Report for 1985,* 34) that apical development is not of overriding importance as a criterion for determining N timing. In 1986, the first application of spring N ranged from a month before the double ridge stage to two weeks after the terminal spikelet stage, yet grain yield varied by only a non-significant 0·2 t ha^{-1}.

Straw incorporation

The series of multidisciplinary experiments continued in winter wheat with the cv. Mission replacing Avalon. This change allowed quantitative assessments of volunteers in a year when they were of major importance. A new experiment at Shenley Dens Farm, Whaddon, courtesy of Mr J. Hoskins, was started on much heavier and wetter land than at Rothamsted.

Comparison of straw incorporation methods on different soil types

Yields. In this second year of the experiment yields were less than in 1985 especially on the lighter soil at Woburn. Mean yields again differed little between burnt or incorporated straw on either site but yields tended to be larger on ploughed plots with burning and on tined plots with incorporation (Table 5). (Prew, Field Experiments; Moffitt, Farm; Henderson and Powell, Entomology; Kerry, Nematology; Gutteridge and Jenkyn, Plant Pathology; Harper, Soil Microbiology; Christian, Goss and Johnston, Soils and Plant Nutrition)

Growth. Plant growth during the winter was poor at both Rothamsted (R) and Woburn (W) with no visual differences between treatments. Dry weights of plants in spring reflected this poor growth (R 76 g m^{-2}, W 55 g m^{-2}) and were similar to the poorest plots in the

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TABLE 5

Effects of cultivations and straw treatments on grain yield (t ha^{-1}) of winter wheat

	Shallow tillage 10 cm	Deep tillage 20 cm	Shallow tillage +plough	Plough 20 cm
Rothamsted				
Straw burnt	7·84	8·06	8·63	8·18
Straw chopped	8·53	8·54	8·25	7·98
Woburn				
Straw burnt	7·22	6·78	7·60	8·10
Straw chopped	7·72	7·59	7·29	7·58

previous year. The only differences between treatments were slightly more dry matter on all tined plots at Rothamsted and on straw-incorporated tined plots at Woburn. These differences were attributed to the increased numbers of volunteers on these plots and were repeated, though to a lesser extent, in final ear numbers.

Volunteers. Volunteers were prevalent as a result of the dry autumn. Fertile ear counts of the sown variety, Mission, and the Avalon volunteers showed that the percentages from volunteers were generally fewer on ploughed plots (burnt R 0·6, W 0·6 or straw incorporated R 2·0, W 8·4) than on tined plots (burnt R 24·8, W 3·8 or straw incorporated R 28·4, W 28·8). The difference between sites on tined burnt plots may reflect the much better burn achieved at Woburn. (Bacon, Soils and Plant Nutrition; Prew, Field Experiments)

Pests. Straw treatments had no effect on stem borers (*Opomyza florum*), larvae of the blossom midge (*Sitodiplosis mosellana*) overwintering in soil or summer populations of cereal aphids. However, percentages of plants attacked by stem borers were greater on ploughed than unploughed plots (R 38 vs. 27, W 59 vs. 42). Numbers of blossom midge larvae in the top 15 cm of soil were 48% (R) and 86% (W) fewer with ploughing. At Rothamsted aphid numbers per tiller in summer were greater on ploughed plots (*Metopolophium dirhodum* 4·6 vs. 1·6, *Sitobion avenae* 1·6 vs. 0·8). (Powell, Ashby and Wright, Entomology)

Diseases. Take-all was prevalent on the site but detailed assessments are not yet available. However, preliminary results show that root infection of Mission and Avalon did not differ although the worst take-all patches in June were seen where volunteers were most dense. (Gutteridge and Jenkyn, Plant Pathology)

Effects of shallow straw incorporation

Yields. On this experiment straw treatments did affect yields, which were smallest where straw was incorporated and largest where burnt. Autumn nitrogen and fungicide also decreased yield as did delayed timing of cultivations on burnt and chopped/incorporated plots (Table 6). All these yield decreases were associated with increased amounts of take-all. (Prew, Field Experiments; Moffitt, Farm; Henderson and Powell, Entomology; Kerry, Nematology; Gutteridge and Jenkyn, Plant Pathology; Christian and Johnston, Soils and Plant Nutrition)

Growth. In November there were more plants on burnt (BU) than on baled (BA) or chopped (C) plots (BU 417, BA 298, C 307 plants m^{-2}) perhaps indicating faster germination of either sown crop or volunteers, because by April the effect was reversed (BU 380, BA 465, C 489 plants m^{-2}). However, the increased plant numbers did not result in propor-

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TABLE 6

Factors tested and their effects on grain yield (t ha^{-1}) of winter wheat

	Straw treatment		
	Burnt	Baled	Chopped
	7·75	6·87	6·42
Effect of:			
Early cultivation	+0·40	−0·37	+1·08
Autumn N	−0·13	−0·39	−0·50
Fungicides	−0·60	−0·39	−0·30
Insecticides	+0·35	+0·01	+0·34

tionally increased dry weight (BU 55, BA 52 and C 58 g m^{-2}). (Bacon, Soils and Plant Nutrition; Jenkyn, Plant Pathology; Prew, Field Experiments)

Volunteers. Counts of fertile ears showed that on the early-cultivated plots there were more volunteers on the baled and on the chopped plots than on the burnt (BU 120, BA 266, C 206 volunteer ears m^{-2}); with the later cultivation only baled plots had more (BU 128, BA 195, C 131 volunteer ears m^{-2}). There were fewer volunteers where fungicides were used (150 vs. 198) probably because plots without fungicide last year had smaller grains and consequently larger combine losses. (Bacon, Soils and Plant Nutrition; Prew, Field Experiments)

Pests. Although damage by *Opomyza florum* was much less than in 1985, the percentage of plants attacked was again greatest on the burnt plots and least on the chopped (BU 3·5, BA 2·4, C 1·7). The autumn pyrethroid spray reduced the damage (0·9 vs. 4·3%). Numbers of cereal aphids per shoot were very few, in mid-July; they were least on chopped plots for both *Metopolophium dirhodum* (BU 1·7, BA 1·8, C 1·1) and *Sitobion avenae* (BU 0·6 BA 0·8, C 0·6). (Powell, Ashby and Wright, Entomology)

Diseases. In November leaf diseases were negligible but first seedling leaves had begun to senesce on chopped plots (0·2%) although not on baled or burnt plots. By April *Septoria tritici* was common and, on second youngest leaves, was more severe with later than early cultivations (3·3 vs. 2·0%); there also tended to be more on chopped than on baled or burnt plots (BU 2·6, BA 2·2, C 3·1%). In July *S. nodorum* also occurred but was less common than *S. tritici*. Without fungicides *Septoria* spp. tended to be more severe on burnt than baled or chopped plots (second youngest leaves BU 4·4, BA 2·9, C 3·3%). In contrast senescence from all causes on these leaves was greatest on chopped plots (BU 19·7, BA 20·8, C 31·7%). Overall fungicides decreased *Septoria* spp. to 0·3% and senescence to 15·7%. Mildew was present but very slight.

Take-all was severe and there tended to be most on chopped and baled plots (take-all rating (TAR) in July BU 158, BA 183, C 190). It was also more severe with later cultivation and where autumn nitrogen and fungicides had been used. The effect of fungicides was largest (TAR 206 vs. 148) and was present from very early in the season (percentage plants infected November: 13 vs. 9, April: 72 vs. 61, July: 97 vs. 91). The reasons for this effect are not clear. As the differences were present in November, before any fungicides had been applied to this crop, it seems to be a residual effect. There were fewer volunteers but presumably larger residues of straw and roots from the better crop with fungicides in 1985, and it is possible that these larger residues resulted in increased inoculum levels.

Eyespot was slight; the fungicide more than halved the percentage of stems infected in July (9·1 vs. 23·2). (Jenkyn, Gutteridge and Feekins, Plant Pathology)

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Straw incorporation on a heavy wet site. This experiment was started in autumn 1985 and tested the incorporation of winter barley straw before a winter barley crop. The soil is a clay drift over clay (Lawford series) with typical drainage problems. The factors tested were unploughed, worked to 15 cm (U) vs. ploughed to 20 cm, worked as necessary (P); straw was burnt (B) or chopped (C).

Yield. The burnt plots yielded better (P 6·79, U 7·13 t ha^{-1}) than the chopped plots (P 6·48, U 6·88 t ha^{-1}) and with both, the unploughed system was better than the ploughed. These differences in yield do not seem well related to the growth and disease assessments. (Prew, Field Experiments; Moffitt, Farm; Powell, Entomology; Jenkyn, Plant Pathology; Bacon, Christian and Johnston, Soils and Plant Nutrition)

Growth. The unploughed plots emerged and grew faster than the ploughed following sowing on 28 September but by November, although they had more shoots per plant (1·30 vs. 1·07) and were larger (49·1 vs. 38·5 mg dry weight per plant), the plants were very chlorotic and the first seedling leaves were more senescent (4·8 vs. 1·2%). By April growth on unploughed plots was still slightly better (64 vs. 58 g dry wt m^{-2}) but burnt plots had many more shoots per m^2 than chopped (1142 vs. 852). By anthesis the benefit with burning was smaller (519 vs. 453 shoots m^{-2}) and by maturity there were no treatment effects on final ear numbers. (Bacon, Soils and Plant Nutrition; Jenkyn and Gutteridge, Plant Pathology; Prew, Field Experiments)

Volunteers. No treatment had more than 10% of volunteers in the final ear numbers; there were most on chopped unploughed plots (9%), less on burnt unploughed (4%) and fewer than 2% on the ploughed plots. (Bacon, Soils and Plant Nutrition: Prew, Field Experiments)

Diseases. Mildew was very slight until June when areas of the second youngest leaf infected were greater on the ploughed than unploughed plots (5·9 vs. 2·6%). Leaf blotch was negligible in autumn but in April and June there was most in the chopped unploughed plots (2·7 vs. 0·5% and 3·9 vs. 1·3% of second youngest leaf, respectively).

Throughout the season there were more plants with take-all on the unploughed than the ploughed plots (November 72 vs. 21; April 78 vs. 41; June 99 vs. 90) and they were more severely infected (TAR in June 196 vs. 130). This was unexpected but probably related to the field not having been ploughed for many years. The cultivation treatments would therefore have caused large differences in the vertical distribution of take-all inoculum and hence greater effects on infection than previously reported. (Prew, *Annals of Applied Biology* (1981) **98,** 218–226). Effects of straw treatments on take-all were inconsistent. Eyespot was prevalent in April (20% shoots infected) but was well controlled by basal fungicides and in June only 3% of straws had moderate or severe infections. (Jenkyn, Gutteridge and Feekins, Plant Pathology)

Intensive potato production

The experiment described in 1982 (*Rothamsted Report for 1982*, 39–41) continued for its fifth year on the same sandy loam site at Woburn with the first of three crops of potatoes testing the cultivars and cropping frequencies shown in Table 7. Sub-plots tested all combinations of three two-level factors: with and without the nematicide oxamyl at 5 kg ha^{-1} worked into the seedbed, with and without a combined fungicide treatment to the seed of prochloraz at 35 g and tolclofos methyl at 240 g t^{-1} of tubers, and with and without the molluscicide methiocarb at 0·22 kg ha^{-1} on each of six occasions from 7 July to 15 September.

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TABLE 7

Effects of previous cropping, cultivar and nematicide on yield of tubers t ha⁻¹

Cultivar sequence*			Tuber yields 1986		Nematodes spring 1986 eggs g^{-1} soil
1982	1984	1986	None	Oxamyl	
–	–	Désirée	56·0	57·2	2
Désirée	–	Désirée	37·1	57·9	77
–	Désirée	Désirée	38·5	56·5	38
Désirée	Désirée	Désirée	27·2	50·4	69
Désirée	Maris Piper	Désirée	31·0	48·9	78
–	Désirée	Maris Piper	50·1	60·5	22

SED (42 d.f.) 5·6 t between sequences, 3·3 t within sequences

* All were in potatoes Pentland Crown in 1980, all spring barley in other years.

Penetrometer studies in barley stubbles late in 1985 indicated that the soil 14 to 28 cm deep was more compacted in the two-course rotations, so in 1986 all plots were cross-worked with a Bomford 'Earthquake' deep-tine cultivator. All potato plots were irrigated until the end of September to prevent the soil moisture deficit exceeding 25 mm. The haulms were destroyed with diquat on 9 October and the crop was harvested on 22 October.

Potato cyst nematodes and tuber yields. In untreated soil the yields of Désirée potatoes were much less in the four-course and two-course than the six-course rotations. Although these smaller yields were related to the abundance of potato cyst-nematodes (*Globodera rostochiensis*) in the soil at planting time (Table 7), there appears to be another factor involved to some extent in yield loss in the repeated two-course rotations. Thus in oxamyl-treated soil, there were no differences in yields of Désirée tubers between the six-course, four-course and two-course (second potato crop) rotations, but yields were less in the two-course (third potato crop) rotations. In untreated sub-plots, Maris Piper yielded more in the two-course (second crop) rotation than did Désirée but it also responded significantly to oxamyl.

Few potato cyst nematodes or other plant-parasitic nematodes were found in soil 20 to 40 cm deep.

Virus diseases. The crop was assessed on 3 July but no virus diseases were found.

Slugs and tuber diseases. No slug damage was apparent in untreated sub-plots and in sub-plots treated with methiocarb yields were slightly less. Fungicidal seed dressings had no effect on tuber yields, their effects on tuber quality at harvest and after storage are not yet available.

Conclusions. In the first potato test crop tuber yields were maintained in four-course and two-course (second potato crop) rotations by incorporating oxamyl in the seedbed but in the repeated two-course (third potato crop) rotations yields were slightly less. Potato cyst nematodes are obviously damaging but one or more additional factors may be involved in yield loss in very short rotations. Loss of internal drainage in this poorly structured soil is an obvious candidate. (Whitehead and Webb, Nematology; Hide, Govier and Read, Plant Pathology; Henderson, Entomology; Addiscott, Soils and Plant Nutrition)

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