ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1986

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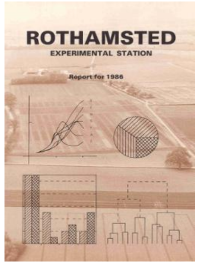

Agronomy and Crop Physiology Division

R. D. Prew

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INTRODUCTION

Dr R. K. Scott relinquished the Divisional Headship to concentrate on his activities as Head of Broom's Barn Experimental Station; no new Divisional Head was appointed pending decisions on the management structure for the new Institute of Arable Crops Research. In the interim R. D. Prew was appointed Acting Coordinator of the Rothamsted-based work of the Division and to the Chairmanship of the Working Party for Field Experiments.

The Division has again made a major contribution to the Station's multidisciplinary field programmes, also to the preliminary work on the agronomy of lupins. These multidisciplinary programmes continue to attract much interest from the farming community and play a major part in demonstrations both on Station and at major outside events such as Cereals '86. The present financial constraints have resulted in some curtailment of Station services run by members of the Division, e.g. visitors, constant environment space. However, by dint of much hard work, the services to the field programme have been maintained.

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THE FARMS AND THE FIELD EXPERIMENTS SECTION

The Farms and the Field Experiments Section continued to provide a service to the Rothamsted staff for the planning, conduct and recording of field experiments. For most of the year there was a steady demand from visitors for field demonstrations. The programme is controlled by the Working Party for Field Experiments whose membership during the year was F. V. Widdowson followed by R. D. Prew, as Chairman, W. Day, D. C. Griffiths, G. Inions, J.F. Jenkyn, A. E. Johnston, R. Moffitt, W. Powell, C. J. Rawlinson and A. G. Whitehead with J. McEwen as Secretary. The Working Party and its Commodity Groups and sub-committees held 24 indoor meetings and made 21 tours of the field experiments. Towards the end of the year several of the meetings were held jointly with staff of the Long Ashton Research Station to aid future integrated planning.

The total number of plots at Rothamsted and Woburn was 6973. Of these 4623 were managed by the Farms with yields taken from 4249 and 793 were managed by the small-plot staff with yields taken from 755; on the remainder the work was divided between Farms, small-plot staff and scientific departments.

Weather

The season was one of very variable weather with the worst spring for many years. A mild wet January which was followed by a very cold February, with snow cover and 27 ground frosts, and a wet March and April delayed spring work. However, a dry spell then allowed planting of cereals, beans and potatoes in good conditions.

Rainfall in May was average but June was very dry and warm and the dry spell continued into early July. Harvesting of winter barley began on the last day of July. The beginning of August was dry and harvesting went well, although rain later in the month interrupted work. Cereal harvest was completed by 10 September.

September was exceptionally dry with 13 ground frosts. The fine weather continued into the first half of October allowing uninterrupted progress on autumn work. Late October and all of November, however, were wet and mild, making the end of potato harvest and the later cereal sowings difficult.

Crops and experiments

Of the 335 ha farmed (259 ha at Rothamsted and 76 ha at Woburn), cereals occupied 206·8 ha, potatoes 20·1 ha, beans 15 ha, and oilseed rape 11·3 ha. The remainder was grass, fallow, access headlands and small areas of triticale, rye, sugar beet, maize, peas, lupins and sunflowers.

Wheat. All was autumn-sown with 99·4 ha at Rothamsted and 27·8 ha at Woburn. The main cultivars were Avalon and Longbow with some Mission, Brimstone and Moulin. Although sowing was timely the severe winter and cold early spring checked growth. It was not until the warmer weather of May when, aided by nitrogen fertilizer, crops grew rapidly.

Crops after cereals were given prochloraz and carbendazim ('Sportak Alpha') against eyespot. Leaf diseases were few until late in the season when propiconazole ('Tilt') and carbendazim plus maneb ('Septal') were given to control Septoria and mildew. Cereal aphids were few and there was no benefit from an aphicide spray in an experiment comparing aphicides. Cultivar Brimstone was given a growth regulator and some quality wheats were given liquid urea post-flowering to improve grain protein.

In July crops which had looked promising started to ripen prematurely and patchily, particularly where they followed cereals. Few crops lodged and harvest was easier than last year despite interruptions by weather and the need for much drying. Yields were generally

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similar or better than last year after break crops but were often less after cereals. Quality was much better particularly for Avalon which had good protein and Hagberg numbers. The quality of some of the newer varieties was disappointing, Moulin had poor protein and Brimstone poor Hagbergs.

On Broadbalk cv. Brimstone was grown for the second year. Yields from the longest consecutive sequences were unusually poor, many 3 to 4 t ha^{-1} less than wheat after potatoes where several yields again exceeded 9 t ha^{-1}. As last year the combination of farmyard manure and spring nitrogen at 96 kg ha^{-1} gave the largest yield, 9·9 t ha^{-1}, but this year several of the plots given fertilizers alone also gave yields above 9 t ha^{-1}.

In the long-term straw incorporation experiment (p. 33) the cultivar was changed from Avalon to Mission. Avalon in 1985 produced little straw, which broke up badly when threshed and it was difficult to get an effective burn for a good comparison with chopped and incorporated straw. In this second year mean yields were 8·3 t ha^{-1} at Rothamsted, 7·5 t ha^{-1} at Woburn. These were 1·5 and 2·0 t ha^{-1} less than last year perhaps because of increased soil-borne diseases. Again the effects of treatments were slight.

In another experiment at Rothamsted where straw was deliberately incorporated only to a shallow depth (10 cm) for a study of effects on pests and diseases a yield of 6·4 t ha^{-1} was obtained. Yield was lost compared with burning the straw, particularly when the cultivation treatments were delayed (p. 34).

Cultivars were compared in experiments at Rothamsted after a two-year break and after wheat and at Woburn on light land after potatoes. Mean yields were 10·6, 9·0 and 7·7 t ha^{-1} respectively. Ambassador and Slejpner yielded well on all three sites, both gave the top yield of 11·2 t ha^{-1} at Rothamsted after the break. Brimstone was also a leading cultivar at both Rothamsted sites but not at Woburn.

Although the wet August bank holiday interrupted cereal harvest the rain, together with that on 13 to 14 September, was invaluable for sowing 1987 crops. The ground was softened for seedbed preparation and germination was helped. In the subsequent dry weather sowing was uninterrupted until rain in mid-October, which made conditions difficult for some later sowings. Most of the wheat sown was Avalon but there were about 20 ha of Mercia and smaller areas of Brimstone, Mission and Galahad.

Barley. The area of winter barley was increased to 42·5 ha partly to provide suitable sites for oilseed rape next year.

The main cultivar was Igri but Panda and Pirate were grown on the Factors Limiting Yield experiment (p. 23). Mean yields of Panda and Pirate following oats were 7·9 and 8·3 t ha^{-1} respectively, following barley they were 6·3 and 6·6 t ha^{-1} respectively.

October-sown Igri on the Cultivation/Weedkiller experiment gave a mean yield of 6·5 t ha^{-1} compared with 8·0 t ha^{-1} last year. Burning straw gave virtually no advantage compared with tining-in chopped straw.

An early-sown experiment compared the effects of volunteers from a previous barley crop and insecticides on BYDV. The worst yield was 3·8 t ha^{-1} without volunteer or aphid control. Controlling volunteers alone increased this to 5·6 t ha^{-1} and the use of cypermethrin alone gave 5·8 t ha^{-1}. With both volunteer control and cypermethrin the yield was 6·6 t ha^{-1}.

As most winter barley followed a cereal it was sprayed in spring with prochloraz plus carbendazim ('Sportak Alpha') against eyespot. At flag leaf emergence there was some mildew and *Rhynchosporium*, and a spray of triadimenol ('Bayfidan') was applied. All crops were harvested in good condition in early August.

There were only 26·6 ha of spring barley, most was sown late. Cultivar Triumph was sown in March on Hoos Barley and gave up to 5·7 t ha^{-1} with fertilizers alone, 5·9 t ha^{-1} with farmyard manure, 7·1 t ha^{-1} with the combination of farmyard manure and 96 kg N ha^{-1}.

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The same cultivar, also sown in March on the Rothamsted Subsoiling and Deep PK experiment gave up to 7·9 t ha^{-1}. The main cultivar was Klaxon which in a cultivar trial at Rothamsted gave 6·5 t ha^{-1}, exceeded only by Cameo and Regatta with 6·6 and 6·9 t ha^{-1}. At Woburn in a similar comparison yields were less but Klaxon with 4·3 t ha^{-1} was best. In the Woburn Ley Arable experiment Klaxon gave several yields over 6 t ha^{-1} but only where leys were part of the rotation. Without leys yields were all less than 5 t ha^{-1}.

Triticale and rye. Small areas of triticale and rye were grown for comparisons with other cereals in different farming situations. Both were included in a comparison with winter wheat and barley on sites at high risk from take-all at Rothamsted and Woburn. On both sites, given high or low inputs of agrochemicals, largest yields came from the triticale cv. Lasko. The relative advantage of triticale was greatest at Woburn and on both sites with low inputs. Although inferior to triticale the rye cv. Dominant, gave larger yields than wheat at Rothamsted, than wheat and barley at Woburn. However on sites after a break all winter wheat cultivars exceeded the yield of Lasko at Rothamsted and nearly all did so at Woburn. Rye cv. Animo, also included in the Woburn experiment after a break, was inferior to triticale.

Last year spring barley grown on the Long Term Liming experiments at Rothamsted and Woburn failed on plots with pH 4·0 and no phosphate. Triticale, cv. Lasko, grown on this experiment this year gave yields of 5·5 and 6·5 t ha^{-1} respectively on the same plots. At Rothamsted on other plots in the experiment the crop responded both to phosphate and to increasing pH, up to 6·0, to give 8·6 t ha^{-1} but at Woburn responses were very small.

Oats. Fortunately only 12·4 ha were sown in autumn, cultivar Bulwark, as all but 2 ha at Woburn were killed by the severe winter, some were resown to spring oats.

Beans. The experimental programme was much smaller than in previous years and only 15 ha were grown. Winter beans, cultivar Banner, accounted for 10 ha but some plants were killed during the harsh winter.

In the third year of the Seed Rates and Sowing Methods experiments the largest yields, mean 5·5 t ha^{-1}, again came from the earliest sowing on 19 September, and the least, mean 3·9 t ha^{-1}, from the latest on 13 November. As before yields from the latest sowing were maximized by using the largest seed rate of 36 seeds m^{-2} and by ploughing-in seed. However this year benefits from smaller seed rates for earlier sowings were not seen probably because all populations were decreased by winter kill.

Winter beans were sprayed twice with benomyl ('Benlate') and chlorothalonil ('Jupital') to control chocolate spot. Some were also sprayed with mancozeb plus maneb ('Kascade') against rust and although this was prevalent no benefit was shown from spraying in an experiment on rust control.

A few winter beans were grown on light land on the Ley Arable Experiment at Woburn and yielded a respectable 5 t ha^{-1}

Few spring beans, mostly Minden, were grown. In an experiment on varieties and plant health Minden gave up to 5·1 t ha^{-1}. This was not exceeded by any of the other varieties. Control of pests and pathogens increased mean yield from 4·4 to 4·8 t ha^{-1}.

Both winter and spring beans retained their leaves until late, and were, therefore, desiccated with diquat ('Reglone') prior to harvest. All were cut by 6 October.

Oilseed rape. There were 11·3 ha all grown at Rothamsted, mostly cv. Bienvenu. Some Jet Neuf was grown for experimental purposes and several other cultivars were compared.

Despite better harvesting conditions than in 1985, with harvest completed on 3 August, yields were similar. The mean yield on the Factors Limiting Yield experiment (p. 26) was

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3·7 t ha^{-1} compared with 4·0 t ha^{-1} last year. In the experiment comparing cultivars all gave similar yields of about 3·5 t ha^{-1} except for Liradonna which gave only 3·0 t ha^{-1}. In another experiment comparing two precision drills with a conventional disc drill on two sowing dates there was little difference between drills but sowing on 22 August gave 4·3 t ha^{-1} compared with 3·8 t ha^{-1} sown on 6 September.

The biggest differences in experiments were obtained where straw treatments before sowing were compared. Although yields after chopping and incorporating straw were only a little less than after burning for a sowing on 22 August they were nearly 2·0 t ha^{-1} less for a sowing on 9 September, probably because of much greater winter kill.

The area sown for 1987 was increased to 21 ha as the experimental programme is still expanding. Most was cv. Ariana to obtain information on factors affecting the performance of a double-low variety. All sowings have established well.

Potatoes. The area was increased slightly to 20·1 ha (13·9 ha at Rothamsted and 6·2 ha at Woburn) because of a large programme of experiments at Rothamsted. Few King Edward are now grown, the main cultivars were Désirée, Pentland Crown and Cara at Rothamsted, Cara and Pentland Crown at Woburn. As it is not possible to irrigate most of the light land at Woburn Désirée, which is prone to scab in droughts, is little grown.

Planting conditions were ideal and good seedbeds were obtained with one pass of a rotary harrow. A dry period followed which limited the effectiveness of the paraquat/linuron ('Gramoxone'/'Linuron 15') weedkiller used. Fortunately crop competition prevented weeds becoming serious. At Rothamsted the seed crop and some of the non-experimental potatoes were irrigated until the end of August, but not thereafter to avoid soils becoming too wet for lifting. Field experiments are seldom irrigated as information on seasonal effects on treatments is often important.

A regular fungicide programme was maintained using mancozeb ('Dithane 945') initially, fentin hydroxide ('Du-ter') later. Aphids were numerous and pirimicarb ('Aphox') was added to the blight sprays to control them.

At Rothamsted lifting of the seed crop was completed on 29 September, of experiments and other ware crops on 3 October. At Woburn lifting did not start until 14 October because priority was given to sowing winter cereals. It was completed on 11 November. Lifting conditions were ideal except for a few days towards the end.

Most field experiments gave total tuber yields in excess of 50 t ha^{-1}. In an experiment at Rothamsted which compared maincrop and early cultivars, Maris Piper gave the best mean yield of maincrops followed by Pentland Squire and Désirée (56, 52 and 49 t ha^{-1} respectively). The early cultivars Arran Comet, Wilja and Estima gave 58, 56 and 54 t ha^{-1} respectively when left to maturity.

In an experiment comparing six maincrop cultivars Désirée gave 58 t ha^{-1} at Rothamsted, 63 t at Woburn, exceeded by Pentland Crown and Wilja at Rothamsted (61 and 59 t ha^{-1} respectively) and by Kingston, Pentland Crown and Wilja at Woburn (68, 64 and 65 t ha^{-1} respectively). At both sites the new cultivar Romano and the eelworm resistant cultivar Cara yielded least, the latter perhaps not fulfilling its late-bulking potential because all haulms were destroyed together.

Lupins. About 0·5 ha of *Lupinus albus* were grown, most was cv. Vladimir with a little cv. Kalina. The wet spring and late delivery of seed prevented sowing before late April. Maturity was consequently delayed and only a small area had been harvested by the end of November. Growth regulators, desiccants and fungicides had little effect on maturity.

Sunflowers. About 0·5 ha were grown. Despite delay in sowing until early May some of the many varieties tested were mature by mid-September and six of the seven experiments were harvested by the end of October. Yields ranged from 1·1 to 3·6 t ha^{-1}.

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Grass. Grassland was less productive than last year and only one cut of surplus grass was taken. Grass experiments were cut twice instead of the usual three times.

Cattle

One hundred and thirty seven have been sold fat and 30 stores bought.

Equipment

The four tonne per hour continuous drier which was taken out of the Rothamsted grain store last year was installed at Woburn and proved invaluable. Two Simplex radial drying silos were taken out to make room for it, slightly lessening storage capacity.

At Woburn the New Holland 1520 combine, which was short of separating capacity, has been replaced by an ex-Rothamsted 1530. A used New Holland 8040 was purchased to replace this at Rothamsted.

Because of a breakdown the submersible pump in the borehole which supplies irrigation water at Rothamsted was raised for a complete overhaul after more than 20 years' service.

Visitors

The Field Experiments Section arranged 154 separate programmes for visitors. The programmes ranged in complexity from individual tours of the field experiments to combined visits to scientific departments plus farm for parties of more than 50. There were about 1600 visitors this year, almost one-third came from overseas and about one-fifth were farmers.

Staff

Farms. G. T. Pearce retired from the Woburn staff after nearly 46 years' service. R. Sadler was appointed. Marion Steggall left.

Field Experiments Section. P. H. Finch and D. S. Martin-Smith left. Fiona Gordon was appointed. J. McEwen gave four outside talks on field beans to groups of farmers and advisers. He served as a member of the Arthur Rickwood Farm Advisory Committee during the year. R. D. Prew gave several outside talks to farmers and commercial groups on the results of the wheat multidisciplinary programme. He chaired a session on soil-borne pests and pathogens at the British Crop Protection Conference held in Brighton. He served as a member of the Boxworth Farm Advisory Committee.

PHYSIOLOGY AND ENVIRONMENTAL PHYSICS DEPARTMENT

Much of the Department's research is concerned with providing quantitative descriptions of the interactions between crops and their environment. As a consequence, experimental studies are often closely linked to the development of mathematical models. An important objective is the application of such models to practical situations; work on modelling apical development of wheat, which has been part of the inter-Institute collaboration on wheat crop modelling, is now being pursued further to generate a practical predictive scheme. To be able to develop quantitative descriptions, we must continue to extend our understanding of underlying physiological processes (e.g. photosynthesis and leaf growth) and integrate this understanding with knowledge of growth and nutrient requirements of crops. Collaborative work on wheat and sugar beet is reported here in which we are attempting this

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integration, particularly in relation to crop quality. The physical environment receives particular attention in studies of particle dispersal in crops, with major emphasis on the movement of pathogen spores. New approaches to analysing splash dispersal have been developed, and studies of dry dispersal of spores have revealed important information about the disease light leaf spot in oilseed rape, and its dispersal.

Plant and crop physiology

Timing of nitrogen supply and growth of winter wheat. Delaying N fertilizer in spring may improve the efficiency of N uptake and grain quality. However, such delay may decrease yield if leaf area and light interception are seriously decreased before anthesis, when grain number is determined, or after anthesis, while grains are growing. Yield may also be affected if later application changes photosynthetic efficiency. Some physiological responses to N timing were studied in the September sowing in the experiment described on p. 31.

Leaf expansion and senescence. Leaf area index up to anthesis was smaller when spring N was delayed until the two-node stage (late single treatment, LS) than when N was given earlier. The 15% smaller area was mainly a result of fewer shoots, as mean area per shoot at anthesis was only 5% less, but there were differences in areas of individual leaves. Leaf expansion had nearly ceased before the LS nitrogen was given and leaves were therefore smallest with this treatment. Maximum areas of the flag and penultimate main shoot leaf did not differ between the other three treatments. Maximum areas of the third and fourth leaves increased progressively with successive earlier application of the first lot of N.

Senescence of the top three leaves of ear-bearing shoots was slower with LS: consequently green area of the flag leaf with LS was similar during the second half of grain growth, and that of the second and third leaves was greater with LS than with other treatments throughout grain growth. Slower senescence with LS was probably related to less shading rather than late N uptake because N fertilizer applied after flag leaves emerged did not affect senescence. The consequence of these differences in senescence was that leaf area index was smaller with LS than with other treatments only until 30 days after anthesis, when it still exceeded 4·5; thereafter all treatments had similar values. (Thorne; Mullen, Rainbow, Stevenson and Hague)

Light interception and growth. The percentage of photosynthetically-active radiation intercepted at the beginning of May ranged from 35 to 50%, depending on N treatment, and increased steadily to 93% with LS and 97% with the other spring N treatments at anthesis. Total above-ground growth was proportional to light interception, the average efficiency between 19 May and 25 June being 2·6 g MJ^{-1}. Dry weight of ears at anthesis with LS was not decreased in line with decreased light interception, though grain number at maturity was 7% less than with the other treatments. (Thorne; Pearman and Scott)

Photosynthesis. Net photosynthetic rates of the flag and third leaf were measured near anthesis at a photosynthetically active photon flux density of 800 μmol quanta $m^{-2} s^{-1}$, with CO_2 partial pressure in the leaf chamber near ambient, and leaf temperature within 2°C of ambient. Photosynthesis and stomatal conductance of flag leaves were similar for all treatments, including wheat given no spring N, though a difference of 10% would have been statistically significant. Photosynthesis and stomatal conductance of third leaves were greatest in wheat given no spring N, and greater with LS than with other treatments. Both effects presumably relate to delayed senescence resulting from less shading rather than to differences in N supply. The responses of net photosynthesis to CO_2 and irradiance were also measured and are being analysed in relation to physiological models (p. 50).

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Light and CO_2 responses of flag leaves were measured at 20°C in the laboratory. Leaves from plots given no N exhibited a decrease in photochemical efficiency and a much larger decrease in carboxylation efficiency and the maximum rate of photosynthesis (P_{max}) in bright light and with saturating CO_2 compared to those from other plots. Efficiencies and P_{max} decreased with increasing leaf age under all treatments. Carboxylation efficiency and P_{max} were strongly related to the amounts of total soluble protein and RuBP carboxylase protein per unit leaf area, though at high N content the increase in photosynthesis tended to be less than that in protein. However, the *in vitro* activity of extracted RuBP carboxylase per unit carboxylase protein was greater at high N. The extra N in leaves from fertilized plots conveyed an advantage in the grain-filling period, as remobilization of proteins was delayed and photosynthetic capacity was maintained for longer. (Lawlor; Kontturi, Young, Driscoll, Harrison and Mitchell)

Development of winter wheat. In September-sown Avalon (p. 31) emergence, initiation of the first ten primordia and appearance of the first three leaves occurred later than expected from the temperatures, probably because of the dry seedbed. After rain in November, apical primordia were initiated at a similar rate to that observed in 1984–85. Appearance of later leaves was faster than in previous September-sown crops, though not as fast as in the October sowing. The N residues did not affect development as they did in 1984–85 (*Rothamsted Report for 1985*, 63), probably because the benefit from the previous rape crop, as judged by the growth response, was much less. (Thorne and Wood; Stevenson)

Interacting effects of sowing date and drought on winter wheat. Winter cereals at Rothamsted do not respond greatly to irrigation, even in years of substantial drought, but spring-sown cereals are affected more. The explanation may be either that winter cereals develop deep, dense root systems which exploit a large soil volume, or that the crops develop earlier, before drought affects yield components such as ear number. We examined these hypotheses in an experiment on the mobile shelter site with Avalon sown in September (E), November 1985 (M) and January 1986 (L). The crops emerged on 6 October, 11 December and 24 March 1986, and were sheltered from rain from mid-April. Plots were either irrigated weekly (I) or allowed to dry throughout the season (D). Total dry matter production with IE was 20 t ha^{-1}, IM decreased this by *c.* 10% and IL by almost 50%. Drought decreased total dry matter by 25% with E, by *c.* 40% with M and by 30% with L. Grain yield was 8·5 t dry matter ha^{-1} with IE and IM but was decreased by 27% with IL; there were fewer ears and fewer grains per ear. Drought decreased grain yield by 13% with E and by 30% with M and L. Mass per grain was decreased by 7% and 12% with IM and IL compared to IE.

Total water use with IE was 345 mm, and was 5 and 14% less with IM and IL. Soil water use was 209, 203 and 190 mm for DE, DM and DL, indicating that final soil water content and potential were similar. This was substantiated by measurements of leaf water potential, which were very similar in mid-July for all droughted crops. Stomatal conductance was higher with IL than IM and IE, and drought decreased conductance so that DE reduced water loss earlier than DL, one reason for the similar total water use. Water use was little affected by sowing date despite maximum lamina area index ranging from 4 to 2·6 with I and 3·5 to 1·2 with D treatments. Results will be analysed further in relation to observations made on root distribution and density with *in situ* observation tubes and by coring. (Lawlor and W. Day; A. T. Day, Young, Croft, Driscoll, Harrison and Mitchell with Weir and Barraclough, Soils and Plant Nutrition)

Yield compensation in oilseed rape. Within the multidisciplinary experiment (p. 26), the two sowing dates produced very different plant populations. The plots sown late (SL)

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produced fewer plants than those sown earlier (SE) (72 vs. 136 plants m^{-2}), developed more side branches per plant (6·6 vs. 4·9) with a larger final dry weight of side branches per unit ground area (313 vs. 223 g m^{-2}). On these branches there were more fertile pods (245 vs. 100 per plant) and a greater dry weight of all pods (949 vs. 845 g m^{-2}) but still 12% fewer pods per unit area. This resulted in a higher total seed yield (4·42 vs. 3·93 t ha^{-1} at 90% dry matter) from fewer, heavier pods.

The terminal and first two side branches had fewer pods per unit ground area for SL (32%, 28% and 12% less than SE) but branches 4 to 7 had more pods (14%, 43% 49% and 66%). Each category of branch had more pods for SL than SE (10% on the terminal to 85% more on branch 7). Development of side branches can thus lead to substantial yield compensation, but the consequences for timing and uniformity of maturity need to be considered. (Leach; Mullen and Rainbow)

Variation in yield and quality of sugar beet. Information from many N-response trials forms the basis of current general recommendations for N fertilizer use in sugar beet. However, the wide variety of soils used for the crop in Britain and the variability of our winter and spring weather require more specific recommendations on amounts and timing of N application, tailored to individual fields in particular years. The ability to give such advice will depend upon knowledge of soil N supply, the relationship between supply and the dynamics of uptake, the causes of variation in the N composition of the crop and the consequences for physiological processes governing growth, yield and quality.

Soil nitrogen supply, nitrogen uptake and yield. The main beneficial effect of N is to increase radiation interception by increasing leaf expansion, and the rate of canopy expansion has been shown to relate to shoot N concentration (*Rothamsted Report for 1985*, 66). However, although large crops grown in different seasons or at different sites tend to contain more N, no simple relation exists between soil N at the start of vigorous growth in June, N uptake and early shoot N concentrations. For instance, plots at Broom's Barn in 1982 had 174 kg N ha^{-1} in the soil, the shoot contained 3·84% N in June and final uptake was 260 kg N ha^{-1}, whereas in 1984 a similar amount of available N produced a shoot containing 4·66% N, and this was only marginally smaller than in a crop grown on fen peat at Chatteris in 1985, with almost three times the amount of soil N. Measurements of total N in the crop and soil have shown that in three of the past five years substantial losses of N occurred, probably through leaching, when the crop was growing actively in June and July, with serious consequences for N uptake and hence for N concentrations in the shoot and developing leaves.

There is no simple relation between total N uptake and absolute yields. A crop grown on a sandy loam at Broom's Barn in 1982 produced record yields of 28·1 t dry matter ha^{-1} and 15·4 t sugar ha^{-1} with an uptake of 240 kg N ha^{-1} whereas crops grown on a silty loam at Trefloyne in 1979 and 1980 and on a fen peat at Chatteris or a manured sandy loam at East Wretham in 1985 produced similar dry matter but less sugar with much greater uptakes of N. However, in all cases the optimum uptake for maximum sugar yield was within the range 200–220 kg N ha^{-1}. Total N uptake did modify crop quality, relating closely to the concentrations of amino-N in the storage root at harvest.

Predicting the nitrogen fertilizer requirement. If uptake of 200–220 kg N ha^{-1} does produce maximum sugar yield on all soil types, prediction of fertilizer requirement will be greatly simplified. Accurate prediction requires information on how much N the soil contains in spring and how much becomes available from organic reserves during growth. For sugar beet, the value of using a computer model to predict mineral N in spring from autumn measurements will be greatly enhanced if simulations can be extended until mid-May so that losses of spring fertilizer may be corrected.

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Following a preliminary evaluation of the model (*Rothamsted Report for 1985*, 66), a three-year series of trials was started in 1986 in collaboration with the Soils and Plant Nutrition Department, Broom's Barn and British Sugar to test the model under commercial conditions. Soil N was measured in 30 cm zones to a depth of 90 cm in autumn or early winter to provide a starting input and again just before drilling and in May to test model predictions.

Total mineral N to 90 cm depth in autumn ranged from 43 kg ha^{-1} on a coarse sand, and 50–75 kg ha^{-1} on medium loams and silts, to 160 kg N ha^{-1} in a sandy soil to which an animal-waste slurry had been applied and more than 400 kg N ha^{-1} in a fen peat. The measured amounts of N at drilling ranged from 30 to 120 kg ha^{-1} (excluding the fen peat site) and model simulations using autumn data predicted these to within 15 kg ha^{-1} for half the sites and to within 35 kg ha^{-1} for the rest. Prediction of N distribution down the profile were less accurate; amounts in the top 30 cm were underestimated and below 60 cm overestimated. Improvements to the leaching submodel and more specific information on soil properties may improve model performance. (Milford and Pocock; Grzesiukowicz with Jaggard, Broom's Barn, and Whitmore, Soils and Plant Nutrition and Dr M. J. Armstrong, British Sugar)

A technique for counting and sizing plant cells. Enzymic techniques of cell separation which retain the integrity of cell membranes and give better estimates of cell volume have been tested. Pectinase (0·5% w/v) in 0·5 M mannitol and 0·3% potassium dextran sulphate (KDS) after pre-incubation in mannitol/KDS solution successfully separated tobacco leaf cells within two hours. Recovery of intact cells was estimated at 70–80% using Evan's blue dye. The technique will be improved and applied to cereal and sugar-beet material. (Pocock; Grzesiukowicz)

Cellular events in winter wheat leaf growth. The Coulter counter has been used to examine cell division and expansion during the growth of winter wheat leaves. Material was obtained from an experiment in 1985 testing no N fertilizer vs. 300 kg N ha^{-1}, and drought vs. irrigation (*Rothamsted Report for 1985*, 63–65). On irrigated plots, the extra N increased both lamina and sheath lengths by 35%. The flag leaf lamina extended to more than half its final length whilst still enclosed within the sheath of the subtending leaf; the flag leaf sheath, although distinguishable from early in leaf development, did not elongate until the lamina tip had emerged.

Prior to leaf emergence, cell numbers within the lamina increased substantially but cell volumes changed little. After emergence, cell numbers were constant and cell volumes increased in unfertilized plants, and both cell division and expansion continued in fertilized plants. Overall, extra N increased cell number in the lamina by 50% and cell volumes by 15%. (Leach; Rainbow and Scott)

Effects of nitrate supply on thylakoid composition and function. The effects of nitrate nutrition on the composition of thylakoids and their efficiency in light harvesting, electron transport and carboxylation have been studied in wheat cv. Kolibri grown in a recirculating hydroponic system with 20, 1 or 0·1 mM nitrate. Compared to 20 mM nitrate, only 0·1 mM altered components of the thylakoids significantly, decreasing chlorophyll, thylakoid protein and lipid per unit leaf area. The lipid/protein and lipid/chlorophyll ratios decreased but there was no change in chlorophyll *a*/*b* ratio. The changes suggest that under conditions of N deficiency, protein complexes are closer packed in thylakoid membranes, but that the ratio of light harvesting complex to photosystems I and II is not changed.

Photosystem efficiency per unit chlorophyll was greater with 0·1 mM nitrate but P_{max} was not. Photochemical efficiency per unit area was slightly greater but carboxylation efficiency,

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which depends largely on the amount of RuBP carboxylase, was substantially smaller, and so was P_{max}. Exposing leaves to bright light for three hours decreased both P_{max} and efficiency, and the effect was greater with 0·1 mM nitrate. This greater susceptibility to photoinhibition may relate to the closer packing and higher efficiency of photosystems in the thylakoids and to the decreased ability (other than in CO_2 assimilation) of the low N system to use excitation energy in the thylakoids effectively. (Macnab and Lawlor; Young, Driscoll and Mitchell with Dr N. R. Baker, University of Essex)

Mathematical models of crop processes

Grain growth. A model of grain growth dynamics has been developed to determine the effect of temperature on growth rate and duration, to investigate the pattern of grain growth and to relate it to dry matter production after anthesis. An algorithm was derived to fit a monotonically decreasing growth rate to grain weight as a function of thermal time. It was assumed that there was a high initial rate, i.e. any 'exponential' growth soon after anthesis was excluded, and a discontinuity to zero rate at physiological maturity. The errors in grain growth data were assumed to be random but with density functions having a finite range. An efficient and locally stable procedure was used that satisfied the monotonicity constraint and allowed for the end discontinuity. The main function of the algorithm was to compute a shape-preserving spline approximation to grain growth data using cubic B-splines which span a finite number of data points.

The 'optimal' base temperature (T_B) for grain growth rate was defined as that which minimized the variation in rate with respect to thermal time during early growth. Weak sufficient conditions on the form of grain growth as a function of time and temperature were established for which growth rate admits an 'optimal' T_B. They defined a linear relationship between grain growth per unit time and temperature and its rate of change, and also defined the temperature dynamics for which the model assumptions hold.

The model was tested on winter wheat crops grown at Broom's Barn between 1981 and 1983, and gave T_B of 2·0°C and 7·5°C for rate and duration respectively. Grain growth rate could be divided into two phases in thermal time; during the first phase, about 30% of the duration from the start of 'linear' grain growth, growth rate was independent of total dry matter production rate per grain. The second phase showed a consistent increase in the coefficient of variation of growth rate across crops, and the rate was positively correlated with dry matter production. (Chalabi and Day)

Photosynthesis. A model is being developed to describe crop-level photosynthesis in terms of leaf-level responses. Photosynthetic rates are being analysed as a function of environmental and treatment variables such as light, temperature, nutrition and age. Measured light and CO_2 responses for individual leaves are used to characterize a model with four parameters: quantum yield, mesophyll resistance, dark respiration and a photorespiration constant. An initial generalized linear analysis has identified effects of leaf position and age, and treatment. (Chalabi and Day; Scott)

Apical development of winter wheat. The AFRC development model for cv. Avalon has been critically examined by parameter optimization on data from the multi-site survey in 1983/4. Optimization for the periods emergence to double ridges and double ridges to terminal spikelet indicated that the effects of temperature and vernalization had previously been overestimated and that of photoperiod underestimated. Alternative models indicated in the literature gave no improvement. The vernalizing effectiveness of different temperatures as described in the AFRC model was adequate, and the vernalization requirement function has been improved.

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Error in modelling development intervals comes from imprecise estimation of the date on which a development stage is reached, dependent on sample size and frequency, from differences between the weather perceived by the crop and that observed at the weather station, and from variation in the definition of the stage. The first of these accounted for much of the residual error for double ridges to terminal spikelet, but far less for emergence to double ridges. The use of daily mean temperatures rather than simulated three-hourly temperatures (used in the AFRC model) did not have any significant effect.

Data from other years confirmed the advantage of the optimized model over the AFRC model, though the difference for the double ridges to terminal spikelet phase was small. Analysis of two variety trials indicated that the model can be extended to varieties other than Avalon by simple modification of vernalization and maybe also of photoperiod response. In particular, development of spring wheats was well modelled by just removing the vernalization response. (Travis, Day and Chalabi)

Aerobiology

Dispersal of airborne pathogens

Deposition of spores in crops. Studies using artificially released *Lycopodium* spp. spores in a wheat crop have shown that deposition on a sloping surface can be adequately described as the sum of deposition on its horizontal and vertical projections. Low in the canopy, deposition on horizontal surfaces was by gravitational settling and deposition on vertical surfaces was almost negligible. High in the canopy, deposition on horizontal surfaces was twice that expected by settling alone. Deposition on vertical surfaces was about half that on horizontal surfaces and five times greater than predicted from inertial impaction rates based on mean wind speeds. More efficient deposition high in the canopy is due to turbulence. Turbulence is therefore important when estimating spore deposition on upper leaves, where infection may well have the greatest effect on crop yield. (McCartney with Dr D. E. Aylor, Connecticut Agricultural Experiment Station)

Dispersal of* Pyrenopeziza brassicae *spores from oilseed rape. Spores of *P. brassicae*, the cause of light leaf spot in rape, were observed to have been dispersed from an infected crop several hours after rain and were often trapped in groups of four. This suggested they were ascospores produced by the perfect stage of the fungus, previously only reported on brassica debris from Ireland and New Zealand, and never on oilseed rape.

In wind tunnel experiments, airborne spores were found downwind of infected crop debris and investigation revealed small apothecia (80 μm diameter) on decaying leaf laminae. Larger apothecia were later found on dead petioles. The fungus was cultured in the laboratory from ascospores released from apothecia on infected petioles from the field. Conidia from the cultures produced light leaf spot symptoms on oilseed rape seedlings. The identification has been confirmed by the Commonwealth Mycological Institute.

The occurrence of the perfect stage of *P. brassicae* may have important implications for the epidemiology of light leaf spot in brassicas; the airborne ascospores have the potential to be dispersed over large distances and the greater potential for genetic variation may affect pathogenicity and tolerance to commonly-used fungicides. (McCartney, Lacey and Walklate with Rawlinson, Plant Pathology)

Dispersal of splash-borne pathogens

Splash droplet dispersal modelling. A heavy-particle trajectory model has been developed to predict ensemble-averaged behaviour of water droplets up to 3 mm diameter in turbulent flow. The model includes Markov-chain turbulent dispersion, the modification

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of air turbulence due to particle inertia, conservation of particle mean momentum, and deposition. Components have been tested for some limiting cases and in simplified turbulent flows. Applications include airborne and splash-borne spore dispersal, spray movement and raindrop penetration in crop canopies. Theoretical work based on mass and momentum conservation during splash events has identified scaling parameters that relate the impact force of raindrops on a given surface to the potential for splash transport. (Walklate)

Splash droplet production. Size and initial velocity of splash droplets have been measured using high-speed photography. The size distribution was log-normal while the velocities of droplets in a given size class were best described by a square-root normal distribution. Smaller droplets tended to have higher initial velocities than large ones. Small incident drops produced fewer and smaller droplets, with fewer droplets projected below the horizontal; droplets splashed from barley leaves tended to be larger and travel faster than those splashed from bean leaves. (Macdonald, McCartney and Walklate)

Splash dispersal of* Rhynchosporium secalis *conidia. In rain-tower experiments conidia of *R. secalis*, the cause of leaf blotch in barley, were dispersed more effectively from infected straw lying on a metal plate (simulating inoculum at the base of the crop) than from infected leaves held on a nylon mesh (simulating infected leaves at mid-canopy). Proportionally more of the available conidia were dispersed from the straw and droplets carried the spores higher and further. Although there were fewer spores in droplets splashed from straw than from leaves, the relationship between splash droplet size and number of spores per droplet was similar. Incident drops 3 mm in diameter were about 100 times more effective than 1 mm drops in dispersing conidia. These observations suggest that the raindrop size spectra could partly determine risk periods for *R. secalis* dispersal. (McCartney and Walklate; Lacey with Fitt and Creighton, Plant Pathology)

Staff and visiting workers

D. W. Wood left after nine years at Rothamsted. K. Z. Travis joined the Department in April on a three year MAFF-sponsored contract to model crop development as an aid to management. O. C. Macdonald completed the studies towards his Ph.D. and joined the staff in October on a three year MAFF-sponsored contract to study factors controlling dispersal and deposition of spray droplets in cereal crops.

Mr M. J. Kontturi of the Finnish Agricultural Research Centre at Jokioinen, joined the Department for six months on an OECD fellowship to work on analysis and estimation of ribulose bisphosphate carboxylase-oxygenase activity and photosynthesis.

H. A. McCartney spent six months at the Connecticut Agricultural Experiment Station, New Haven, Connecticut, USA working on spore dispersal and deposition. He also attended a meeting of the International Organization for Biological Control Working Group on Models in Integrated Crop Protection held at Wageningen, The Netherlands 27–29 October 1986. P. J. Walklate attended the 3rd International Conference on Aerobiology, 6–9 August, Basel, Switzerland. W. Day spent a week in Avignon and Paris on an AFRC/INRA grant discussing wheat modelling, and attended an EEC sponsored workshop on Agricultural Water Management held in Leuven, Belgium in November. D. W. Lawlor attended the 6th International Photosynthesis Congress at Rhode Island, USA in August, and went to East Germany for two weeks in September under British Council sponsorship to visit research stations and university departments concerned with the application of plant biochemistry and physiology to agriculture. D. W. Lawlor also attended the EEC Kick-off meeting on the Energy from Biomass programme in April.

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BROOM'S BARN EXPERIMENTAL STATION

1986 and the growth of the crop. Frequent rain and poor drying conditions in late March and much of April caused both a delay in the start of sowing and a protracted sowing period. Only 4% of the crop was sown by the end of March, and only 35% by mid-April. Very little drilling occurred during a 10-day period in the third and fourth week of April but conditions then became favourable and a further 50% was sown during the last few days of April. Drilling was not completed until the second week of May. It was 26 April before 50% of the crop was sown—the latest for over 20 years.

The seed quality as measured by the standard laboratory germination test was the best ever; the germination of recommended varieties varied between 88 and 97% and averaged 94%. Field establishment was also good. The British Sugar Specific Field Survey (an annual survey of about 700 randomly selected sugar-beet crops, on which much of the information in this review is based) indicated that establishment averaged 67% and that an adequate plant density of 75 000 plants ha^{-1} was achieved on 62% of fields, compared with an average of 39% in the previous five years. The conditions following the sowing of most of the crop around the end of April were generally good. The soil was warmer than usual because of the late sowing and, at Broom's Barn, rain fell on most days in the first three weeks of May ensuring an adequate supply of water to the seeds. However, no single day had more than 6 mm of rain so there were few problems with slumping of the soil surface or the formation of soil caps.

Some exceptionally poor stands did occur elsewhere, often where seedlots with poorer germination were sown just before mid-April. Subsequent heavy rainfall caused slumping then capping where the surface dried which led to 1000 ha being redrilled. Strong winds at the end of May caused serious seedling losses on light soils, especially in the north, and a further 6000 ha had to be redrilled. There was evidence that incorporating manganese during pelleting slowed emergence, reduced establishment by about 6% and did not decrease deficiency symptoms, so its continued use will be reviewed.

At Broom's Barn, where two fields are sown with sugar beet each year, an area on the lighter field was sown directly into ploughed and furrow-pressed land in an attempt to reduce the effect of seedbed cultivation wheelings. Large clods or surface crusts were broken down with a Crosskill-type seedbed former on the drill. However, establishment was generally poorer than on the conventionally-prepared seedbeds, mainly because some seeds sown directly into ploughed and furrow-pressed seedbeds were left uncovered.

Each year a prediction is made of the level of bolting in the national crop, based on the number of days during April when the maximum air temperature does not exceed 12°C. The forecast, made on 1 May was for up to 15% bolting in crops sown before 23 March, up to 3% in those sown between 23 and 29 March, up to 1% in crops sown between 30 March and 12 April and virtually no bolting in crops sown after 12 April. Because most crops were sown late, a low bolting year was anticipated with only 20% of the crop affected and a calculated weighted mean of 0·36% bolting by the end of August. Bolter counts, made for the Specific Field Survey at the end of July, showed 1·2%, 0·4% and 0·2% bolting in fields sown in the periods 21–31 March, 1–10 April and 11–21 April respectively. Very few fields were sown before 20 March. On average 0·3% bolting was recorded which increased to 0·4% by the end of August when 30% of the crop was affected. There were small differences between cultivars and Ovatio, Julia and Primahill were the most susceptible.

The Specific Field Survey indicated that 13% of the total sugar-beet area had volunteer beet seedlings between the rows of sugar beet when examined in May, and 24% in June. These figures were similar to the 12% and 19% recorded in May and June 1985. In the monitoring study initiated by ADAS and continued by Broom's Barn, 61 of the 226 infested fields grew sugar beet in 1986. In 25 fields infestation levels were similar to those recorded

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when they were last in sugar beet, in 26 infestations were less and in seven they were increased. The Specific Field Survey revealed that, by the end of August, bolters had been hand pulled in 55% of infested fields, cut in 2% and treated with chemical in 4%; however in 39% of infested fields no control measures were used. These figures have remained similar for several years and the eradication of weed beet cannot be expected until all growers take effective control action.

The application of pre-emergence residual herbicides by a band-sprayer attached to the drill is no longer practised widely. Although May weather was unfavourable for spraying, weed control was generally satisfactory. This reflects the wide range of herbicides now available and the flexibility of modern application techniques. In crops sown directly into ploughed and furrow-pressed seedbeds overwintering weeds proved difficult to control. Under this husbandry system it is essential that herbicides which have effective contact activity are used to kill established weeds.

Any difficulties of weed control in 1986 were overshadowed by the damage caused to some sugar-beet crops by residues of the sulfonylurea herbicide, chlorsulfuron, applied to previous cereals. This chemical is particularly active, but development work in the UK gave little indication that residues in the soil could persist at a level sufficient to affect sensitive crops such as sugar beet. Chlorsulfuron, as a component of cereal herbicides, was first used on a large scale in 1983 and its use expanded significantly in 1984 with application predominantly in the autumn. At the time it was recommended that sugar beet should not be sown within 12 months of autumn application. In 1985 there were one or two instances where damage to sugar beet was thought to be related to residues of chlorsulfuron, but many more cases occurred in 1986. On both sugar-beet fields at Broom's Barn small areas of stunted reddish coloured beet were attributed to damage by chlorsulfuron, which had been applied in autumn 1984 to the preceding winter barley crop. These varied from patches 12 m wide by 2 m long to single rows where boom overlap may have occurred or where the rows may have coincided with the previous year's tramline wheelings. In areas where spray overlaps might have been expected, such as inside the edges of headlands, few signs of damage were found. The manufacturer has placed more stringent restrictions on cropping following the autumn application of chlorsulfuron, and sugar beet should not now be sown within two years of the chemical being applied.

The rapid emergence of most crops, and the high proportion of seeds germinating, resulted in less pest damage than usual. Fieldmice (*Apodemus sylvaticus*) reportedly caused damage over a wider area than in 1985. However, the overwhelming majority of this damage was slight and the area resown due to fieldmouse attack was only 80 ha (half of that in the previous year), after March sowings. Leatherjackets were also less of a problem than in 1985, possibly because the dry weather during the previous autumn adversely affected the survival of newly hatched larvae. The severe weather in February, when the ground was frozen for several weeks, may also have contributed to the mortality of leatherjacket larvae. Other soil pests were less apparent than normal, except in the King's Lynn and Wissington factory areas where pygmy beetles (*Atomaria linearis*) were prevalent in some crops.

Grazing by birds was also less, possibly because alternative foods were available when most crops were emerging. Only in the King's Lynn factory area was there extensive grazing, mainly due to pheasants. There were several reports of mangold fly (*Pegomya betae*) damage in June and some crops were treated twice with insecticide sprays. Crops which had been treated with granular insecticides suffered much less damage than untreated crops.

The wet weather during and immediately following sowing produced soil conditions which suited the ectoparasitic nematodes which cause Docking disorder (*Trichodorus* spp., *Paratrichodorus* spp. and *Longidorus* spp.). Nevertheless, the area of sugar beet reportedly damaged by these nematodes was relatively small (5400 ha). This partly reflects the widespread use of soil pesticides, but may also result from an underestimate of the affected

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area because in this year symptoms were masked by more obvious problems such as blowing (which affected a large proportion of the sandy soils on which Docking disorder occurs).

Since 1973, soil-applied granular pesticides have been used increasingly to control Docking disorder and other pest problems. In 1985 they were used on 106 100 ha of sugar beet (52% of the total crop area). Aldicarb was used on 44 900 ha and was particularly favoured for controlling Docking disorder. Problems with the manufacture of aldicarb during 1984 and 1985 (including the tragedy at Bhopal) resulted in shortages in 1986 of 'Temik' and 'Sentry', the two sugar-beet pesticides which contain this chemical. Aldicarb was consequently applied to only 18 300 ha in 1986, being replaced mainly by carbosulfan. Trials in 1985 comparing the range of granular pesticides on fields at risk from arthropod pests or Docking disorder provided useful information on the relative efficacy of the alternative materials (carbosulfan, oxamyl, carbofuran, benfuracarb, bendiocarb and thiofanox) and were repeated in 1986. The use of pre-emergence insecticide sprays, such as gamma-HCH, to control soil arthropod pests has decreased over the last three years from around 20% to 8%. This decline in usage is probably a result of a campaign by British Sugar development staff to reduce the number of wheelings prior to drilling. The area untreated with pesticides at drilling increased from 28% in 1984 to 38% in 1986.

June was much drier than average at Broom's Barn and by the end of the month the estimated soil moisture deficit had reached 35 mm. The first irrigation would best have been applied before the end of June but the opportunity was missed due to complications arising from the need to spray against downy mildew. After heavy rain on 4 and 5 July there were no further periods of prolonged moisture stress at Broom's Barn and by 24 August the soil moisture deficit on unwatered plots had reached only 95 mm. As a result there was no measurable response to irrigation in an experiment on sandy loam although a total of 57 mm was applied later in July and August. In many beet growing areas however, the dry period which began in June continued well into July and there would have been worthwhile responses to irrigation on light soils.

Although most of the experiments at Broom's Barn were not sown until late April or early May, foliage cover on crops grown in the recommended way was 40–45% on Midsummer day—almost the same as in 1985. Expansion of the foliage depends strongly on May and June temperatures and, at Broom's Barn, these were slightly greater than average in 1986, but 1·5°C less than average in 1985. Crops suffered very little water stress in the wet, cool months of July and August and throughout this period root yields were almost the same as in 1985, reaching 50 t ha^{-1} by the end of August. On many fields throughout eastern England there were reports of nitrogen deficient foliage. This may have been partly due to the general reduction in nitrogen fertilizer dressings, the average dose having dropped to 115 kg ha^{-1} compared with 123 kg ha^{-1} in 1985. However, it may also have been caused by relatively little mineralization of organic nitrogen in the soil during the abnormally cool weather of late July, August and September. However this is unlikely to have affected sugar yield.

Another severe winter, following an autumn during which aphid migrations were less than the previous year, prompted the issue in March of a forecast of low virus incidence (<1%) by the end of August. Migrations of *M. persicae* did not begin in the beet-growing area until late June with the first aphid being caught in the Broom's Barn suction trap on the 24th. British Sugar fieldmen found few green aphids in most areas until the first week in July, when a sudden increase was noted in coastal parts of East Anglia and South Humberside. Spray warning cards were issued at this time in the Cantley, Ipswich, Spalding and Brigg factory areas. The national incidence of virus yellows at the end of August, as measured by the Specific Field Survey, was only 1·3% with the highest (6·5%) in the Spalding factory area. However, during September there was a sudden and dramatic increase in visible symptoms of virus, almost all due to infection with beet mild yellowing virus (BMYV) following very large migrations of *M. persicae* in late July and early August. The source of these aphids and

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the virus they were carrying is still the subject of investigation, but in some places (especially in the Ipswich and Bury St Edmunds factory areas) virus infection was linked to nearby mangold clamps on which aphids had overwintered. In the Spalding factory area there were many glasshouses in the vicinity and there and around Royston, where virus infection was 100%, it seemed that incidence might be associated with nearby potato or brassica crops. At the time that these migrations of *M. persicae* were taking place many growers, especially in the Spalding factory area, were spraying their crops with insecticides to control black aphids, *Aphis fabae*. These treatments did not appear to have any effect on virus spread, suggesting that most of the infection was primary, i.e. introduced by winged aphids, and impossible to prevent with current insecticides so late in the season. Experiments at Broom's Barn in 1985 (*Rothamsted Report for 1985*, 48–50) indicated that losses from late but complete infection with BMYV were around 10% or less. Infections which did not become visible until late September probably had a negligible effect on yield.

Black aphids were particularly numerous in the northern region during August and spray warnings were issued in the Brigg, York, Kidderminster and Newark factory areas. High numbers persisted for much longer than usual (until late August in some areas) and caused visible damage in some fields. Wet weather in late August eventually encouraged the spread of *Entomophthora* fungus in aphid colonies which then declined rapidly.

As in 1985 powdery mildew was much less prevalent than from 1980–84. It was first seen in the Bury St Edmunds factory area in the third week of August and by the end of that month the Specific Field Survey showed that only 2% of the total crop area was infected. Within infected fields the average incidence of infected plants was at a record low level of 5%. About 8% (16 000 ha) of the crop was sprayed with sulphur to control the disease. Little downy mildew was recorded nationally but at Broom's Barn on Dunholme field it was prevalent, particularly in the variety Regina. Up to 4% of plants in some plots in a nitrogen experiment were found to be showing downy mildew symptoms towards the end of June. Emergency clearance was obtained to use the fungicide 'Fubol' 58 WP (metalaxyl+ mancozeb) and two sprays controlled the disease.

Beet necrotic yellow vein virus, the cause of rhizomania was identified for the first time in soil imported into this country from The Netherlands. The identification was made by the Ministry of Agriculture Harpenden Laboratory as part of the routine monitoring of imported potatoes and other root vegetables destined for processing or packing in this country. On this occasion the waste soil was disposed of by the processors in a municipal tip, in accordance with the Ministry's Voluntary Code of Practice for the Safe Disposal of Waste from Imported Vegetables, which seeks to ensure that such material does not contaminate agricultural land.

By November, 169 samples had been submitted to the Broom's Barn plant clinic from fields having problems of unknown cause. Most came from British Sugar fieldstaff, but 19 from other advisers. By far the major problem (39 samples) was suspected damage by residues of herbicides applied to previous crops (usually chlorsulfuron on cereals). Accurate or certain diagnosis was difficult except where differences in treatment were known to have occurred, as the symptoms were variable and overlapped with those of other problems. Other common diagnoses were soil acidity (21), Docking disorder (15), *Heterodera schachtii* (15), *Aphanomyces* (6) and strangles (7). The strangles were sometimes associated with *Aphanomyces* but also with periods of high wind early in the season.

On the basis of a simple model of the conversion of radiant energy to sugar, Broom's Barn predicted that the UK crop would yield 7·1 t sugar h^{-1}. The late but widespread infection with BMYV in East Anglia was presumed to have a negligible effect on yield. Once again many crops seemed to have absorbed very little nitrogen in the autumn; the sugar concentration in the roots was high and impurities were low. The final national sugar yield was 7·3 t ha^{-1} (40·4 t ha^{-1} roots at 18.1% sugar).

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Plant establishment

Effect of cultivation technique on establishment. Since 1981, seedling emergence has been monitored on seedbeds produced by several different cultivation techniques. Soil physical measurements have been used to examine the effects of water availability, temperature, impedance and other factors on the time course of emergence. In the first four years, differences in establishment between treatments were small (*Rothamsted Report for 1984*, 46–47). In 1984 heavy rain was followed by a period of rapid drying and the soil surface hardened to form a severe cap which prevented up to half the seedlings emerging. After the cap started to form, emergence was related to the integral impedance, measured using an integrating penetrometer.

Although treatment effects on final establishment were small there were differences between years in the rate of emergence. Many of the differences in emergence rate were removed by plotting emergence against thermal time above 3°C calculated from hourly soil temperature measurements. By comparing the thermal time course for a particular year with that for an unstressed crop, the effects of other factors were identified. For example, in 1984 the effects of the capped soil surface could be separated from the effects of a period of cold weather.

As none of the experiments in 1981–84 involved prolonged drying conditions, four cultivation treatments in 1985 and 1986 were covered with polythene tunnels from immediately after sowing until emergence had ceased. In dry conditions the thermal time courses of emergence for all treatments fell below that for an unstressed crop. The number of seedlings emerging before the covers were removed ranged from 7% to 45% in 1985 and from 26% to 54% in 1986. In these drying conditions treatments that had been levelled using a furrow-press during autumn ploughing gave the most seedlings. In 1985 the best emergence was achieved when the overwintered seedbed was drilled with no further cultivation but in 1986 the soil surface was too uneven for the drill to cover all the seeds and most seedlings emerged on the seedbed produced by a shallow spring cultivation with a rotary power harrow. The other treatments were on land left ploughed but not pressed on which deeper cultivation in spring was necessary to produce a level seedbed. Seedbeds dried more rapidly and fewer seedlings emerged. The total emergence on each seedbed before it dried out was proportional to the hydrothermal time elapsing before the water potential fell below a threshold of −1·7 MPa. Hydrothermal time is the product of water potential (measured using filter papers inserted horizontally into the soil at seed depth) above a base potential, temperature above a base temperature and time (*Rothamsted Report for 1983*, 44).

Sowing into land levelled in autumn and without subsequent spring cultivation is a promising technique as it reduces the amount of spring work and avoids compaction due to wheelings. However, the use of this technique has caused problems in drilling when the surface of the soil has been left too rough. The treatment resulting in most consistent emergence has been to level with a furrow-press in autumn and to give a shallow cultivation in spring. This allows the drill to work on a level surface and to sow the seeds into or near undisturbed soil. A plentiful supply of water to the seed is thus maintained in dry conditions; in wetter conditions the choice of cultivation technique seems much less critical. (Gummerson)

Seed advancement, establishment and bolting. At present growers are advised not to sow before 20 March because of the risks of poor plant establishment and increased bolting. Some consider that the risks from earlier sowing are less than the risk of reduced yields if conditions then deteriorate and drilling is not possible until late April or May, and on average over the last 15 years, 6% of the crop was sown before the recommended date.

Seed advancement increases the rate of emergence and often results in better establish-

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ment particularly from early sowings. Since part of the stimulus to bolt can be reversed by early warm conditions, prolonged advancement treatments may, if sufficiently high temperatures are used, give an additional benefit by partially devernalizing seed and decreasing bolting.

Studies in 1985 and 1986 used the technique described previously (*Rothamsted Report for 1985*, 42–43), whereby seeds were steeped in water, partially dried to restrict water availability and stored in a damp state. In this way, seeds could be safely exposed to 25°C for up to six days. Seeds, advanced by increasing the moisture content and storing for three or six days at 15°C, 20°C and 25°C, together with untreated seed, were sown in the field on 28 February, 1985. All the advancement treatment combinations made emergence more rapid and increased establishment. Bolting percentages were 23% from untreated seed and seed held for three days at 20°C, 30% from advancing at 15°C and 10% where advancing was at six days at 20°C and three and six days at 25°C.

In 1986, seedlots shown to be the most and least bolting-resistant in experiments by the National Institute of Agricultural Botany were steeped, partially dried and advanced for one, two, four and six days at 25°C. These, together with untreated controls, were sown in the field on 17 March. Advancement for up to four days made emergence progressively more rapid. Establishment was increased most following advancement for two or four days from 54% to 76% with the bolting-resistant seed and from 63% to 78% with the bolting-susceptible seed. Bolting was also progressively decreased by advancement for up to four days. Untreated seed from the bolting-resistant stock gave 6% bolters whereas advancement for one, two or four days gave 4·7, 1·7 and 0·8% respectively; comparable results with the susceptible stock were 9·0, 3·8, 2·5 and 1·3%. With both seedlots, no further improvement was given by extending the treatment from four to six days. (Durrant)

Hymexazol treatments to control seedling diseases caused by soil fungi. Several field experiments were undertaken between 1980 and 1982 testing fungicide seed treatments for the control of seedling diseases caused by *Aphanomyces cochlioides* and other soil-borne fungi (*Rothamsted Report for 1982*, 72–73). These led to the commercial use of hymexazol incorporated in the seed pellet at 10·5 g kg^{-1} on infested soils and in late or redrilled crops where damage by *A. cochlioides* is anticipated. Since then further experiments have investigated the optimum rate of hymexazol for incorporation in the EB3 organic pellet (which has replaced the mineral pellet used in earlier experiments), and sought to determine whether treating all seed used for the UK crop is justified. Seed steeped in thiram prior to pelleting, in addition to seed steeped in diethyl mercuric phosphate (EMP), was tested, as the former treatment will be adopted in the near future for the control of seed-borne *Phoma betae*.

Six experiments in 1985 tested the effect of incorporating hymexazol in the seed pellet at four rates from 3·5 to 14·0 g kg^{-1} and ten experiments in 1986 tested six rates from 1·75 to 17·5 g kg^{-1}. In this series of experiments, conducted by British Sugar, disease-prone sites were not deliberately selected. There was no direct evidence of post-emergence seedling disease in 1985 or in eight of the ten experiments in 1986. Nevertheless, hymexazol seed treatment consistently increased seedling establishment in 1985 and at some sites in 1986. Also, thiram-steeped seed, with or without hymexazol, produced more rapid emergence and slightly higher levels of seedling establishment than EMP-steeped seed. Hymexazol added at 3·5 g kg^{-1} to EMP-steeped seed in 1985 and to thiram-steeped seed in 1986 also increased the rate of seedling emergence. These unexplained improvements in emergence and establishment are consistent with other reports that hymexazol may have beneficial effects unrelated to disease control. The remaining two experiments in 1986 were on a site with a history of seedling disease caused by *A. cochlioides* and treating thiram-steeped seed with hymexazol at a rate of 3·5 g kg^{-1} or above increased the number of seedlings established from 75% to an average of 81% in one experiment and from 51% to 63% in the other. The

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proportion of seedlings with disease symptoms was decreased by low rates of hymexazol and disease was completely eliminated by rates of 7·0 g kg^{-1} or above.

Two experiments in 1985, using EMP-steeped seed, tested a combination of seed and soil applications of hymexazol on sites where damage was anticipated. Untreated seed and seed with hymexazol incorporated in the pellet at 7·0 g kg^{-1} were tested in factorial combination with soil treatments using hymexazol granules applied in the seed furrow at 0, 0·5 and 1·0 kg a.i. ha^{-1}. Some seedling disease caused by *A. cochlioides* was recorded at both sites. In the experiment on an organic soil, seed treatment increased establishment of disease-free plants from 51% to 74%. In the second experiment, at Broom's Barn, where soil capping severely restricted emergence, establishment of disease-free plants was increased from 34% to 40%. Soil application of hymexazol at both rates increased establishment to a similar extent to that given by the seed treatment. The combination of seed and soil treatment gave no additional benefit. The experiment was repeated at one site in 1986 with the inclusion of an additional hymexazol seed treatment at 3·5 g kg^{-1}. Seedling disease was low and seed and soil treatments had beneficial but largely equivalent effects.

These experiments, performed over a range of sites and sowing dates confirmed that, on average, small increases in seedling establishment are obtained by treating sugar-beet seed with hymexazol, and that moderate attacks by *A. cochlioides* are controlled by the 10·5 g kg^{-1} rate of application currently employed. It has yet to be determined whether hymexazol can give control under the severe disease pressure that can occur in late sowings or resowings in moist soils with high inoculum levels of *A. cochlioides*. (Payne with Mr J. W. F. Prince, British Sugar)

Environmental and nutritional aspects of crop growth and productivity

Management of headlands on beet fields. In recent years 'headland' zones have increased in area because larger machines need more space to turn. An aerial survey of fields larger than 10 ha showed that, on average, headlands accounted for 14·6% of the total cropped area. On fields giving about average yields for the district, the headland yielded 5 to 25 t roots ha^{-1} less than the rest of the field. In the worst cases about 30% of the headland was bare of plants, and other areas suffered as a result of soil compaction.

Since 1984 nine experiments have been made to test cultivation treatments for headlands. Common farm practice is to drill seeds into the headland first and then to use this area for turning. In our experiments this treatment usually gave the poorest yields. There was little yield difference as a result of using shallow (3 to 5 cm) or deep (10 to 15 cm) cultivations to prepare seedbeds after the bulk of the field was drilled. Neither cultivation was deep enough to eradicate compaction, much of which was reinforced by traffic after drilling. Within the headlands lowest yields were not in the outermost few rows, but 6 to 8 m into the field where traffic turns.

Despite improvements to yield made by drilling the headland after the bulk of the field and by cultivating to loosen the topsoil, headlands always yielded less sugar (between 0·5 and 1·5 t ha^{-1}) than the central portion of the field. This loss is probably inevitable unless fewer and less-compacting operations are made. On farms where yields from headlands are consistently poor it may be most economic to leave part of the headland unfertilized and uncropped for machines to turn. With appropriate management, these zones could have benefits in nature conservation. (Gummerson, Jaggard and Clark)

Variability of seedling growth. Variability in sugar-beet seedling growth arises partly from differences between seeds and partly from differences in the microenvironment within the seedbed. A reduction in seedling variability resulting from improved seedbed conditions could have several benefits: increased rate of growth of the crop as a whole, more effective

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use of herbicides and inter-row cultivations as a result of better timing and reduced harvest losses as a result of more uniform storage roots.

This new study investigates the variability which arises immediately after emergence and thus complements other studies of the period from germination to emergence. So far, the influence of emergence date on seedling size has largely been removed by restricting the study to groups of same-day emergers while the effects of inter-plant competition have been avoided by concentrating on early post-emergence growth. The first measurements, in 1986, have revealed that the variability of same-day emergers can be strongly affected by seedbed conditions. The chosen measure for variability was the coefficient of variation of total leaf area per plant CV(L) based on sequential measurements of leaf length and breadth.

At Broom's Barn, two contrasting treatments in a long-term soil fertility experiment were compared. On high fertility plots believed to have no nutrient limitations, CV(L) for same-day emergers increased from 23% to 27% between 7 and 35 days after emergence whereas on low fertility plots known to be particularly deficient in potassium, CV(L) increased from 24% to 52% during the same period. The increase in CV(L) on plots receiving standard fertilizer applications both at Broom's Barn and at another site were intermediate between the above values; between 7 and 35 days after emergence, CV(L) for same-day emergers increased from 25% to 38% on sandy loam at Broom's Barn and from 23% to 37% on loamy sand at Fakenham. For a late planting (12 June) at Broom's Barn, CV(L) increased from 27% to 56% between 7 and 26 days after emergence. In this case the large increase in seedling variability could have been due to moisture stress.

The next objective is to measure the variability due to differences between seeds by eliminating the variability due to differences in the microenvironment. This will be done by growing the plants in a glasshouse using well mixed soil with ample nutrients and water. A further step will be to investigate how far the variability due to differences within normal seedbeds can be reduced by practical measures such as giving supplementary nutrients and water. (Dunham and Brown).

Fibrous root growth. Studies of the fibrous root growth of sugar beet at Broom's Barn (*Rothamsted Report for 1983*, 46 and *Rothamsted Report for 1984*, 47–49) have continued. Intact seedling root systems have been washed out of large soil cores while samples of older root systems have been washed out of soil auger samples. The studies were extended to off-station sites in 1985 and 1986. From year to year and between sites, certain consistent features of sugar-beet fibrous root growth have now emerged. An early example is the pattern of production of primary laterals from the main root. For both field-grown and glasshouse-grown seedlings, the early primary laterals arise from the tap root at a regular average spacing of 2–3 mm irrespective of soil type. Later, additional primary laterals appear, many of them emerging at the same positions on the tap root as the earlier ones.

At Broom's Barn in 1982–84, between about 55 and 100 days after sowing (DAS) the total length of root, R (cm cm^{-2}), showed a very similar linear increase (given by $R=1{\cdot}9$ DAS $-96{\cdot}5$) despite very different sowing dates. During this period the sizes of both the top and the root system increase rapidly. At the end of this phase, growth of the top and fibrous root system slows, and partitioning of dry matter shifts in favour of the tap root. The timing of this change can vary from year to year and hence the maximum fibrous root length can also vary.

The depth of rooting of sugar beet has been taken as that depth at which the fibous root density falls below 0·01 cm root per cm^3 soil. By this definition, the rooting depth of the Broom's Barn crops increased at 1·6 cm day^{-1} from 40 DAS onwards in 1982–84. This rate was maintained at least until a depth of 120 cm was reached. Prior to 40 DAS the root system extended more slowly. Measurements on seedling root systems in 1986 gave an early rate of about 0·7 cm day^{-1}.

Measurements of the horizontal extension of lateral root growth in field-grown seedlings

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in 1986 indicated a rate of 0·4 cm day^{-1}. This accords with the observation, repeated several times, that the fibrous root systems of individual plants meet between the rows at about 80 DAS, assuming a delay of about 17 days before the appearance of the first laterals. With known average rates for the vertical and horizontal extension of the fibrous root system, it will be possible to model the increase in rooting volume of individual plants. The root system will be assumed to extend laterally in all directions until it meets that of adjacent plants, both within the row (i.e. at about 10 cm from the plant) and between the rows (i.e. at about 25 cm from the plant). Thereafter, it will be assumed that the rooting volume continues to expand only downwards.

Although these rates of extension have been derived mainly from measurements made at Broom's Barn, similar growth patterns were recorded in 1985 in a deep loamy sand at Lexham and in a silt loam at Spalding. However, in the same year, in a shallow loam over chalk at Swaffham Prior, the root system of an apparently healthy crop was seriously restricted. This was particularly evident in the latter half of the season and must have been largely due to the physical barrier of the chalk. There was no compensatory root growth in the upper part of the soil profile, however, and it is suspected that other factors, possibly nutritional, were involved. (Brown and Dunham)

Diseases and pests

Pesticides for Docking disorder control. Since the limited clearance of aldicarb ('Temik') and oxamyl ('Vydate') in 1973, granular pesticides have been used extensively to control damage to sugar-beet seedlings caused by *Trichodorus* spp., *Paratrichodorus* spp. or *Longidorus* spp. which results in Docking disorder. In 1986, of the 106 200 ha of sugar beet treated with pesticide granules at sowing (52% of the national crop) 26 000 ha were treated primarily to control Docking disorder. Several other products are now available including carbofuran ('Yaltox'), thiofanox ('Dacamox'), bendiocarb ('Garvox'), carbosulfan ('Marshal') and benfuracarb ('Oncol'). Independent assessments of many of these newer materials have not been made on fields at risk from nematode damage, so a series of experiments was started in 1985 on two such fields per year.

In 1985 and 1986, experiments were conducted at Docking, Norfolk (where the soil contained large populations of *T. cylindricus*) and Bielby, North Humberside (where the soil contained large populations of *T. primitivus* and *T. anemones*). All experiments consisted of four randomized blocks, each containing an untreated plot and the following pesticide treatments each split for low and high rates: aldicarb (0·52, 0·78 kg ha^{-1}), carbofuran (0·60, 0·90 kg ha^{-1}), carbosulfan (0·60, 0·90 kg ha^{-1}), oxamyl (0·60, 0·90 kg ha^{-1}), benfuracarb (0·60, 0·90 kg ha^{-1}), furathiocarb (0·60, 0·90 kg ha^{-1}), bendiocarb (0·30, 0·45 kg ha^{-1}) and thiofanox (0·56, 0·84 kg ha^{-1}). As expected no treatment improved plant establishment but several improved early growth producing more vigorous plants during mid-summer. Examination of soil samples taken in June to 0–20 cm depth from within the sugar-beet rows in some treatments showed that numbers of active *Trichodorus* in rows treated with aldicarb (0·78 kg ha^{-1}) and benfuracarb (0·90 kg ha^{-1}) were only about 40% of those in untreated rows, numbers in rows treated with carbofuran (0·90 kg ha^{-1}) were about 50% of those in untreated rows.

Severe plant loss due to wind damage in the experiment at Docking in 1986 meant that it could not be harvested. In the other three experiments the mean sugar yield of 6·85 t ha^{-1} in untreated plots was increased by the pesticide treatments (low and high rates respectively) to the following: aldicarb 9·0 and 8·74 t ha^{-1}, carbofuran 8·79 and 8·67 t ha^{-1}, carbosulfan 8·51 and 8·76 t ha^{-1}, oxamyl 8·47 and 8·77 t ha^{-1}, benfuracarb 8·51 and 8·44 t ha^{-1}, furathiocarb 8·65 and 8·84 t ha^{-1}, bendiocarb 8·04 and 7·80 t ha^{-1}, thiofanox 7·39 and 7·58 t ha^{-1}. All of the materials recommended for Docking disorder control (aldicarb, carbofuran, carbo-

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sulfan, oxamyl and benfuracarb) gave large and worthwhile yield increases—for example the additional yield following the treatment with aldicarb at 0·52 kg ha^{-1} (costing £27 ha^{-1}) would have been worth about £363 ha^{-1}. The experimental material (furathiocarb) gave similar large increases and even the two materials which are not considered to be efficient nematicides (bendiocarb and thiofanox) gave worthwhile (though smaller) yield increases. (Cooke)

Insurance use of soil pesticides. One of the purposes of the British Sugar Specific Field Survey is to identify situations within current farming practice which require attention from the research and advisory services. The information which has been collected on pesticide usage shows that the total sugar-beet area treated at drilling with granular pesticides has increased steadily from 43% in 1979 (the first year of the Survey) to 52% in 1986. In recent years about 13% of the area has been treated primarily to control the ectoparasitic nematodes which cause Docking disorder, and a further 12% to control the arthropods of the soil pest complex. Surveys and experiments suggest that this level of pesticide usage against these two important problems is justified. The proportion of the crop treated primarily to control *Myzus persicae* and early virus yellows has decreased from 8% in 1979 to less than 1% in 1986; this is partly in response to advice from Broom's Barn that severe, early outbreaks of the disease (against which granular pesticides may be effective) would not occur. However, treatments have increasingly been applied merely as general insurance measures (14% of the total crop area in 1979 rising to 25% in 1986). Unnecessary treatments not only waste money, they present a threat to the environment and may encourage the development of resistant biotypes. A continuing priority at Broom's Barn will therefore be to improve the efficacy of pesticide usage by enabling growers to specify more precisely the soils on which treatments are justified, as well as defining the optimum materials, rates and application methods.

Research has shown that techniques for forecasting damage by ectoparasitic nematodes or soil arthropods based on soil samples or baited traps are impractical because of the poor relationship between pest numbers and subsequent damage. Nevertheless, the diagnostic service offered by Broom's Barn enables the cause of damage to be identified and preventive measures planned with more precision for the next sugar-beet crop. Advice is given that fields treated as a general insurance measure should contain drill widths of untreated beet; pesticides should not be used if they fail to give consistent improvements to the health or vigour of the crop. Some instances of pesticide usage, reported under the general insurance category, occur where the target pest is known, but chemical control is not recommended (e.g. against birds or beet cyst nematode). Research is planned to investigate the possible use of pesticides to deter or control these pests and continue to rationalize the use of these materials. (Cooke and Dewar)

Powdery mildew epidemiology. As part of the Specific Field Survey conducted annually by the fieldstaff of British Sugar, a fixed number of fields, selected at random from within each fieldman's area, have been assessed since 1980 for the incidence of powdery mildew (*Erysiphe betae*) at the end of August. Prior to 1984 five such fields and, since then, ten fields per fieldman have been examined. Ten counts, each of 25 plants, are made across a diagonal of each field to determine the proportion of plants infected. In addition, the date of application of any control measure is recorded. From this information, the area of each field and mid-July estimates of the total area of sugar beet sown each year, it is possible to calculate both the proportion and the total area of the national crop affected and treated. The estimated proportion of the crop infected with powdery mildew, based on fields showing any level of infection at the end of August, ranged from 51% (108000 ha) in 1980 to 2% (4100 ha) in 1986.

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Because *E. betae* is an obligate parasite that can grow only on *Beta* spp. its main over-wintering hosts after the root crop has been lifted are the wild beet (*Beta maritima*) which is confined to coastal regions, and seed crops of sugar beet, fodder beet and red beet. Various environmental factors that might be considered important in determining the extent of survival of inoculum on these sources during the winter, and the extent of the development of the epidemic in the subsequent spring and summer were examined, using meteorological data gathered at Broom's Barn. In 1980–86 there was a relatively strong inverse relationship ($r=-0{\cdot}84$) between the percentage national area infected and the cumulative number of frost days (in which air temperature fell below 0°C) in the first three months of each year. No significant correlation was found with any one of a number of other factors, such as the mean air temperature or the total number of days with rainfall >0·2 mm during the spring and summer months, or the area infected in the previous year. Clearly the severity of the winter, affecting the survival of inoculum able to infect the root crop, was an important factor and may have accounted for the exceptionally low incidence of the disease in the last two years. However, data from additional years are needed before annual forecasts of the likely severity of the epidemic can be made with any confidence.

Powdery mildew, though developing eventually in a large part of the sugar-beet growing area of England every year, does not usually appear until mid-late July at the earliest. The question arises as to whether, given an abundant supply of inoculum, the disease would be able to develop in crops earlier than this. To examine this, and to determine the effect of time of inoculation on disease development and yield loss, experiments were carried out at Broom's Barn in 1985 and 1986 using artificially inoculated plots. In both these years national disease levels were very low; the earliest natural occurrences in sugar-beet crops in England were recorded during the last week in August and not until the middle of September at Broom's Barn. Plots were inoculated by transplanting a single powdery mildew infected plant from the glasshouse into the centre of each, on one of two successive dates (24 June, 19 July) in 1985 and three successive dates (1 July, 22 July, 12 August) in 1986.

In 1985, severity of disease was assessed on one occasion only (5–7 August) by recording the average disease score (on a 0–5 scale of increasing severity) on 135 plants in the centre five rows of each plot. There were significantly greater levels of disease on the earlier inoculated plots of both a susceptible (Nomo) and relatively resistant (Sharpes Klein Monobeet; SKM) cultivar at this time. Both cultivars were quite severely infected, suggesting that environmental conditions were favourable to disease development and that the absence of naturally occurring powdery mildew in sugar-beet crops at this time was more likely to have been due to the absence of inoculum. The average yield losses of Nomo and SKM, as a percentage of the yield of sprayed control plots, were 23% and 7% respectively. However, though the resistant cultivar suffered only one third of the loss of the susceptible, its yield in the absence of the disease was only 85% of the latter.

In 1986, assessments were carried out at approximately seven day intervals from the time of first appearance of the disease (5 August) until the end of September. The time from inoculation to first appearance of disease on plants adjacent to the infected transplant in each plot (latent period) decreased from 35 days in the case of the first inoculation to seven days in the inoculation carried out on 12 August. It appears that disease development in this particular year was inhibited by environmental or host-related factors during the period (July) following the earlier inoculations. Regressions fitted to the data for powdery mildew severity with time showed that, the earlier the inoculation, the more rapid was the rate of development of the disease, once established. The faster rate of development in plots was reflected both in an increased rate of spread to uninfected plants within the plots and in the more rapid colonization of leaves thereafter. Thus, despite the fact that the disease first appeared in all plots at about the same time (5–19 August) there were considerable differences in disease severity between the different inoculation treatments one month later. This

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highlights the importance of forecasting the potential inoculum load as well as the likely time both of infection and of the appearance of the disease, if optimum spray timing is to be achieved. (Asher)

The efficacy and persistence of aphicides in controlling virus yellows. The aphicides used most commonly on sugar-beet crops are pirimicarb and demeton-S-methyl (DSM), but, although both are effective in killing aphids present at the time of their application, there is evidence that they are less effective at limiting the spread of virus yellows (*Rothamsted Report for 1985*, 50–51). This is due partly to the advent of resistant aphids which are not killed by the insecticides but, more importantly, to the lack of adequate persistence of the active ingredients in the tissues of rapidly growing plants.

The search for alternative insecticides has been hampered in recent years by the lack of aphids in trials in conventionally-sown crops. To overcome this problem, trial crops were deliberately sown late (28 June 1985 and 26 June 1986) to attract aphids flying later in the season and provide suitable numbers for insecticide bioassays. Insecticide sprays were applied on 23 July 1985 and 30 July 1986, when the plants were at the four-leaf stage. Numbers of *Myzus persicae* and *Aphis fabae* were recorded 2, 9 and 14 days after treatment in 1985, and 2, 7 and 14 days after treatment in 1986.

In both years there were over 150 aphids per plant at the time of spraying and numbers increased considerably in the untreated plots during the assessment period; *A. fabae* were much more abundant than *M. persicae* (Table 1). In 1985, numbers rose to over 450 per plant

TABLE 1

The effects of aphicides on numbers of Myzus persicae (Mp) *and Aphis fabae* (Af)

		Days after treatment											
	Rate of product	1985						1986					
Treatment	ha^{-1}	2	9	14	2	9	14	2	7	14	2	7	14
			Mp			Af			Mp			Af	
Untreated		35	101	53	188	353	224	67	90	192	152	245	693
Pirimicarb	280 g	7	34	19	35	224	129	4	22	44	10	91	356
DSM	420 ml	11	35	30	15	141	106	4	15	48	4	46	251
Cyhalothrin	100 ml	22	26	14	100	224	105	19	13	30	43	127	357
Cyfluthrin	250 ml	22	47	19	59	272	129	14	22	23	33	130	369
Deltamethrin + heptenophos	300 ml	24	32	17	64	218	137	8	13	28	6	101	402

nine days after treatment but, thereafter, declined due to the activities of predators and parasites, and infection with *Entomophthora sp.* fungus. In 1986, numbers reached almost 900 per plant in untreated plots before *Entomophthora* infection decimated the populations. Predators and parasites were fewer in that year.

Initial knockdown of both *M. persicae* and *A. fabae* by pirimicarb and DSM was good in both years but within 10–14 days numbers rose again to high levels indicating that the persistence of these insecticides was poor (Table 1). Two new pyrethroids, cyhalothrin and cyfluthrin, gave poorer control than pirimicarb and DSM after two days and had little effect on re-immigration. The concept of applying a mixture of a systemic insecticide to kill aphids already present in the crop, and a pyrethroid to repel subsequent immigrants was tested using the commercial product deltamethrin plus heptenophos (D+H; 'Decisquick'). Initial knockdown with this product was only as good as the single pyrethroids in 1985, but was similar to pirimicarb and DSM in 1986. However, as with all the chemicals tested, persistence was poor after about a week.

During the course of these trials the plants increased in size from the four-leaf to the eight or even ten-leaf stage. The lack of persistence of all chemicals tested was probably due to

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their dilution in the plant tissues as the leaves present at the time of spraying expanded, and new leaves emerged. In a situation where large numbers of aphids are immigrating continuously into a young sugar-beet crop, the only way to achieve adequate control with currently available insecticides is by spraying at intervals of two weeks or less, or by using granules with systemic activity at drilling.

The incidence of virus yellows was assessed in these trials at the end of September when symptoms were visible. In 1985, virus incidence (mostly beet mild yellowing virus, BMYV) in the untreated plots was 52%. All treatments significantly reduced virus levels, but not in accordance with their aphicidal efficacy. The lowest levels (12%) were given by cyhalothrin and D+H, intermediate levels (19% and 21% respectively) by pirimicarb and cyfluthrin and virus incidence was relatively high (44%) in the DSM plots. In 1986 the incidence of virus (again BMYV) was much higher and every plant, regardless of treatment, became infected. Infection may have occurred before treatments were applied, since a high proportion of *M. persicae* caught alive in a nearby suction trap in late July was found to be infective when fed on sugar-beet seedlings.

These trials showed that in years when winged aphids are active at a time when the crop is very young, conventional sprays are unable to prevent them colonizing the crop and infecting it with viruses. (Dewar)

Virus yellows: field inoculation studies. Most of the spread of virus yellows within fields is believed to be caused by the apterous progeny of the migrant *Myzus persicae* which set up the initial foci of infection in sugar-beet crops. The rate of spread is influenced by the speed with which the initially-infected plants themselves become sources of infection. Rates at which beet yellows virus (BYV) and beet mild yellowing virus (BMYV) could be detected by enzyme-linked immunosorbent assay (ELISA) in leaves inoculated in the field with either virus, were compared. Studies were also made of the ability of aphids to acquire and transmit the two viruses.

One hundred and twenty plants of the cultivar Nomo were inoculated with one of the viruses in early June, when at the two to four-leaf stage. The exercise was repeated on separate plants that had reached the 15 to 20-leaf stage in mid-July.

Inoculations were made by placing on each plant a clip-cage containing 10 apterous adult *M. persicae* which had fed on glasshouse grown sugar-beet plants infected with either BYV or BMYV. The cages were removed after 48 hours, and the plots sprayed with pirimicarb. At intervals after inoculation, non-viruliferous *M. persicae* were placed in clip-cages on alternate leaves of selected plants; 48 hours later the aphids were transferred from each cage to a separate *Montia perfoliata* plant, where they were allowed to feed for a further 48 hours. Symptoms on the *M. perfoliata* plants, indicating that the aphids had acquired and transmitted the viruses from the sugar-beet leaves, were recorded after five weeks. Following transference of the aphids from the sampled sugar-beet leaves, a disc was cut from the part of each leaf on which the aphids had been feeding and ELISA used to detect BYV and BMYV. Thus for alternate leaves on each sampled plant an absorbance reading was obtained plus an assessment of infectivity.

BYV was detected by ELISA in the youngest leaves one week after inoculation at the two to four leaf stage. Within three to four weeks all leaves gave absorbance readings denoting infection. The oldest and middle leaves, which were the only ones to show yellowing symptoms, generally gave the highest absorbance readings. Absorbance values declined later in the season, indicating a drop in virus concentration as plants aged. BYV was readily acquired and transmitted by *M. persicae* from all infected leaves from one week after inoculation.

BMYV took longer to increase within inoculated plants, and low absorbance readings were obtained until four weeks after inoculation. Few leaves on inoculated plants giving high

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absorbance readings and distribution of BMYV within the plant was erratic. There were few successful transmissions from infected leaves to *M. perfoliata* in the early part of the season, but many more during August.

When plants were inoculated at the 15 to 20-leaf stage, both viruses were detected three to four weeks after inoculation. BYV and BMYV were both acquired and transmitted from a high proportion of infected leaves during August and September.

The results indicated that young field-grown sugar beet inoculated with BYV became sources of infection more rapidly than those inoculated with BMYV. This may explain why within-field spread of BYV usually occurs earlier than that of BMYV. The use of furrow-incorporated granular pesticides and aphicidal sprays may therefore be more effective in decreasing spread of BYV than of BMYV. (Smith)

Broom's Barn Farm

Cereals. During 1985 it was decided not to burn straw in future but to chop and plough in any that was not baled and used for cattle bedding. Consequently the spring barley and winter wheat straw in the five year rotation (sugar beet, spring barley, winter oats, winter wheat, winter barley) was treated in this way. Farmyard manure was spread on the oat stubble instead of the wheat stubble to avoid any problems that might be created by ploughing in straw and manure during the same year.

All the land for winter cereals was ploughed and furrow-pressed (following sub-soiling on the spring barley stubble) but because conditions were so dry, many clods were formed and further cultivations were necessary on all areas before drilling, which was completed by 15 October. Brock wheat was sown on Brome Pin and Bullrush fields, Igri barley on Flint Ridge and The Holt and Pennal oats on Little Lane and Marl Pit. Germination was slow but final establishment was good everywhere except on the heavy, stony areas of Little Lane. Cypermethrin was applied to crops which emerged early to prevent barley yellow dwarf virus, but the weather (either wet or frosty) prevented herbicide spraying in the autumn. Weed populations were very low; chickweed was the most common weed but on most fields it was severely affected by the frost and did not compete with the crop. A mecoprop/ioxynil/bromoxynil mixture was used in the spring with the addition of isoproturon on the winter barley to control annual meadow grass.

The wild and volunteer oats were controlled in the wheat with flamprop-M-isopropyl at the end of May. The combination of a relatively easy beet harvest in autumn 1985, early ploughing and severe February frosts left seedbeds for spring barley in excellent condition and Triumph was sown on Hackthorn and White Patch fields on 18 and 21 March. Early spring growth of all cereals was slow, so the first nitrogen was applied in mid-March. The winter wheat and winter barley had three applications totalling 250 kg ha^{-1} and 140 kg ha^{-1} respectively, the winter oats had 120 kg ha^{-1} in two applications and the spring barley 100 kg ha^{-1} in one application.

Little disease was apparent early in the year and the first fungicide was applied to the winter wheat and winter barley during May with the growth regulator. The barley required no further treatment but the wheat was sprayed once more at ear emergence to control Septoria and mildew. Few grain aphids were seen and aphicide was only used on experiments. Mildew on winter oats and spring barley was controlled by a single spray in late June.

Harvest started with the winter barley on 24 July. The heavier of the two fields yielded more grain at 6·7 t ha^{-1} than the lighter field at 6·2 t ha^{-1}. This trend was maintained for the other cereal crops, probably because the increased moisture holding capacity of the heavy soil was of benefit through the very dry period in June. The oats were harvested during a dry spell in mid-August and yielded 6·3 t ha^{-1} from the lighter field and 7.0 t ha^{-1} from the heavy field. There were some very drying winds at this time and on one day grain came from the

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combine with as little as 12% moisture. Yields of spring barley which was cut immediately after the oats were the best ever at Broom's Barn; 6·4 t ha^{-1} from the heavier field and 5·9 t ha^{-1} from the lighter one. Very heavy rain prevented further harvesting until the first week of September when the winter wheat was cut and yielded 7·8 t ha^{-1} on the heavier field and 7·4 t ha^{-1} on the light field. Despite the variable weather only 30% of the grain required drying.

Sugar beet. During the autumn of 1985 the land was prepared for sugar beet by using a furrow press with the plough. Both March and April had 13 mm more rain than average with rain on at least 20 days in each month which prevented drilling on both fields (Dunholme and New Piece) until late April. By the end of April 30% of the crop has been sown; a further 63% was sown by 19 May leaving only about 1 ha for requested late sowings, the last of which was on 26 June. Seedling emergence was good (up to 90%) from all sowings.

A granular insecticide (aldicarb plus gamma-HCH) was used in the seed furrow on 64% of the crop to decrease the risk of early virus infection and to help plant establishment; it was not used where it would interfere with experimental treatments.

Weed control started with a pre-emergence band spray of chloridazon at drilling. Where the crop was drilled directly on to furrow-pressed soil paraquat was added to kill the overwintered weeds. This was not effective and surviving weeds had to be removed by tractor and hand hoeing. The remaining weed control was by sequential low doses of herbicide.

In the wet conditions of early June patches of severe infection with downy mildew were found in some experiments. Clearance was obtained for 'Fubol' 58 WP (metalaxyl+ mancozeb) to be used to control the disease and two sprays were applied, in late June and early July. Sulphur was applied on New Piece to control powdery mildew because diseased plants were used to inoculate an experiment in that field; sulphur applications were unnecessary on Dunholme. Early in the season aphids were not sufficiently prevalent to make general spraying necessary. However, many *Myzus persicae* invaded the crop in late July, and patches of plants showed symptoms of beet mild yellowing virus in early September. On late-sown areas infection was particularly striking. All of New Piece was irrigated; most received 45 mm in three applications, the remainder had 60 mm in four applications.

Harvest started on 29 September in very dry conditions. These improved when some rain fell in mid-October but quickly deteriorated by the end of the month with more heavy rain which continued through November causing some difficulties on the heavier of the two fields. The last beet were harvested on 11 December but due to the good crop and high sugar percentages in this area, deliveries to the factory were not completed until 15 January. The final root yield was 43·0 t ha^{-1} with sugar percentages ranging from 16·9% to 19·8% and averaging 18·3%; tares averaged 10·0% dirt and 6·0% tops. National yields averaged 40·4 t ha^{-1} at 18·1% sugar.

Livestock. During October and November 1985, 101 Friesian steers were bought and fed to appetite on a basic diet of one-third brewers grains and two-thirds beet pulp, plus 1 kg per head per day of barley with added minerals. Some hay was fed during the settling-in period and barley or oat straw was always available. All were implanted with 'Ralgrow' and 'Finaplix' to increase liveweight gain. The steers were sold during Spring 1986. (Golding)

Staff and visitors

M. J. Armstrong left to join British Sugar as an agricultural development officer. Kay Brown and Helen Smith were awarded Ph.D. degrees by Nottingham University and the University of East Anglia respectively.

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R. K. Scott took over the Chairmanship of the SBREC sub-committee on rhizomania and the working group on seed. Several members of Broom's Barn staff contributed to the work of the International Institute for Sugar Beet Research (IIRB); R. K. Scott was appointed Vice-Chairman of the Scientific Advisory Committee and other members attended meetings of the study groups on breeding and genetics (P. C. Longden), pests and diseases (M. J. C. Asher, A. M. Dewar and H. G. Smith) and weed control (W. E. Bray). P. C. Longden presented a paper and W. E. Bray chaired a session at the IIRB Winter Congress at Brussels which was also attended by R. K. Scott and M. J. Durrant. D. A. Cooke attended the meeting of the European Society of Nematologists at Antibes, France. M. J. C. Asher visited Italy on a tour of rhizomania-infested areas and research institutes. R. K. Scott was invited to lecture at the University of California, Davis. He combined this with a lecture tour of the major centres for sugar-beet research in Colorado, North Dakota and Minnesota.

A. M. Dewar and G. H. Winder attended a meeting of the International Organisation for Biological Control at Bonn in November. R. K. Scott and P. C. Longden joined a study tour to Austria organized by Anglo Maribo seed company; R. K. Scott and M. J. Durrant joined a study tour of France organized by Miln Masters seed company; W. E. Bray joined a study tour of Germany organized by BASF.

Several members of staff contributed to the United Kingdom Irrigation Association conference on 'Irrigating Sugar Beet' at Silsoe in February, the British Crop Protection Council Conference at Brighton in November, and the Association of Applied Biologists conference on 'Crop protection of sugar beet and crop protection and quality of potatoes' at Cambridge in December.

Visitors to the Station included senior staff from sugar-beet centres in Germany, the Netherlands and Denmark, the President and Vice-President of Amalgamated Sugar, USA, a group of research directors and senior staff from developing countries, and groups of students from Edinburgh School of Agriculture, Newcastle University, Silsoe College, Wye College (London University), the School of Biological Sciences (University of East Anglia), Lincolnshire College of Agriculture, and Hertogenbosch (the Netherlands). Other visitors included young farmers and members of the Institute of Bankers. Dr R. E. Green and two other members of staff of the Royal Society for the Protection of Birds spent several months at Broom's Barn working on the ecology of stone curlews.

Training courses were organized for Independent Crop Consultants, British Sugar Steckling Inspectors (held at Holmewood Hall) and MAFF beet cyst nematode surveyors. A large national demonstration on irrigating sugar beet took place at Lexham, Norfolk in July with extensive participation by Broom's Barn which included a season-long field experiment. Members of staff gave talks on a range of topics concerning sugar beet to farmers meetings organized by British Sugar, ADAS, agrochemical companies and the local agricultural training board. M. J. C. Asher, R. K. Scott and A. M. Dewar appeared on farming programmes for Anglia TV and BBC.

Winter meetings were held at Broom's Barn on 'Problems associated with close sugar-beet rotations' (R. A. Dunning, D. A. Cooke, M. J. C. Asher and P. C. Longden), 'Sugar beet research and development in France' (K. J. Thompson) and 'Agricultural Research and Development by British Sugar' (C. W. Peck).

The work of Broom's Barn is undertaken for the Sugar Beet Research and Education Committee.

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