ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1985

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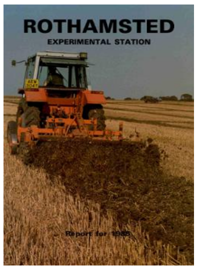

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INTRODUCTION

The Division comprises Broom's Barn Experimental Station, the Rothamsted Farms, the Field Experiments Section and the Physiology and Environmental Physics Department. A major activity is the planning and execution of multidisciplinary field experiments with staff from other Divisions. The Head of Division chairs the Working Party for Field Experiments which takes overall responsibility for planning the Station's field programme. Members of the Division take a prominent part in the Working Party and its sub-groups, and the Farms and the Field Experiments Section take responsibility for executing the programme. Crop physiologists in the Physiology and Environmental Physics Department work as part of a team with physiologists, agronomists and chemists from Broom's Barn in field-based research programmes on sugar beet. Other members of the Physiology and Environmental Physics Department play a similar role for other crops aiming to explain and predict crop responses to weather and crop husbandry.

BROOM'S BARN EXPERIMENTAL STATION

1985 and the growth of the crop. The weather in March was cold and wet, and only 4% of the national sugar-beet crop, mainly on the lightest soils, was sown by the end of the month, compared with 67, 19 and 39% sown in March of 1982, 1983 and 1984 respectively. The majority of the crop was sown during the first and third weeks of April, both of which were warm and dry. The trend of improving establishment in recent years continued in 1985; surveys of nearly 800 fields showed that, on average, establishment was 66·5%—about 5%

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greater than five years ago. Nevertheless, 58% of crop still did not achieve the target of 70% establishment which is necessary to produce an adequate plant density. The major cause of poor establishment, as last year, was capping; 2·5% of the national crop had to be redrilled following capping, with a further 1·0% redrilled for other reasons. The rain in the second week of April was sufficient to cause the surface of some soils to slump and form a cap when it dried during the following week. The problem was alleviated to some extent by the relatively rapid emergence resulting from the warm conditions after sowing. Frost damage caused 0·3% of the national crop to be redrilled. There were five ground frosts in April and three in May, those on 24 and 26 April being particularly severe.

Drilling at Broom's Barn followed a similar pattern to the national crop and several experiments were sown in the first week of April. The range of establishment from these sowings was 64–75%, seedlings being lost due to capping, frost damage and soil pests (especially slugs). A straw incorporation experiment, drilled during a break in the rain in the second week of April, capped quite badly giving only 58% emergence. Sowings made later in April on heavier land gave variable establishment depending on how well the drill was able to cover the seed. In a virus yellows experiment, a difficult seedbed resulted in emergence varying from 50–80%. Showers at the end of April only slightly reduced the strength of the caps which had formed. The first week of May was dry, causing seedbeds with insufficient fine aggregates to dry out with consequent decreases in establishment. Heavy rain later in May produced more capping which decreased the establishment of the later sowings.

The number of days on which the air temperature did not reach 12°C in March, April and May was close to average but, because of the late sowing, it was judged that most seeds and seedlings had not received enough post-sowing cold to become vernalized, and a forecast for few bolters was made. This was confirmed by counts made in July in 705 fields as part of the British Sugar Specific Field Survey, which showed 0·9% bolting in crops sown in March, 0·6% in crops sown in the first ten days of April and 0·4% in sowings later than this. It is still, however, a matter of concern that 88% of fields contained some bolters and that a third of growers with affected crops took no action to prevent seed returns. There were small differences between cultivars, with Proma (0·9%) and Julia (0·7%) being the most bolting susceptible.

In addition to bolters arising from seed sown this year, 19% of crops surveyed also had weed beet seedlings (arising from seed shed in previous years) between the rows of sown seeds when examined in June. This is less than the 36% found to be infested last year, although it is too soon to say if this represents an improving trend.

The increasing area of fodder beet, particularly in western factory areas, also contains bolters, which can interpollinate with sugar beet and perhaps contribute to the weed beet problem. Farmers with sugar beet or fodder beet should appreciate the risk presented by bolters and must be persuaded that it is in their long-term interests to control them to prevent seed returns.

Fieldmice were very active in a number of areas and there were reports of several fields in which pelleted seeds were dug up from lengths of row and their embryos eaten. Almost 150 ha were redrilled as a result of such damage.

Reports from the Agricultural Development and Advisory Service (ADAS) forewarned that leatherjackets would be a problem in fields following grass leys, and some serious damage caused by these pests occurred in northern and western beet-growing areas during April. Slow growth of the crop in May due to the cold, wet conditions allowed other soil pests, such as springtails, millepedes and pygmy beetles, to cause more damage than usual, necessitating redrilling in some fields, especially on silt soils. Slugs were also a problem in heavier soils.

In some areas crops had to be redrilled following grazing of young cotyledons by birds, especially pheasants and partridges, or damage by flea beetle. Heavy infestations of beet leaf

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miner were first observed in late May/early June, but were not serious enough to warrant treatment in most fields.

The wet weather in May also encouraged the activity of the ectoparasitic nematodes which cause Docking disorder (*Trichodorus* spp., *Paratrichodorus* spp. and *Longidorus* spp.), and symptoms of damage were reported on over 18000 ha of sandy soil (about 9% of the national crop).

Granular pesticides were applied in the seed furrow at sowing to 52% of the national crop to minimize damage by many of the pests which affect establishment or early growth. Although there was often a specific reason for these applications (11% of the national crop was treated principally to control arthropod pests of seedlings, 13% to control Docking disorder, 3% to limit the spread of virus yellows), much of the crop (26%), was treated as a general insurance. Although outbreaks of pest attack are difficult to predict, pesticide usage to control some specific problems is often justified. For example, although Docking disorder was widespread in 1985, symptoms in treated fields were usually very slight, and yield losses would undoubtedly have been far greater in the absence of pesticides. However, many of the general insurance treatments were probably unneccessary and should have been discouraged. More work is needed to enable growers to identify more precisely where pesticide usage is warranted and to improve our advice on the relative efficiency of the increasing number of materials which are available.

Manganese deficiency was found in 31% of beet fields examined at the end of May, with 6·6% of plants affected. The problem occurred on some soil types where it is not normally seen, probably because wet soil conditions in the spring decreased manganese availability and, more importantly, cold weather during the end of April and early/mid May (when mean temperatures were 1–2°C below average) caused slow root growth.

Nationally there is a continuing decline in the use of full rates of herbicides in a traditional way either as soil-incorporated pre-drilling treatments or as pre-emergence treatments. More reliance is now placed upon post-emergence programmes involving repeated overall sprays of herbicides at much reduced rates in low volumes of water. This allows more accurate timing of sprays to control successive weed flushes at their most susceptible stage, generally with improved crop safety. In the cool and moist conditions in the spring of 1985, satisfactory activity against weeds was obtained whether the sprays were applied to the soil or the foliage. However, the high incidence of manganese deficiency and a period of warm weather with some cold nights in late May/early June led to crop damage by some herbicide applications. Season-long weed control was mainly satisfactory although a few gappy crops were affected by weeds in the autumn.

At Broom's Barn all of the sugar-beet crop received a pre-emergence application of a residual herbicide at drilling. This gave satisfactory weed control when followed by up to two low rate applications of a contact/residual herbicide applied when the weeds were in the cotyledon stage.

The productivity of sugar-beet crops is extremely sensitive to the temperature experienced during May and June, when the canopy is developing. In 1985 during this period, the mean air temperature at Broom's Barn was 1·1°C less than the long-term average; it was, however, warmer than 1984, and as a result the canopy grew faster. A crop grown at Broom's Barn with standard, recommended husbandry had 46% foliage cover on Midsummer day, 1985, compared with only 28% in the previous year. This advantage over last year was typical of southern East Anglia. However, for most of England, where the early summer of 1984 was warm, the reverse was true, and the foliage cover in that year was better than in 1985.

Through the late spring and early summer the weather at Broom's Barn was wet, and rainfall remained at about average levels during July and August. However, moderate soil moisture deficits developed, the estimated deficit on unirrigated plots at the end of August

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being 100 mm. The response to irrigation on our sandy loam soil was large, at 1·1 t ha^{-1}. Usually we expect beet to grow at about the potential rate set by the aerial environment during September and October, whether irrigated or not. However, in 1985, this period was exceptionally bright and dry, with only 27 mm of rainfall, and non-irrigated crops probably grew at less than the potential rate, at least during the early part of the autumn.

The plant clinic is one of several ways in which information and advice passes from Broom's Barn, via British Sugar, to the sugar-beet grower. In 1985 we received 220 samples of plants and soil from crops with problems difficult to diagnose; most came from British Sugar staff, but some were from other advisers or from growers. The commonest diagnoses were Docking disorder (48 samples), soil acidity (34), waterlogging and anaerobic soil conditions (18), *Aphanomyces* attack often associated with soil acidity (16), trace element deficiency (12), frost damage (12), soil compaction (10), wind damage (9), and phosphorus deficiency associated with waterlogging and anaerobic conditions (7). The principal function of the clinic is to use our specialist knowledge to help British Sugar's staff diagnose and remedy problems encountered by growers, but it also keeps us informed of the various problems which occur in the field. Although the examination of samples is laborious and may involve several scientists, it is a valuable service to the industry which finances us, and can provide us with an early indication of problems which will require investigation.

The threat of serious aphid infestations, posed by the large migrations of *Myzus persicae* recorded at Broom's Barn during autumn 1984, disappeared after the extremely severe winter which killed most aphids overwintering as active stages. An exceptionally large number of ground frosts (80) was recorded at Rothamsted from January to March which, according to the Watson-Hull forecast, indicated a very low incidence of virus yellows ($<1\%$) at the end of August both nationally and in the more susceptible southern areas. The Specific Field Survey results confirmed this forecast and only 0·8% of plants were recorded nationally as infected at the end of August. The highest regional incidence (only 2·3%) occurred in the Ipswich factory area. However, severe outbreaks of virus yellows were reported in four localities, with some fields showing 80–90% infection; the sources of infection were found to be a red beet clamp, and fodder-beet clamps which had been used as stock feed through the summer. The increase in fodder-beet production may therefore be a potential disease threat to the sugar-beet root crop in the future.

As expected after the severe winter, few green aphids were found in beet crops in June, and numbers generally remained below the threshold for spraying (1 per 4 plants) at that time. However, a large migration of *M. persicae* in late July/early August was detected by the suction trap at Broom's Barn. Although this may have introduced yellowing viruses to the area, crops were probably at a stage when this would have little or no effect on yield.

In the Virus Yellows Field Survey, 346 fields throughout the beet-growing area were examined by British Sugar fieldmen at the end of August. Leaves from plants diagnosed as being infected with virus yellows were sent to Broom's Barn and tested by enzyme-linked immunosorbent assay (ELISA) for beet yellows virus (BYV) and beet mild yellowing virus (BMYV). Of the 297 leaves tested, 56% contained BMYV, 4% BYV, 1% both viruses and 39% no virus. A generally low incidence of infection was recorded in the surveyed fields, the maximum being a field in the Peterborough factory area with 18%, confirming the results of the Specific Field Survey.

As predicted by researchers at Imperial College, London University, from numbers of eggs laid on spindle trees in the autumn, black aphids, *Aphis fabae,* became very numerous in northern East Anglia and eastern East Midlands during July. This stimulated the issue of spray warning cards in the Bardney, Bury St Edmunds, Cantley and Ipswich factory areas. Spraying was certainly justified in some sheltered fields where the highest aphid numbers occurred, but in many other fields it is doubtful whether yields would have been affected if crops had not been sprayed, since beet plants, adequately supplied with water throughout

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the wet summer, would probably have been able to compensate for damage caused by feeding of the aphids. The wet summer also encouraged the spread of *Entomophthora* fungi in aphid colonies, causing a rapid decline in numbers in early August.

As a result of a severe winter and the cool, wet growing season, powdery mildew occurred late in 1985 and generally at low levels. By the end of August only 13% of fields in southern East Anglia were infected, and in the remainder of the country the incidence was less than 1%. As a result, sprays (mainly sulphur) were applied to only 13% of the national sugar-beet crop compared with 46% in 1984.

Downy mildew was, as usual, found predominantly in the Spalding and Peterborough factory areas, where it was recorded in 30% of fields during July and August. However, levels of infection did not exceed 5%.

For many years successive Beet Eelworm Orders and a clause in the contract between British Sugar and the grower restricted the frequency with which sugar beet could be grown in the rotation. These measures, which were mainly intended to minimize damage by beet cyst nematode (*Heterodera schachtii*), were discontinued in 1977 and 1983 respectively. Despite the lack of rotational restrictions, the British Sugar Specific Field Survey showed that only 1% of crops sown in 1985 were in fields which grew sugar beet in 1983 or 1984. However, the proportion of crops sown with only a two year break from sugar beet increased from 23% in 1979 to 30% in 1985, and the proportion with only a three year break increased from 30% in 1979 to 33% in 1985. A further survey, made annually since 1977 by the Ministry of Agriculture, Fisheries and Food (MAFF) of 300 sugar-beet crops in the East Anglian Fens, indicated that even more crops in this area are grown in short rotations; in 1985 2% of crops were grown after a one year break and 46% after a two year break. The MAFF survey has shown that an increasing proportion of crops in the Fens contain detectable populations of *H. schachtii*; cysts were found on 34% of crops in 1985 compared with 8, 13, 20, 16, 19, 24, 26 and 34% in 1977–84. Although six other surveyed areas are less severely affected (0–7% of crops contained detectable infestations), the situation in the Fens gives cause for concern and has necessitated a research programme to assess crop losses in commercial fields and investigate alternative control measures to crop rotation.

The brighter-than-average summer weather, the good health of the foliage and the lack of prolonged water stress during the summer, all indicated that the national crop should produce above average yields of sugar. On the basis of our simple model of the conversion of radiant energy to sugar, we predicted that the UK crop would yield 6·6–6·8 t sugar ha^{-1}. This agrees well with the final national sugar yield of 6·7 t sugar ha^{-1}. The sugar was in roots of very high quality; the dry autumn caused high sugar concentrations (18–20%) and restricted the uptake of nitrogen late in the plants' growth, so giving low concentrations of amino-nitrogen impurities.

Plant establishment

Seed advancement studies. At present, sugar-beet seed for commercial use in the UK is not thoroughly washed to remove germination inhibitors or advanced to initiate early growth processes, even though such treatments would improve both the rate at which seedlings emerge and the number of plants which establish. However, there may soon be an opportunity to replace the present fungicide seed treatment (a short steep in a solution of diethyl mercuric phosphate, used principally to control *Phoma betae*) with a more protracted treatment which combines seed advancement with the use of the non-mercurial fungicide, thiram (*Rothamsted Report for 1984,* 44–45). Studies were made to determine the most effective method of seed advancement in the absence of *Phoma betae* and thiram. Initially, two techniques, steeping seed in aerated water or moistening seed on damp filter paper, were compared under controlled conditions and in the field.

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The simplest technique, that of steeping seed, improved emergence and establishment most when the treatment was applied for 12 h at 25°C. Steeping for longer or at a higher temperature could decrease emergence, hypocotyl extension and seedling dry weight. The performance of moistened seed was significantly better than that of steeped seed. As the moistening technique is unsuitable for the treatment of large quantities of seed, a more feasible method was sought which gave the same improvement. This was achieved by a treatment sequence which comprised steeping for three hours followed by partial drying to 130% of original seed weight, storage in this damp state for 33 h at 25°C and air-drying.

Untreated seeds, and seeds given the steeping plus partial drying treatment, were sown in the field on 2 April 1985. The 'partially-dried' treatment decreased the time to half-final emergence from 33 to 16 days, increased establishment from 63 to 73%, and increased individual seedling dry weight 58 days after sowing from 93 to 147 mg. Calculations suggest that these improvements in the early growth of the crop would increase sugar yield at harvest by approximately 0·6 t ha^{-1}.

Further experiments are planned, using seeds severely infected with *P. betae,* to test the effect of introducing thiram at different stages in the 'partially-dried' treatment sequence on the efficiency of disease control. (Durrant and Loads)

Environmental and nutritional aspects of crop growth and productivity

Straw incorporation. Increasingly, arable farmers are being encouraged not to dispose of surplus straw by burning, and the incorporation of chopped straw into the soil is becoming more popular. Because 90% of sugar-beet crops follow a cereal, many are likely to be grown in fields where straw has just been incorporated. Straw has a low nitrogen content and can only be broken down rapidly by the soil flora if there is access to a readily available form of nitrogen. The residual mineral nitrogen in the soil following today's cereal crops is considered adequate to allow such rapid breakdown. The degradation process may lock-up some nitrogen which would otherwise be leached by winter rainfall; however, it is possible that the same process might decrease the amount of nitrogen which is available to beet the next spring. A series of experiments at Broom's Barn on sandy loam soil will investigate whether sugar beet following incorporated straw needs more nitrogen fertilizer than crops where the straw is carted off. Although experiments on other crops suggest that this is unlikely, we consider that the beet industry should have some additional evidence—otherwise there is a grave risk that many growers will increase their nitrogen applications and so decrease the quality of their crops.

Incorporated straw also affects the soil fauna. It could provide seedling pests of sugar beet with an alternative food during the spring, so reducing the risk of damage. Conversely, it could increase the risk of damage by supporting large populations of seedling pests over the winter. Observations of pest populations and their effects on beet seedlings are being made at Broom's Barn, and on ADAS Experimental Husbandry Farms wherever their straw incorporation studies are cropped with sugar beet.

In the experimental series at Broom's Barn, the straw removal and straw incorporation treatments will continue after the sugar-beet crop throughout a rotation of four cereal crops, before the experiment is again cropped with beet. This will allow us to check whether a short history of straw incorporation releases sufficient nitrogen to decrease the optimum rate of nitrogen fertilizer (see *Rothamsted Report for 1983,* 176). (Jaggard, Dewar and Webb)

Predicting the nitrogen fertilizer requirement. Large economic penalties arise from applying either too little or too much nitrogen fertilizer to the beet crop. If too little, then leaf expansion is slow and yield is lost; if too much, then root quality is reduced because the concentration of amino-N increases and that of sugar decreases. There are therefore benefits

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to both grower and processor for accurately and consistently predicting the nitrogen fertilizer requirement.

Measurements on sandy soils have shown that sugar beet needs to take up 200–220 kg N ha^{-1}. This amount was measured in experiments between 1969–79, when the maximum sugar yield was 7–10 t ha^{-1}, and again in 1982 when there was a record yield of 15 t ha^{-1}. This contrasts with wheat, where high grain yields are associated with large nitrogen uptakes. Other recent studies indicate that the amount of nitrogen needed by sugar-beet crops to produce a complete and active leaf canopy is similar in all seasons. Clearly, if a total nitrogen uptake of 200–220 kg ha^{-1} can be shown to produce maximum sugar yield on all soil types, the prediction of nitrogen fertilizer requirement will be greatly simplified. Our prediction will require information on how much nitrogen the soil contains in spring (Nmin) and how much becomes available from organic reserves during growth, since the greater their contribution to crop uptake the less nitrogen fertilizer needed.

At present, the amount of mineral nitrogen in soil in the spring is seldom measured and used to adjust rates of fertilizer application for beet. In practice, to do the necessary soil sampling and analysis for all fields would be too labour intensive. A computer model to predict Nmin in spring from rainfall, soil temperature, soil water retention characteristics and a knowledge of soil mineral nitrogen in autumn has been developed in the Soils and Plant Nutrition Department at Rothamsted (see p. 167). The model has been tested for winter wheat, and preliminary runs with sugar-beet data for sandy loam soils have been promising. At present, the model simulates Nmin during the cool winter months but we wish to extend this until about mid-May, when beet should receive its second and final nitrogen application.

In 1986, 24 experiments will be made in cooperation with British Sugar. Sites have been chosen to include all the major beet-growing soil types, and to enable the influence of previous cropping and the use of organic manures to be investigated. On all sites the applicability of the Rothamsted model to predict Nmin in March and May will be tested by comparing measured and simulated soil mineral nitrogen values. Measurements of nitrogen in crop and soil in spring and autumn from unfertilized plots will be used to estimate the net amounts of nitrogen mineralized during growth. Data from fertilized and unfertilized plots will be used to estimate the overall efficiency of uptake of nitrogen from all three sources. The accuracy of the predicted nitrogen fertilizer requirement will be tested at 13 of the sites, where yield response trials will be carried out. The experiments should provide a database to test the value of providing specific and localized recommendations to growers on nitrogen fertilizer usage. (Armstrong and Jaggard, with Milford and Pocock, Physiology and Environmental Physics and Addiscott and Whitmore, Soils and Plant Nutrition)

Timing of P, K, Na and Mg fertilizers. On soils where nutrient indices of P, K and Mg are all greater than two, current advice for the sugar-beet crop is to apply these fertilizers on the preceding cereal stubble. The aim is to minimize damage to soil structure caused by spreading fertilizers in the spring, and to minimize seedling losses caused by the high osmotic potential which can occur in dry springs when these nutrients are applied shortly before drilling. Recent evidence from the Specific Field Survey has shown that autumn application is also being used on sandy soils where nutrient indices, particularly of potassium, are likely to be less than two. There is little evidence to show the most appropriate application time on soils of index zero or one, or on sandy soils where leaching is likely to be rapid, particularly during wet winters.

Leaching is of particular concern for the sodium nutrition of the beet crop. Sodium is only held weakly by the soil complex, and its beneficial effect on yield by stimulating early leaf growth may be lost if winter rainfall moves the nutrient below the root zone. In 1984, experiments were started to investigate the timing of sodium application on beet yields, and

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the influence of rainfall (simulated by irrigation before drilling) on sodium leaching and availability. Crops were grown with no sodium fertilizer or with 375 kg NaCl ha^{-1} applied in October or March, or as a split dressing of 250 kg ha^{-1} in the autumn and 125 kg ha^{-1} in the spring. The unfertilized treatment yielded 9·0 t sugar ha^{-1}, those fertilized in autumn or spring yielded 10·0 and 9·8 t ha^{-1} respectively and that given the split dressing yielded 10·6 t ha^{-1} (SED 0·43). This demonstrates the yield advantage of applying sodium to the beet crop and suggests that timing of application might be important.

Studies of the effect of soil and weather factors on sodium availability and yield are continuing at Broom's Barn, but in future they will be linked with a series of experiments in commercial crops that will investigate the timing of P, K and Mg fertilizers as well as Na. The first experiments will be made on sandy loam soils with K indices of one and a loamy sand with a K index of zero. These soils are prone to leaching and are of a type where spring applications are becoming more popular. (Armstrong and Squire)

Irrigation. Trials in England spanning nearly 40 years have shown that when irrigation of sugar beet is beneficial, the responses are commonly about 0·2 and 0·4 t sugar ha^{-1} per 25 mm water applied on medium-textured and light-textured soils respectively. The responses obtained by farmers are generally lower than these. In relation to water actually transpired however, sugar beet commonly yields 0·6–1·0 t sugar ha^{-1} per 25 mm. Existing data are currently being re-examined in order to establish this value more precisely. Already it appears that better scheduling of irrigation on sugar beet could lead to more efficient use of the water applied.

The fibrous root system of sugar beet does not start to proliferate until about early June, by which time evaporative demand is high. Except in wet summers the crop's water balance then depends critically on the rate at which the root system explores fresh soil as well as on the soil's water holding capacity. This is reflected in the recommended limiting soil moisture deficits derived from evidence accumulated over many years at Broom's Barn. In June, only a small deficit can be tolerated without growth being reduced whereas towards the end of the summer much larger deficits can be tolerated. At Broom's Barn the root system normally extends downwards to at least 120 cm at a steady rate of 1·6 cm day^{-1} whether the crop is irrigated or not. Studies of fibrous root development in contrasting soil profiles at off-station sites began in 1985.

At present, sugar-beet growers are advised to use a water balance sheet to schedule irrigation so that soil moisture deficits remain below the specified limits for the period June to September. We plan to refine this advice in several ways. The evaporative loss in the water balance is obtained by multiplying the Penman potential evaporation by the ratio of actual to potential evaporation appropriate to the crop's stage of growth. Experience at Broom's Barn shows that this ratio passes 1·0 at 50% crop cover and remains about 1·2 while full healthy cover persists. We now plan to give a detailed account of this relation between evaporation ratio and crop cover for both unstressed and stressed crops. We shall also seek to improve the reliability of the specified limiting deficits, particularly those for lighter textured soils, and determine whether they can be adjusted for special circumstances such as unusual weather or seriously retarded growth due to previous stress. The efficacy of irrigation in a dry April or May will be investigated as part of a project concerned with the response of seedling growth to environmental factors. Mobile crop shelters will be used to produce specific soil moisture deficits. Although we shall continue to rely on the water balance method combined with limiting deficits we shall explore other approaches to irrigation scheduling. These include alternative models of crop water supply and demand as well as the use of plant parameters such as leaf-air temperature differences to indicate current crop water stress.

The two immediate aims of the present irrigation research programme at Broom's Barn

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are: 1, more precise scheduling of irrigation with respect to stage of plant development and soil type; 2, prediction of yield penalties when limiting deficits are exceeded. At the physiological level, the goal will be to discover how different degrees of moisture stress affect parameters such as rates of leaf expansion and photosynthetic conversion. (Dunham, Messem and Brown)

Diseases and pests

Infectivity of alate aphids with beet yellowing viruses. *Myzus persicae* is widely regarded as the principal vector of beet yellows virus (BYV) and beet mild yellowing virus (BMYV); however, other species can also transmit these viruses, although their role as primary infectors of the crop is unknown. Many of the alate aphids found on sugar beet at Broom's Barn during routine sampling in May and June 1984 and 1985 were species other than *M. persicae*. They included *Aphis fabae* and *Macrosiphum euphorbiae* which can colonize the crop, as well as non-colonizers such as *Brachycaudus helichrysi* and *Cavariella* spp. In order to determine whether these and other species carried and could transmit either of the two viruses, alate aphids were caught alive in a 1·6 m suction trap and caged on test plants. *Montia (Claytonia) perfoliata* seedlings were used as test plants in 1984 but, due to possible confusion between symptoms of BMYV and beet western yellows virus (BWYV) infection, (*Rothamsted Report for 1983,* 51), sugar-beet seedlings were used in 1985. All plants were subsequently tested with ELISA to determine whether they were infective with BYV, BMYV or both.

In 1984, 650 aphids from 40 species, were tested; 23 aphids were infective with BMYV, one, a *M. persicae,* was infective with BMYV and BYV and none was infective with BYV alone. Three of the four species which transmitted BMYV were non-colonizers of sugar beet: *B. helichrysi* (four infective of 39 tested), *Myzus ascalonicus* (1/8) and *Phorodon humuli* (1/1). The other infective species was *M. persicae* (17/259), and most of those tested were caught in the autumn when a large migration was recorded by the 12 m suction trap at Broom's Barn. None of the 54 *A. fabae* or 31 *M. euphorbiae* tested was infective.

In 1985, only 12 species known or thought likely to be vectors were tested. Virus yellows was scarce in commercial sugar-beet crops and, of the 230 aphids which were tested, only two were infective: one *M. persicae* (1/52, infective with BMYV) and one *B. helichrysi* (1/71, infective with BYV). Again, neither the one *M. euphorbiae* nor any of the 57 *A. fabae* tested were infective.

This study has shown that species not normally associated with sugar beet can introduce yellowing viruses to the crop. Further studies of natural aphid infectivity should be made, especially in years when virus yellows is widespread. These, together with information on the life cycles of the non-colonizing species, would improve our understanding of the introduction of yellowing viruses into the crop. (Thornhill and Hinckes)

The role of the host plant in the population dynamics of *Myzus persicae* on sugar beet. Factors which influence the population density of *M. persicae* on beet crops play an important role in determining the extent of secondary spread of both BYV and BMYV. As part of a continuing research programme on this important aspect of virus yellows epidemiology, the effects of host plant condition on the aphid's performance (development, reproduction and survival) on sugar beet were investigated.

The study concentrated on two areas: (a) the influence of plant age on aphid performance on healthy plants, and (b) the changes in performance resulting from the plant's inoculation with beet yellowing viruses. All the experiments were undertaken in the field, and caged aphids were used so that host plant effects could be separated from other influences, such as immigration, or mortality caused by natural enemies and adverse weather. Most experiments involved the detailed monitoring of batches of apterae kept individually in clip-cages

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from birth to death, on healthy and virus-infected plants sown at different times. Leaf number was used as an index of plant age and growth stage. Longevity, development and reproductive rates of aphids were calculated on a °C day scale using hourly temperatures recorded inside clip-cages.

As healthy plants aged, the potential rate of increase of apterous *M. persicae* declined very markedly for two reasons. Firstly, aphid performance was very poor on both mature and senescent leaves, with only young, expanding leaves being suitable. Secondly, even when apterae were kept only on young leaves (by moving them to new leaves every four days) survival and reproduction declined rapidly with increasing plant age. This reduced the potential rate of increase per generation from over 20-fold for aphids born on plants at the six leaf stage to less than twofold for those born on plants with over 20 leaves.

To discover whether plant age affected immigrant alatae similarly, alatae were cultured on *Capsella* in a glasshouse and transferred to beet in the field as young adults. They proved much less sensitive to changes in plant age than apterae when clip-caged on young leaves but their longevity and reproduction was markedly reduced on fully expanded leaves. The proportion of alatae found wandering on the clip-cage walls, rather than settled on the leaves, increased with plant age and leaf age. However, when alatae were released into aphid-proof field cages each containing one or two plants of the same age, the proportion subsequently found on the cage walls was only slightly affected by plant age. This suggests that the increased restlessness on older plants in the clip-cage experiments would have been expressed as brief flights or walking if the aphids had not been confined, so that alatae may play an increasing role in within-field virus spread as the crop ages.

Changes in aphid performance resulting from the plant's infection with virus were investigated using beet inoculated with BYV at about the ten-leaf stage. Apterae clip-caged on these plants at different times after inoculation and on different leaves showed large improvements in survival, development and reproduction. Improvements were generally greatest on leaves showing the strongest virus symptoms. They occurred so rapidly that even aphids born at the time of infection with virus could benefit from changes in the plant's physiology and achieve rates of increase per generation of about 50-fold, double those achieved on the most suitable leaves of young, virus-free plants. The improvements persisted throughout the growing season. An experiment on population development on virus infected and healthy plants in whole-plant cages confirmed the results of the clip-cage studies and provided some data on the effects of BMYV on aphid performance, which were less dramatic than those of BYV. Whole plant experiments also suggested that in the field a significant proportion of apterae and alatae on healthy beet fail to find the young leaves most suitable for development and reproduction.

The results of this study have several implications for future virus yellows control strategy. The dramatic decline in aphid performance as healthy plants age, strongly suggests that further development in the use of plant leaf number in virus yellows risk assessment would be fruitful. Secondly, as young expanding leaves are the only parts of the plant on which rapid multiplication of *M. persicae* can occur on healthy plants, the ability of an aphicide to reach and persist on these leaves is an important requirement for arresting yellows spread. Lastly, the large, rapid and sustained improvements in aphid performance following BYV infection suggest that if numerous foci of infection become established in young crops, a significant amount of secondary virus spread is likely whatever chemical control measures are applied subsequently. Thus special emphasis must continue to be placed on minimizing overwintering sources of infective aphids and developing long term forecasts and early season monitoring. (Williams)

Aphid repellents. The control of beet yellowing viruses is mainly based on insecticides directed against the vectors. When rationally timed, the spraying of aphicides may restrict

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secondary spread, but it rarely prevents virus introduction into a crop. In addition, the occurrence of insecticide resistance which is now widespread among aphid populations, threatens the efficiency of conventional control techniques. There is, therefore, a need for alternative measures, and the use of non-aphicidal behaviour-controlling chemicals, such as repellents which disrupt the aphid-plant interaction, can be envisaged.

The ability of a repellent, dodecanoic acid (DA), to limit the colonization of sugar beet by winged aphids and the subsequent spread of virus was investigated. This chemical has been shown to have repellent properties, as well as the ability to inhibit feeding and virus transmission (*Rothamsted Report for 1977,* Part 1, 145–146; *Rothamsted Report for 1980,* Part 1, 125).

In a first experiment, the effect of DA on the natural colonization of sugar beet by the black aphid, *Aphis fabae,* was investigated, because heavy infestations of this species were forecast for East Anglia in 1985. No black aphids were found in the experiment before the end of June, but during July suction trap catches at Broom's Barn indicated that *A. fabae* alatae were migrating continuously into the crop, although only in low numbers during the first two weeks. Spraying of DA (2·5 kg ha^{-1}, in aqueous emulsion containing 1·25% xylene and 0·05% surfactant) was delayed until 15 July when aphid numbers began to increase substantially. Aphids were counted on eight plants per plot. The mean number of *A. fabae* three to four days after spraying was lower ($P<0{\cdot}05$) in DA-sprayed plots (23·8 per plant) than in untreated plots (31·1 per plant), but there was no significant difference in numbers of alatae (3·6 per plant in DA-sprayed plots, 4·1 per plant in untreated). Subsequent counts showed similar, although not significant, differences between treatments, until their peak in early August when the mean numbers of *A. fabae* were 105·8 per plant in DA-sprayed plots and 113·8 per plant in untreated plots. Thus, although DA initially reduced the level of aphid colonization, the effect did not persist for long.

A second experiment investigated the effect of DA on secondary virus spread. In each of 64 plots (2·5 m×3 m) three central plants were artificially inoculated in early June with either BYV or BMYV. The plots were sprayed in mid-July with DA; two days later, 20 apterous *M. persicae* from a clone which was moderately resistant to organophosphorus insecticides (R_1) were released on these central plants. Aphids were subsequently killed with an aphicide spray (pirimicarb) in mid-August, and the spread of virus recorded visually three weeks later by counting the number of plants per plot which became infected. Results indicated that spraying of DA failed to limit the spread of either BYV or BMYV. Observation of symptoms on 4–5 September showed that BYV was transmitted to 5·1 plants in DA-sprayed plots and to 4·9 plants in untreated plots, and that BMYV was transmitted to 6·5 plants in DA-sprayed plots and to 6·1 plants in untreated plots. Virus spread was slightly, but not significantly, greater (5·6 plants with BYV and 9·6 planted with BMYV) in plots which were sprayed twice with DA (on 15 and 31 July); this may be due to increased movement of vectors induced by the repellent.

Although the aphid repellent DA decreased the natural colonization of sugar beet by *A. fabae,* it had no significant effect on the spread of either BYV or BMYV. The use of repellents in control strategies may improve control of the primary introduction of virus but it is unlikely to effectively control secondary spread. (Herrbach)

Effects of BYV and BMYV on yield of sugar beet. Surveys carried out by Broom's Barn in cooperation with British Sugar in 1981–84 determined the incidence and distribution of BYV and BMYV in the national root crop (*Rothamsted Report for 1984,* p. 43). The results showed that BMYV was the main cause of 'virus yellows', and was widely distributed through the entire beet-growing area, whereas BYV occurred mainly in the south-east of East Anglia. The effects of BYV and of mixed infections with both viruses on yield of roots and sugar have been widely studied, but there is little information on the effects of BMYV

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alone, especially on modern cultivars. Therefore, two trials at Broom's Barn in 1985 were set up to compare the effects of a mixture of strains of each virus on yield, one to compare the effects of different times of inoculation on a commercial cultivar, and the other the effects of a single time of inoculation on 21 breeding lines and three commercial cultivars.

In the first trial replicated 15 m^2 plots (approximately 100 plants) of the cultivar Regina, sown on 18 April, were inoculated with either BYV or BMYV using viruliferous *Myzus persicae* that had been produced either on *Tetragonia expansa* infected with BYV, or on *Capsella bursa-pastoris* infected with BMYV. Inoculations were made in the field by placing a piece of infected leaf, with at least 10 viruliferous wingless aphids, on each plant; the aphids were killed 48 h later by spraying with a mixture of pirimicarb and demeton-S-methyl, at standard rates of each, followed by three more sprays up to 8 August to minimize spread of virus from and between plots. Three times of inoculation were planned for this trial but, because of the low and variable plant establishment over the trial site, only two inoculations were made, the first on 3 June when plants were at the two to four leaf stage, and the second on 23 July when plants had 16–20 leaves (Table 1a). Two further inoculations were made on replicated plots (15 m^2, each of approximately 138 plants) on another trial site at Broom's Barn (cv. Primo, sown 17 April), the first on 1 July when plants were at the 12–14 leaf stage, and the second on 20 August when plants had 20–30 leaves (Table 1b). The plots on both sites were harvested by hand on 6 November, and root yields, sugar percentages and juice impurities determined. The sugar yields from the two trial sites are given in Table 1.

TABLE 1

Effects of BYV and BMYV on sugar yields

Date of inoculation and growth stage	BYV			BMYV		
	Sugar %	Sugar yield t ha^{-1}	Decrease in sugar yield %	Sugar %	Sugar yield t ha^{-1}	Decrease in sugar yield (%)
Site a						
Control	19·34	9·01	—	19·34	9·01	—
3 June 2–4 leaf	19·40	4·83	46	19·28	6·37	29
23 July 16–20 leaf	19·06	7·58	16	19·34	8·09	10
Site b						
Control	19·48	10·17	—	19·48	10·17	—
1 July 12–14 leaf	18·89	8·56	16	18·65	8·64	15
20 August 20–30 leaf	19·34	9·97	2	19·30	10·06	1

All plants in the plots inoculated during June and July developed symptoms, whereas only 5% of those inoculated on 20 August showed symptoms of either virus by the end of September.

The results showed that the mixed strains of BYV and BMYV used in these field trials severely decreased sugar yield and increased juice impurities of the cultivar Regina infected early in the season, with BYV having the greatest effect. When plants were inoculated in early and late July the viruses had less but still significant effects on sugar yield, there being less difference between the effects of the two viruses. By late August plants appeared to be resistant to infection, with only a small proportion of inoculated plants showing symptoms.

The second trial was carried out in cooperation with the Hilleshog Sugar Beet Breeding Company. Twenty breeding lines which had been selected for tolerance to virus yellows, a

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susceptible breeding line, and three commercial cultivars were grown in replicated plots (10·5 m^2; each of approximately 100 plants on this site) sown on 25 April, and inoculated with either BYV and BMYV at the four to six leaf stage on 17–18 June as in first trial. For both viruses 98–100% of the inoculated plants developed symptoms and no lines showed resistance to infection. The plots were machine-harvested on 12 November.

In the absence of virus, most of the breeding lines gave sugar yields comparable with those of the commercial cultivars Regina, Samson and Amethyst. Uninfected Regina yielded 9·5 t sugar ha^{-1}; when infected with BYV Regina yielded only 5·7 t sugar ha^{-1} (40% decrease), and with BMYV 6·9 t sugar ha^{-1} (27% decrease). In comparison, cultivars Samson and Amethyst lost 27% and 22% respectively of their sugar yields when infected with BYV, 27% and 29% when infected with BMYV, thus showing greater tolerance to BYV than the cultivar Regina. In comparison with Regina all the breeding lines suffered less yield loss from BYV infection, ranging from 9% to 31% decrease in sugar yield; losses in sugar yield caused by BMYV infection ranged from 5% to 40%. Some lines appeared to be tolerant to both viruses, but others were more tolerant to one virus than to the other.

The overall results of these trials showed that early infections by BMYV can cause severe yield losses, sometimes as great as those caused by BYV. Prevention of early infection by both BYV and BMYV will give greatest economic benefit, although it is also important to control infections until late July. The breeding lines and the commercial cultivars varied in their responses to the two viruses; some lines showed a level of tolerance to one or both viruses which would be well worth incorporating into commercial cultivars. However, the cultivars Samson and Amethyst appear already to have some tolerance to BYV, a fact that could be exploited by growers in areas where virus yellows is most prevalent. (Smith and Hinckes)

The effectiveness of aphicide sprays. Aphicides are applied to sugar beet principally to limit the transmission of beet yellowing viruses by *Myzus persicae*. A product's ability to do this probably depends as much on its persistence and effects on aphid behaviour as on its ability to kill aphids which are present at the time of application. Experiments were therefore made to investigate aphicide persistence and effectiveness against virus spread. Populations of *M. persicae* were established artificially because this provided more detail than could be achieved in conventional field trials which rely on natural aphid infestation. The aphicides used—pirimicarb, demeton-S-methyl (DSM) and deltamethrin+heptenophos (D+H)—were applied at the recommended rates to beet at the 10–15 leaf stage in field plots. Aphids moderately resistant to organophosphate and pyrethroid insecticides (R1 clone) were used, as this was the resistance-type most prevalent in beet growing areas.

Blocks of ten plants, surrounded by a sticky barrier to prevent aphid emigration, were infested with 1000 apterae per block and sprayed a day later to assess the efficacy of the insecticides against apterous aphids already on the crop at the time of treatment. All three were effective, pirimicarb killing 95% of the aphids and DSM and D+H killing 74%.

Persistence was investigated by clip-caging batches of 120 aphids, five per cage, on sprayed plants at intervals of one to 21 days after the above treatments and recording mortality three days later. Aphids were caged both on mature, fully-expanded leaves at the top of the canopy at the time of spraying and on young rapidly-expanding leaves 4–8 cm long when sprayed.

On mature leaves, pirimicarb killed 99% of the aphids exposed the day after application and persisted well. However, it was markedly less effective and persistent on younger leaves, killing a maximum of 63% three days after treatment and having a negligible effect after ten days. DSM and D+H killed fewer aphids than pirimicarb on mature leaves and had very little effect on aphids on younger leaves. The poor control achieved by all three aphicides on younger leaves was probably due to the low spray dose these received and its rapid dilution in

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the plant tissue as the leaves expanded. Aphicide performance on younger leaves is particularly important because they are much more favourable for *M. persicae* multiplication.

The ability of pirimicarb and D+H to control virus spread was tested in a field trial in which 60 adult apterae were placed on three central, BYV-infected plants in each plot before spraying. Virus spread from the source plants was then monitored using visual symptoms and ELISA tests. Neither aphicide significantly reduced the rate or final extent of virus spread compared with unsprayed controls. This was probably due to their inadequate effect on leaves which were young when treated, combined with subsequent natural aphid infestation. Mean virus incidence levels 50 days after treatment were 65% on control plots and 55% and 52% on pirimicarb and D+H treated plots.

This study showed that experiments using artificial aphid infestations can be a cost-effective way of obtaining detailed information on important aphicide properties under field conditions and provide a valuable supplement to conventional field trials. (Moody and Williams)

Rhizomania. This disease, caused by beet necrotic yellow vein virus (BNYVV) and transmitted by the fungus *Polymyxa betae,* continues to spread throughout northern Europe and remains a threat to the UK sugar-beet crop. The Rhizomania Sub-Committee of the Sugar Beet Research and Education Committee (SBREC), formed in 1984, continued to play a central role in the planning and coordinating of surveys and research work in England. Surveys to detect the disease were carried out again this year in collaboration with British Sugar and the MAFF Plant Health Division. Approximately 150 fields were selected throughout the beet-growing areas of the country for inspection and sampling by British Sugar fieldstaff. Field selection was based on factors considered likely to favour disease development such as short rotations, heavier soil types and low-lying or poorly-drained sites. Plants taken from these fields in August/September were tested for the presence of BNYVV at the MAFF Harpenden Laboratory, using the ELISA technique. A further 20 samples of plants showing rhizomania-like symptoms, collected from other crops, were also tested but none proved positive. In spite of the increased awareness amongst growers and advisers within the industry the disease remains undetected in this country.

The survey of the incidence and distribution of *Polymyxa betae* was extended in 1984 to include 140 fields. Two fields were selected at random from each of 70 beet-growing areas. Soil samples were taken by British Sugar fieldstaff to a depth of 20 cm from between the plant rows near the centre of each field during late May/early June. At the same time 20–30 plants were sampled from adjacent rows. Each soil sample was mixed with an equal volume of sterile silver sand and sugar-beet seedlings were grown in these mixtures in the glasshouse at about 20°C for six weeks. Fibrous roots of some seedlings were then washed free of soil, preserved, and examined under the microscope for *P. betae* and other fungi. The remaining seedlings in each sample were allowed to grow for a further six weeks, when they were used to provide crushed root extracts which were used to inoculate leaves of *Chenopodium quinoa,* a wide-spectrum indicator of virus infection. Roots of the plant samples taken directly from the field were also examined for soil-borne fungi.

P. betae was detected in 126 (90%) of the soil samples and *Olpidium brassicae* in 45 (32%). Because these samples were taken early in the growing season, and from between the rows, it is likely that the population being sampled was that surviving from previous beet crops. However, it was not possible to detect an association between the incidence of *P. betae* and any soil or agronomic factor (e.g. soil texture, pH, length of rotation) because the fungus occurred at almost all sites. By contrast, of the 70 plant samples examined, the incidence of *P. betae* and *O. brassicae* was 13 and 97% respectively. The high frequency of infection by *O. brassicae* indicates that there was sufficient soil moisture during the spring for zoospore motility, an essential pre-requisite to infection by both these fungi. Hence the low level of

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infection of plants by *P. betae,* in spite of its high incidence in soils, may be due to its higher soil temperature requirements (optimum *c.* 25°C) compared with *O. brassicae* (optimum *c.* 15°C). Soil-borne viruses were detected in 19% of the roots extracted from the soil samples. Symptoms produced on *C. quinoa* plants were, in all cases, characteristic of tobacco necrosis virus, which is widespread in soils, transmitted by *O. brassicae* and apparently harmless to sugar beet.

A small plot trial at Broom's Barn examined the rate of development of *P. betae* under field conditions. Seed was sown at 7·6 cm spacing on 24 April 1985, and whole-plant samples removed from each 1 m×2 m plot at weekly intervals from 22 May. The proportion of plants infected with *P. betae,* out of a total of 50 examined on each occasion, increased from zero on 22 May to about 60% on 3 July. The increase in incidence with time was linear ($P>0{\cdot}001$); the rate of increase was less than half that observed in similar studies in a rhizomania-infested area of central Germany, where the 60% level of infection was reached two months earlier. A significant correlation ($r=0{\cdot}92$, $P>0{\cdot}01$) was obtained between soil temperature at 5 cm depth at Broom's Barn, measured at hourly intervals and expressed as cumulative day degrees above 15°C, and percentage plants infected. The incidence of *O. brassicae* on the same plants had already reached 40% in the first sample, four weeks after sowing, and rose to 80% in the second week, thereafter stabilizing at about this level. Clearly there was sufficient moisture for zoospore motility, at least in the early stages of the experiment. The importance of soil temperatures in the spring in determining the rate of infection by *P. betae,* and its implications for the development of rhizomania in this country are to be investigated further. (Asher, Payne and Smith)

Barney Patch. The term Barney Patch was adopted in 1962 to describe a distinctive disorder of sugar beet of unknown cause in which severely stunted plants occurred in discrete, often kite-shaped patches in a few fields. The disorder appeared to be confined to light soils often, but not invariably, with a recent history of grass leys. Affected plants characteristically had shallow, fangy tap roots bearing a proliferation of heavily necrotic, much branched fibrous roots. Observations on stunt disorders in barley and some other crops by ADAS in the late 1970s suggested that a *Rhizoctonia* species might be involved. More recently, barley stunt disorder, which occurs in some barley crops in Scotland following a grass ley, was shown to be caused by a root infecting strain of *R. solani.* This fungus was observed previously on stunted plants from Barney Patches but neither it nor any of the other factors investigated was consistently associated with this disorder in sugar beet.

Two affected fields were studied in 1983. In both, *Rhizoctonia* spp. occurred consistently in a greater proportion of fibrous root pieces from plants within patches than from plants outside the patches. The fungus grew profusely in culture from affected roots of plants sampled in August and was readily isolated but, although still present, declined in viability when samples were taken later in the growing season. The cultural characteristics of isolates conformed to those of *R. solani.* The average root weight of plants from within patches was about 17% of that of plants outside the patches. Measurements of soil bulk densities down the profile in one of the fields failed to show any association of this factor with the distribution of infected plants.

A further eight fields with Barney Patch were studied in 1984 and 1985. The average root weight of plants from within patches was 11% of equivalent samples from outside patches. Stunted plants in all fields were consistently associated with much higher levels of *R. solani* infection of fibrous roots (an average of 72% of root pieces from affected plants were infected compared with 5% from healthy plants).

The effect of infection on final yield at one site was estimated in 1984 by comparing root yield and infection levels in paired samples taken from within and beside 11 discrete patches. Yield reductions associated with individual patches varied between 33% and 87% and

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averaged 59%. Using an aerial photograph, distinguishable patches were estimated to occupy 1·6% of the 6·8 ha field. Relative root yield was inversely related to the proportion of fibrous root infected with *R. solani* ($R=-0{\cdot}76$, $P<0{\cdot}01$).

Growth of sugar beet in bulk soil samples taken in 1984 from within and from around a stunted patch in a second field was compared in a pot experiment. Necrosis of fibrous roots, estimated on a 0–5 scale, and *Rhizoctonia* infection were severe in the former (mean 3·8 and 90% respectively) and apparent in some pots of the latter (mean 1·7 and 26%). When the data from both soils were combined, *Rhizoctonia* infection, disease score and yield were all significantly correlated.

Estimates so far of the effects of *R. solani* in affected fields relate only to areas where disease is severe enough to be obvious. The significance of the pathogen in the remainder of an affected field, or in beet fields generally, is not known. A survey of 136 randomly selected beet fields was conducted in 1985 to determine its incidence.

Samples of approximately 20 randomly selected roots from each field, taken in May/June, were examined for the presence of mycelium of *R. solani.* It was detected on at least one plant in 60% of the fields and on 10% of all the plants examined. No obvious root necrosis was apparent. Currently, representative isolates from the survey and from Barney Patch fields are being typed and their pathogenicity compared. Studies will continue, aimed at determining the significance of *R. solani* as a pathogen of sugar beet in this country. (Payne)

Weed beet

Bolter control with glyphosate. Sugar-beet plants which become reproductive in their first season (bolters) and produce viable seed are an increasing weed problem of arable land (*Rothamsted Report for 1982,* Part 1, 82–83). Several bolter control experiments have been made because prevention of seed returns is the first critical step in controlling the problem. Without control measures, bolters begin to appear in late May or early June and continue to appear until late August or early September, although some of the latest appearing bolters do not flower and so do not need to be controlled to prevent seed return. The first live seeds are found in early August; numbers rise to a maximum of about 2000 per bolter by mid-September and then decline due to shedding. Prevention of viable seed returns thus demands action in July, before the early bolters have live seeds, and in August to prevent late bolters seeding.

Field trials have tested mechanized methods of bolter control. A prototype five-row, tractor-mounted puller was built but was slow in operation and expensive. An electrothermal machine which applied 13 kV to a set of guarded electrodes spanning twelve rows was also tested. This machine, travelling at 5 km h^{-1}, could treat a moderate infestation of bolters at 2·4 ha h^{-1} but was large, heavy, expensive and, because of safety considerations, likely to gain approval only for use by contractors. A third of the sugar-beet crop (about 70000 ha) is already infested with weed beet and needs at least two treatments during a six-week period, so a few large machines in the hands of contractors would not cope with the workload. Smaller machines, owned and operated by farmers and situated on as many farms as possible, would probably result in more widespread and timely control. Bolter cutters would be relatively cheap to produce and easy to operate, and such machines (initially modified orchard grass mowers) were tested. When cutting was carried out early some bolters appeared subsequently and produced viable seeds, and when cutting was carried out late viable seeds were already present and were spread by the treatment. Because cut plants re-branch and grow from lower nodes, they usually have time to produce viable seeds, some within and some above the canopy. Satisfactory control therefore generally required at least two cuts at about fortnightly intervals starting in early August or 28 days after first flowering.

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A wide, multi-row, front-mounted cutter would be of great benefit in putting this technique into farming practice.

Early experience at Broom's Barn with a wild oat rogueing glove charged with 'Roundup' (glyphosate) demonstrated the potential for controlling bolters (and other weeds) which grow above the crop canopy by a selective application of a non-selective herbicide. In recent years several commercial machines have been marketed using either rollers or wicks to transfer chemical to the target weeds, and the wick machines in particular have proved very effective in killing bolters in sugar-beet crops. The optimum times for wiping are different from those for cutting. Glyphosate enters, is translocated and kills plants best under conditions of rapid plant growth, and young pre- or early-flowering stage bolters are easier to kill than older, lignified plants in the post-flowering stage of development near to the point of having live seed on them. Control is very poor when plants are water stressed at the time of application. The effects of applying glyphosate through wick applicators to bolters at early, mid or late flowering stages were studied at seven sites in 1981, eleven in 1982 and five in 1983. Single wipes did not control bolters adequately. The early wipe, whilst giving the better kill of bolters present at the time of treatment, allowed many bolters to escape because they appeared after treatment. The late wipe was even less effective because bolters were already partly lignified and some seeds were already viable when the treatment was carried out. Two wipes gave better control than one, with applications at early and mid flowering stages being the best combination. This reduced seed returns by an average of 92%, and in 13 of the 16 experiments in 1982 and 1983 gave less than 100 viable seeds per bolter, which, over a normal three course rotation, would not exacerbate the problem. The best control was given by the triple wipe at early, mid and late flowering stages. This reduced seed returns by 95% and in 15 of the 16 experiments gave less than 100 viable seeds per bolter.

These results have been incorporated into advice to farmers' with recommendations that crops infested lightly (less than 1000 bolters ha^{-1}) should be hand rogued, moderately (1000–10000 bolters ha^{-1}) wiped with glyphosate and severely (more than 10000 bolters ha^{-1}) cut, because at such a high level of infection effective control by wiping cannot be achieved since many bolters are shielded by their neighbours. (Longden and Johnson)

Communication of research results to the industry

The staff of Broom's Barn spend a large proportion of their time ensuring that the results of their research are incorporated into farm practice as quickly and accurately as possible. We contribute extensively to the British Sugar Beet Review (a quarterly journal distributed free of charge to all beet growers) and the Grower's Guide (a handbook, revised every two to three years, also distributed free to all growers). We give lectures to farmers groups (at least 70 in an average year), organize training courses for British Sugar fieldstaff and advisers (e.g. from MAFF or the agrochemicals industry), and provide and man exhibits at national and regional demonstrations. In addition we offer several specialist services during the course of the growing season:

(a) The Virus Yellows Warning Scheme has operated since 1958, and is a good example of how cooperation between researchers and the agricultural industry can influence farm practice. Information on aphid numbers is gathered daily from early June to mid July by British Sugar fieldmen and is sent to Broom's Barn. It is interpreted in the light of local experience and, after considering other information from the Insect Survey at Rothamsted, a 'Virus Yellows Bulletin' is prepared weekly and sent back to the fieldmen and other interested parties. The factory agricultural managers use the bulletin to help them decide whether to issue Spray Warning Cards which advise growers to examine their crops for aphids and spray if the threshold for treatment is exceeded. The area of beet sprayed each

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year is closely correlated with the number of spray warning cards issued. Early forecasts of the likely extent of virus yellows each year are also issued in March, April and May, so that fieldmen and growers are forewarned of possible epidemics, and can prepare equipment and order materials beforehand.

(b) Yield forecasts, calculated from measurements of temperature, water use and sunlight interception by the crop, are issued by Broom's Barn in early July, August and September. These forecasts allow British Sugar to anticipate the deliveries to the factories at harvest time and they provide valuable assistance in planning the requirements for an efficiently organized processing 'campaign'.

(c) Weed Beet Bulletins are issued three times a year. The first, soon after sowing, forecasts bolting in the current season based on the time of sowing and temperature. The second, at hoeing time, assesses the occurrence of weed beet from seed reserves in the soil and thereby indicates the likely extent of the problem in the current crop. The third, at early flowering, reports the incidence of bolters and their time of flowering which, together with current and long term temperatures, allows an estimate to be made of the date when live seed should occur; this is accompanied by control advice.

(d) Irrigation advice is provided weekly from June to August for each factory area based on local weather data provided by the Meteorological Office. Growers are informed of the average soil moisture deficit locally, and the quantity of water they need to apply to avoid drought stress in their crops.

(e) Forecasts of nitrogen requirements for the current season are provided in March prior to drilling. These are based on measurements of residual nitrogen content at several sandy soil sites, and recommendations can be adapted to suit other soil types which may have experienced less leaching of nitrogen during the winter.

(f) A plant clinic, similar to those operated by ADAS, is available to all growers throughout the year. Samples of soil and sugar-beet plants are sent to Broom's Barn, usually via British Sugar staff; problems are diagnosed (if possible), and advice is given within a few days of receipt.

All the services listed above take a considerable time to provide, and we foresee an even greater demand in the future. Recently some of the information has been made available on viewdata systems such as Prestel-Farmlink and Agviser. This medium allows us to communicate directly with growers as well as with the agricultural industry. As technology and expertise improve, and farmers obtain the appropriate equipment, information dissemination will be increasingly conducted in this way.

Broom's Barn Farm

Cereals. In the autumn of 1984 the land for winter wheat and winter barley was ploughed and furrow pressed. The heavier areas were worked once before drilling and some lighter areas were drilled directly on the pressed land. The land for winter oats was subsoiled following a burn and then prepared with a powered harrow before drilling. All the winter cereals were sown between 28 September and 5 October and then emerged evenly. However, as the autumn progressed and became particularly wet, several small areas turned yellow. These were mainly on headlands and in wheelmarks in the barley where, despite minimum cultivations, waterlogging caused poor rooting and decreased nitrogen uptake. The autumn weed control programme of a chlorsulfuron/metsulfuron-methyl mixture over most of the three winter cereals and chlortoluron plus tri-allate on the headlands of the wheat and barley was not quite completed due to the very wet weather, but this was corrected in the spring with an ioxynil/benazolin/mecoprop mixture which was also used on the spring barley (drilled 12 March on the light land and 2 April on the heavy land). The wild and volunteer oats were controlled in the wheat with flamprop-M-isopropyl in mid May. All

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the winter cereals were treated with cypermethrin in early November to prevent the spread of barley yellow dwarf virus. Nitrogen totalling 250 kg ha^{-1} for winter wheat and 140 kg ha^{-1} for winter barley was applied in three dressings. Winter oats received 130 kg ha^{-1} in two applications and spring barley 100 kg ha^{-1} in one application.

The winter wheat and winter barley were treated in April to control eyespot and mildew. A growth regulator was applied to the wheat in April and to the winter barley in mid-May. The barley required no further treatment, but the wheat was sprayed twice more to control Septoria at flag leaf and ear emergence. Grain aphid numbers were always small but an aphicide was used to control the rose grain aphid which infested the flag leaves. The flutriafol seed dressing protected the spring barley well and mildew did not reach the flag leaf until after flowering, when spraying was considered uneconomic. The oats received one fungicide to control mildew early in the season. Mildew reappeared in the bottom of the dense canopy but it never came sufficiently far up the plants for another treatment to be needed. Despite the very heavy rainfall in June all the cereal crops remained standing until harvest.

Harvest started late, on 7 August, in the winter barley (cv. Igri) which yielded more than ever before at Broom's Barn. Both fields yielded similar amounts of grain; Dunholme 7·5 t ha^{-1} and New Piece 7·6 t ha^{-1}. The winter oats (cv. Pennal) were harvested between the showers during the following ten days and yielded almost as much as last year at 7·3 t ha^{-1} from both Brome Pin and Bullrush fields. The spring barley (cv. Triumph) was ready to cut before the wheat and yielded 5·2 t ha^{-1} from Marl Pit (the March sown field) and 4·8 t ha^{-1} from Little Lane (the early-April sown field). The wheat (cv. Norman) yield was lower than in 1984 but the two fields, The Holt at 7·8 t ha^{-1} and Flint Ridge at 8·4 t ha^{-1}, gave more grain than they had ever done before when growing wheat. As all the crops were standing and were able to dry rapidly between the showers only 20% of the grain required drying, and on one very windy day some wheat was cut at only 13·2% moisture.

Sugar beet. March was cold, with a monthly mean air temperature of 4·6°C (one degree less than the long term average) and with rain on most days which prevented any drilling at Broom's Barn. Most experiments on the two sugar-beet fields (White Patch and Hackthorn) were sown in the first and third weeks of April; establishment was variable with seedling losses due to capping, frost damage and pests. Aldicarb+gamma HCH insecticide granules were applied in the seed furrow to 40% of the area 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 application of chloridazon band sprayed at drilling over much of the crop. With increased confidence in the sequential, low dose herbicide technique, sprays were used when the beet were small without fear of damage to experiments. This, in combination with tractor and hand hoeing, gave good weed control over the whole crop. Green aphids did not reach levels where spraying was necessary except where experiments were artificially infested. A general aphicide treatment was used to control black aphids in mid-August, when a sulphur spray was also applied. The sulphur was used to ensure the main crop was not infected by powdery mildew spreading from an experiment.

Irrigation on the beet crop is all applied from booms. Most of Hackthorn had 90 mm of water in five doses between the second week of July and early September. One-third of White Patch, the heavier of the two fields, received up to 40 mm of water.

Harvest started on 1 October in very dry conditions which continued until the end of the first week of November when rain fell. This made lifting considerably easier for most of November, but by December the soil surface became very wet and caused some difficulties. The last beet were harvested on 17 December and deliveries to the factory were completed before Christmas. Sugar percentages were high throughout the season and ranged between

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16·4% and 20·0% with a final average of 18·5%. The cleaner loader was not used as the conditions were generally very dry. Tares averaged 10·0% dirt and 5·0% tops and the final root yield was 38·9 t ha^{-1}. National yields averaged 38·0 t ha^{-1} at 17·5% sugar.

Livestock. During October and November 1984, 99 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 1985. (Golding)

Staff and visitors

R. A. Dunning and W. J. Byford retired after 28 years and 27 years respectively. Both worked on sugar-beet pests and diseases and were associated with many of the improvements in crop protection techniques which have helped to maintain the position of sugar beet as an essential component of many arable rotations. Anne Willington left to join Pertwee Landforce after completing a five-year appointment, financed by ICI, studying the physiology of the wheat crop. R. J. Dunham was appointed as crop physiologist to study fibrous root growth and irrigation requirements. J. M. Cooper was awarded a B.A. by the Open University.

In September 1985 the East of England Weed Research Unit was established at Broom's Barn to meet the specific needs for research into problems of weeds and herbicide performance in the eastern counties. The unit, which was formed following the reorganization in crop protection research and which involved the closure of the Weed Research Organization at Begbroke near Oxford, is part of the newly established Weed Research Division of Long Ashton Research Station.

As usual, several members of Brooms Barn staff were involved in the work of the International Institute for Sugar Beet Research (IIRB), attending meetings of their Scientific Advisory Committee (R. K. Scott), Weed Control Sub-group (W. E. Bray), Spring Mechanization Sub-group (W. E. Bray, R. Gummerson), Pests and Diseases Study Group (M. J. C. Asher), and Breeding and Genetics Study Group (P. C. Longden). W. E. Bray, W. J. Byford, R. A. Dunning, K. W. Jaggard and R. K. Scott contributed papers to the IIRB winter congress in February, which was also attended by M. J. C. Asher, A. M. Dewar and Helen Smith. M. J. C. Asher visited research centres at Bergen-op-Zoom and Wageningen in September and toured rhizomania-infested areas in the Netherlands. M. J. Armstrong attended an international symposium on nitrogen metabolism in higher plants in Haren, the Netherlands and W. E. Bray contributed to a meeting of the International Confederation of European Beet Growers (CIBE) in Paris. A. M. Dewar and W. A. Thornhill attended a soil pests meeting in Wageningen organized by the International Organization for Biological Control.

Visitors to the Station included agricultural delegations from two eastern bloc countries (USSR and Poland) and several groups of students from the UK and overseas. Dr C. T. Williams spent seven months with us studying the effect of virus infection on the rate of aphid multiplication, and Dr E. Herrbach, from Colmar, France, spent eight months investigating the effect of repellents on aphid numbers and virus spread.

Training courses were organized for Bayer technical representatives, British Sugar fieldstaff (pest and disease recognition), British Sugar Steckling Inspectors and MAFF Beet Cyst Nematode Surveyors. Members of staff gave many 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, A. M. Dewar, R. A. Dunning and R. K. Scott appeared on regional farming programmes for Anglia TV.

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Winter scientific meetings were held at Brooms Barn on 'The fight against rhizomania in European countries' (M. Marc Richard-Molard), 'Husbandry changes in response to the need to prevent wind damage to crops' (Mr Bob Hart) and 'Sugar beet surveys' (Mr Brian Church). Displays of our work were mounted for the Royal Show at Stoneleigh, the British Crop Protection Conference at Brighton, and the Spring and Autumn Sugar Beet Demonstrations at Caythorpe, Lincolnshire, where we also provided a Plant Clinic to which farmers and advisers brought problem samples of soil and plants for analysis and diagnosis.

The work of Brooms Barn is undertaken for the Sugar Beet Research and Education Committee. D. A. Cooke assisted in compiling this report.

THE FARMS AND THE FIELD EXPERIMENTS SECTION

The primary purpose of the Farms and the Field Experiments Section remained the provision of a service for the planning, conduct, demonstration and recording of the programme of field experiments. The programme is controlled by the Working Party for Field Experiments whose membership during the year was R. K. Scott, Chairman, W. Day, D. C. Griffiths, G. Inions, J. F. Jenkyn, A. E. Johnston, R. Moffitt, W. Powell, C. J. Rawlinson, A. G. Whitehead and F. V. Widdowson with J. McEwen and R. D. Prew as joint secretaries. The Working Party and its Commodity Groups and sub-committees held 26 indoor meetings and made 21 field tours of experiments.

The total number of plots at Rothamsted and Woburn was 7473. Of these 4992 were managed by the Farms with yields taken from 4559 and 1006 were managed by the small-plot staff with yields taken from 888; on the remainder the work was divided between Farms, small-plots staff and scientific departments.

Weather

A season of contrasts began with a cold January in which temperatures down to −16°C were recorded at Woburn. A short mild spell in early February allowed the last of the winter wheat to be drilled but cold weather then returned and continued into March. A generally dry but cold spring gave good conditions for spring plantings of cereals, beans and potatoes and this was followed by a very beneficial mild wet period in May.

June was very wet, in one 22-day period rain fell on all but two days and cereals began to lodge. July and August had average rainfall but harvest could not be started until 6 August. It continued with difficulty until 12 September, nearly two weeks later than last year. Grain needed much drying.

September and October were exceptionally dry. Potato lifting and autumn cereal sowing were almost complete by the end of October, only a few small areas following potatoes being sown in November, which was the coldest since 1965.

Crops and experiments

Of the 335 ha farmed (259 ha at Rothamsted, 76 ha at Woburn), cereals occupied 204·1 ha, potatoes 18·2 ha, beans 19·1 ha and oilseed rape 10·8 ha. The remainder was grass, fallow, access headlands and small areas of sugar beet, peas, maize, lupins and sunflowers.

Wheat. There were 84·9 ha at Rothamsted and 14·7 ha at Woburn. All were autumn-sown except for 7·0 ha at Rothamsted.

Winter wheat was sown late in poor conditions followed by cold weather and the crop made little growth until the warmer weather in May. Crops after cereals were given prochloraz and carbendazim ('Sportak Alpha') against eyespot. Most crops had summer fungicides, propiconazole ('Radar') with carbendazim plus maneb ('Septal'), and, where

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needed, pirimicarb ('Aphox') against aphids. Cultivars with conventional straw length, e.g. Longbow, lodged but the short-strawed cultivar Avalon generally stood well although the grain was of very poor milling quality. Straw broke up badly on threshing; opportunities for satisfactory burning were few and more straw than usual was baled or chopped.

The main winter wheat cultivars were Avalon and Longbow with a little Mission, Flanders, for the last time, on the Ley/Arable experiment and Brimstone, for the first time, on Broadbalk. Because several other changes accompanied the variety change on Broadbalk we report separately on this experiment below.

Comparable yields were all less than last year and there were no field yields of 10 t ha^{-1} this year. Some plot yields exceeded this figure but were still generally 1 to 2 t ha^{-1} less than last year.

Avalon in the new long-term straw incorporation experiment gave a mean yield of 9·9 t ha^{-1} at Rothamsted, 9·5 t ha^{-1} at Woburn, with little effect from treatments (p. 32).

An experiment testing aphicides showed an average yield increase from 9·5 to 10 t ha^{-1} and one testing a full fungicide programme an increase from 7·5 to 9·1 t ha^{-1}. In an experiment on some of the factors affecting take-all yields ranged from 8·1 to 10·6 t ha^{-1} with largest effects from previous cropping and sowing date. Sowing on 11 September instead of 15 October gave an increase of 0·6 t ha^{-1} after oats but a loss of 1·0 t ha^{-1} after barley. Wheat after oats gave 10·2 t ha^{-1} but after barley only 9·0 t ha^{-1}.

Experiments comparing 11 cultivars gave mean yields of 9·2 t ha^{-1} at Rothamsted, 9·4 t ha^{-1} at Woburn. Mean yields of 9·5 to 9·7 t ha^{-1} were obtained from Brock, Galahad, Gawain, Longbow, Norman, Renard, Rapier and Boxer at Rothamsted. Avalon and Brimstone gave below average yields, Moulin, with an overall average of 7·6 t ha^{-1} was particularly disappointing.

Sowings in autumn 1985 were done in good conditions and were finished in early November. In the dry conditions shed corn was slow to germinate and control of volunteers was difficult, particularly where stubbles were not ploughed.

Broadbalk. The start of this continuous wheat experiment in autumn 1843 marked the start of Rothamsted as an experimental station. In recent years modifications have been made to keep the experiment in line with current farming practice while ensuring that historical continuity is not lost. In 1968 a modern cultivar, rotations, revised nitrogen treatments and the inclusion of combined farmyard manure and fertilizer treatments were introduced. This year further changes were made.

1. Brimstone was used in place of the now outdated cultivar Flanders.
2. The nitrogen test on fertilizer plots was extended to include 240 and 288 kg N ha^{-1} to permit the new variety to fulfil its potential.
3. The nitrogen test on farmyard manure plots was extended to include 192 kg N ha^{-1}.
4. The three-course rotation of fallow, potatoes, wheat is being extended to a five-course by the addition of second and third wheats after the potatoes. This should provide crops with more severe take-all infection to contrast with the continuous and first wheats.
5. One of the sections in continuous wheat now receives no foliar sprays of fungicide, insecticide or growth regulator to study the consequences of limiting chemical crop protection over a range of fertilizer treatments.

Despite a much less favourable year the mean yield of 6·1 t ha^{-1} was 1·0 t greater than in 1984. Although conditions favoured lodging, Brimstone stood well for most of the summer, possibly because it was not sown until the end of October and had no spring N before mid-April. However, by early August, plots with the two largest rates of N had lodged severely.

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As a result the best mean yield with fertilizer only, 7·8 t ha^{-1}, came from 192 kg N ha^{-1} (with P, K and Mg). This was a little more than from farmyard manure alone, which yielded 7·5 t ha^{-1}, but was much less than the 9·2 t ha^{-1} achieved with farmyard manure plus spring N at 96 kg ha^{-1}. Omission of foliar sprays incurred a mean yield loss of 0·8 t ha^{-1}.

Barley. Most of the 24·3 ha of autumn-sown barley was cv. Panda with some Igri and Pirate; nearly all was sown in September.

The mean yield of Panda in the Factors Limiting Yield experiment (p. 23) was 6·6 t ha^{-1}, this was 2·5 t less than last year. The same cultivar on the Cultivation/Weedkiller experiment gave a yield of 8·3 t ha^{-1} where straw was burnt, and 7·9 t ha^{-1} where it was incorporated. One experiment on barley yellow dwarf virus (BYDV) showed a mean yield increase from 6·0 to 7·0 t ha^{-1} by controlling volunteers and a further increase to 8·0 t ha^{-1} from the use of cypermethrin insecticide applied by electrostatic sprayer in October. A second experiment on BYDV showed an increase from 5·9 to 7·6 t ha^{-1} from glyphosate applied in August to control volunteers. At Woburn an experiment on disease control gave a mean yield of 8·2 t ha^{-1} on the heavy land, 6·8 t ha^{-1} on the light.

Spring barley occupied 42·7 ha. It was sown in good time and gave yields which often exceeded those of the winter crop. The main cultivar was Klaxon but the best yields were recorded from Triumph which gave up to 7·6 t ha^{-1} on Hoos Barley and 8·3 t ha^{-1} on the Rothamsted Subsoiling and Deep PK experiment. Triumph also gave the best mean yield, 7·7 t ha^{-1}, in the trial of nine cultivars at Rothamsted but at Woburn gave only 6·0 t ha^{-1}, exceeded by all other cultivars.

An experiment on mildew control used the old susceptible cultivar Georgie which gave only 6·1 t ha^{-1} without mildew control, although this was increased to more than 8·0 t ha^{-1} by the best combinations of treatments.

An increased area of winter barley was sown in autumn 1985 to allow for an increased demand for winter oilseed rape sites for experiments.

Oats. A total of 37·5 ha was grown, cv. Peniarth at Rothamsted, Panema at Woburn, to provide a break from wheat and barley. Many crops lodged and the mean yield was about 6·5 t ha^{-1} but this includes an area of land restricted for P and K which gives light crops.

The area required in autumn 1985 has been much less, perhaps fortunately, as the crop is now financially less attractive.

Beans. There were 19·1 ha grown entirely at Rothamsted. Winter beans, almost all cv. Banner, were disappointing because of poor sowing conditions followed by the wet summer. Residual weedkillers failed to give effective weed control, there was much haulm, and chocolate spot spread rapidly, requiring several sprays of benomyl ('Benlate') plus chlorothalonil ('Jupital'). As a result yields were about 0·5 t ha^{-1} less than last year. The experiment testing seed rates and sowing methods gave results similar to those last year with the smallest seed rate giving the best yield with early sowing, and larger seed rates giving best results with late sowings. Ploughing-in seed was again slightly better than drilling; the combination of ploughing-in a seed rate of 69 kg ha^{-1} (12 seeds m^{-2}) on 26 September or 1 November gave the best yields of 5·0 t ha^{-1}. Banner in the experiment on the effects of pests and pathogens (p. 30) gave a mean yield of 4·6 t ha^{-1}, the same as an adjacent experiment on the control of *Sitona.* In a comparison of cvs Banner, Beagle and Bourdon yields were 4·8, 5·1 and 5·4 t ha^{-1} respectively.

The season favoured spring beans, cv. Minden, and some very large yields were obtained. The experiment on Rates of P and K to the Subsoil gave a mean yield of 5·8 t ha^{-1}. Best yield in a comparison of four cultivars was 5·9 t ha^{-1} from Minden. In an experiment comparing

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fungicides for rust control, maneb plus mancozeb was the most effective treatment, increasing yield from 5·6 to 7·4 t ha^{-1}.

Oilseed rape. There were 10·8 ha, mostly cv. Jet Neuf with some cv. Bienvenu. It was not possible to start harvest until 6 August by which time there was much loss from shedding. In the Factors Limiting Field experiment (p. 27) this loss was estimated at 1·3 t ha^{-1}. Even so, Bienvenu in this experiment gave a mean combine yield of 4·0 t ha^{-1}. In a comparison of cultivars and fungicide regimes Bienvenu yielded 3·7 t ha^{-1} without fungicides, 4·7 t ha^{-1} with a complete programme. Yields from Jet Neuf in this and other experiments were much less. In an experiment on nitrification inhibitors it yielded from 2·4 to 2·6 t ha^{-1} and at Woburn, on the heavy land of the Minimum Cultivation and Deep PK experiment, it yielded 2·8 t ha^{-1}.

The programme for autumn 1985 expanded further. Early sowings established well in moist conditions but later ones suffered from dry conditions and on one very heavy field emergence was uneven. Most crops received a weedkiller and all were sprayed against flea beetle.

Potatoes. There were 13·0 ha at Rothamsted, mainly cvs Désirée and Pentland Crown, with a few King Edward. At Woburn there were 5·2 ha, mostly cvs Cara and Pentland Crown.

The year was favourable with good planting conditions and ample rainfall. A pre-emergence weedkiller, paraquat plus linuron, was used on most fields but at Woburn this was prevented by excessive rain and metribuzin ('Sencorex') was applied after emergence. A regular fungicide programme was maintained, using mancozeb ('Dithane') initially, fentin hydroxide ('Du-ter') later. This was effective and very little blight was seen except on some plots of King Edward where sprays had been omitted for experimental purposes. The first crops to mature were pulverized and sprayed off with diquat ('Reglone') when there was still ample soil moisture. As soils dried out, sulphuric acid was used but for some crops mechanical destruction was sufficient.

The dry conditions allowed lifting to be completed by early November. All potatoes came into store in clean condition.

Yields from the field experiments were generally large, several giving total tuber yields in excess of 60 t ha^{-1} some in excess of 70 t ha^{-1}.

Lupins. *Lupinus albus* cv. Vladimir was grown on about 0·2 ha. Effective nodulation was given by the *Rhizobium* inoculant used and growth through the season was good. In an experiment comparing desiccants a low rate of diquat was effective. It increased yield from 4·1 to 4·3 t ha^{-1} but had little effect on maturity. All plots were harvested on 17 October. (Jones, Field Experiments)

Sunflowers. This crop was grown on about 0·2 ha, sown in April and harvested at the end of September. Despite problems with weed, bird and *Botrytis* control yields up to 5 t ha^{-1} were recorded from the best of the many varieties tested.

Grass. There was ample grass through the season. At Rothamsted most of the first cut was ensiled as the early summer was wet. Woburn has no silage-making facilities so the first cut was delayed until hay could be made.

Approximately 6 ha of old grass at Rothamsted was ploughed up to provide more land for arable experiments and a lucerne ley was ploughed at Woburn.

Levelling of the areas used for tipping soil from the Redbourn bypass was completed and they were resown to grass.

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Outside site

In addition to Rothamsted and Woburn work was done by the Farms on a heavy-land site at Whaddon used for a further experiment on straw incorporation.

Cattle

One hundred and fifteen have been sold fat and 122 yearlings bought.

Equipment

The old four tonne per hour continuous drier at Rothamsted was replaced by an eight tonne per hour machine which proved invaluable. Without it very considerable difficulty would have been experienced in the 1985 harvest. Additional grain storage bins have been erected at Woburn.

At Rothamsted the underground irrigation main has been extended to allow another 10 ha, separated by the disused Harpenden to Hemel Hempstead railway, to be irrigated.

Visitors

The Field Experiments Section received about 1700 visitors who came in 160 separate groups. Almost half came from schools, colleges or universities, about one-fifth were farmers. Almost all were given tours and demonstrations of the field experiments by members of the Section; for many a programme was arranged which included some of the scientific departments.

Staff

Farms. Jillian B. Curl and David Hobbs resigned. Marion J. Stegall was appointed.

Field Experiments Section. D. S. Martin-Smith was appointed; S. J. Parker left. J. McEwen presented a paper at the Nickerson Protein Crops Conference, two papers at the National Agricultural Centre 'Which Protein Crops?' course and gave two outside talks on field beans to groups of farmers and advisers. R. D. Prew helped to organize the demonstration at 'Cereals '85' on the multidisciplinary trials, and gave talks on these trials to three farmer discussion groups, ADAS S.E. regional advisers conference and to a SERC course on 'Statistics in Agriculture'. He also gave a talk on the AFRC Straw Research Programme to the EHF staff conference and attended a meeting in France of the Anglo-French Collaboration Group on Cereal Production.

PHYSIOLOGY AND ENVIRONMENTAL PHYSICS DEPARTMENT

The environment affects crops by influencing plant growth and also those factors which limit growth, such as disease. Many features of crop responses to agronomic treatments or to weather can be explained through our understanding of plant physiology. This is the basis of the physiological contributions to multidisciplinary studies of oilseed rape (p. 27), winter wheat (p. 35) and winter barley (p. 23). Detailed analyses of the relationship between physiology and other crop processes such as nutrition (e.g. in joint studies on sugar beet with Broom's Barn Experimental Station) are important if we are to exploit our physiological knowledge, and studies of specific physiological processes and underlying metabolic mechanisms (e.g. apical development rates, photosynthetic efficiency) will ensure that our knowledge is soundly based.

The application of conclusions drawn from specific studies to more general situations requires formulation in mathematical models. The AFRC winter wheat model provides a

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description of crop performance that can be used to simulate growth under a range of conditions, and work continues to extend this range. Though detailed descriptions of physiology can be included in such models, many simplifications may be necessary when obtaining quantitative information, and it is essential that the relationships between the observations and the model formulation are well defined. The conclusions that can be drawn from comparison of models with observations must also take into account the inherent variability of crops, particularly when considering predictions of subsequent crop performance or when defining the need for agronomic intervention.

The physical environment influences disease spread in crops via many distinct component processes. Better definition of the release of spores, whether by splash or into dry air, their movement in the turbulent microclimate near the crop, and their deposition is being sought through experiments and theoretical analysis. These studies have broad relevance to the dispersal of gases, particles and droplets within and above the crop canopy.

Plant and crop physiology

Development of winter wheat. The development of winter wheat, as measured by the timing of particular growth stages or by the rate and duration of production of apical primordia, is relevant to the correct timing of growth regulators, herbicides and nitrogen fertilizers, and to the physiological determination of the yield component, grain number per ear. Developmental processes are largely controlled by temperature and daylength and are relatively insensitive to nitrogen nutrition, though occasional apparent effects of nitrogen have been reported. For example, at Woburn in 1983–84 the improvement in nitrogen supply brought about by deep cultivation or application of fertilizer in November and January was associated with earlier appearance of double ridges on the apex of the main shoot (*Rothamsted Report for 1984,* 63).

In 1984–85 the increased nitrogen supply following oilseed rape compared with oats also hastened apical development (p. 35). When first sampled on 19 October, 20 days after emergence, the number of primordia on the main shoot was 0·5 greater after rape than after oats. This difference increased rapidly to 1·7 at the end of October and remained at about 2·0 from mid-December onwards. Wheat after rape produced 14·3 leaves and 21·4 spikelets compared with 13·4 leaves and 20·2 spikelets after oats. However, no equivalent increase in number of fertile spikelets or grains per ear was detected at maturity. The mean thermal time above 0°C needed for initiation of a leaf primordium was 53°C days after rape and 72°C days after oats. Irrespective of previous crop, a spikelet primordium was initiated every 34°C days. These numbers and rates of production of primordia account for the earlier appearance of certain stages. The thermal time between the dates of initiation of the flag leaf in the two crops was 60°C days, appearance of double ridges 43°C days and appearance of the terminal spikelet 24°C days. The comparable figure for double ridges at Woburn in 1984 was 34°C days.

The application of 60 kg N ha^{-1} on 7 November had no comparable effects on development, indicating that apical development is sensitive to nitrogen nutrition only very early in growth, before this fertilizer application. Not until mid-March did the fertilizer nitrogen increase growth as much as did the residues from the preceding rape crop. (Wood, Thorne; Rainbow and Stevenson)

Drought and nitrogen interaction in winter wheat growth. In past years, studies of drought response of cereals using the mobile rain shelters have shown the substantial interaction between drought and nitrogen supply for spring barley (*Rothamsted Report for 1979,* Part 1, 159) and a very limited response of winter wheat to drought (*Rothamsted Report for 1982,* Part 1, 178). In an experiment this year drought had large effects on winter wheat that

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interacted with nitrogen. Winter wheat, cv. Avalon, was grown with three rates of nitrogen (H=300 kg N ha^{-1}, M=75 kg N ha^{-1}, L=none) and three watering treatments (I=weekly watering throughout season to within 30 mm of field capacity, D=dry from early March to harvest, RW=dry until anthesis and then watered weekly). In addition, two irrigated plots which had received 75 kg N ha^{-1} as fertilizer were supplied with about 27 kg N ha^{-1} in the irrigation water on 2 May, 5 June and 26 June (CN, continuous nitrogen supply).

With full irrigation, yields (at 85% dry matter) were H 10·2 t ha^{-1}. M 5·9 t ha^{-1} and L 2·4 t ha^{-1}. Continuous drought decreased yield, especially with high N; decreases were 2·5 t ha^{-1}, 1·4 t ha^{-1} and 0·1 t ha^{-1} at H, M and L nitrogen. Early drought (RW) decreased yields by 1·5 t ha^{-1}, 1·0 t ha^{-1} and 0·1 t ha^{-1} at H, M and L nitrogen respectively. The CN treatment gave 9·2 t ha^{-1}. The much greater yield decrease with continuous drought this year than in 1982 (0·8 t ha^{-1}) probably relates to the increased nitrogen application and earlier start of the drought this year, and to differences in the patterns of growth and water uptake.

The larger part of variation in yield was associated with variation in grain number which ranged from $21 \cdot 4 \times 10^3$ m^{-2} (HI) to $4 \cdot 8 \times 10^3$ m^{-2} (LD), though as expected rewatering after anthesis (RW) had no effect on grain numbers in any nitrogen regime. Low nitrogen rates but not drought decreased ear numbers, and both treatments decreased grain numbers per ear.

Despite very large differences in yield, mean grain mass did not vary greatly, ranging from 45·7 mg (HD and MD) to 51·0 mg (HRW) and 52·6 mg (CN). Hectolitre mass was greater at high nitrogen rate, and ranged from 77·8 kg (MI) to 84·2 kg (HRW). There were small differences in grain size distribution, with some increase in the proportion of grains held in a 3·5 mm sieve for the low nitrogen treatments.

Leaf area indices reached maximum values of 5·4, 2·5 and 1·0 for HI, MI and LI respectively. Drought decreased these maxima by about 15% in H and M treatments, and had large effects on leaf area persistence and radiation interception in the grain filling period. Treatment effects on photosynthesis are described below.

Water use and plant water relations. The total amounts and patterns of soil water depletion differed greatly between treatments, reflecting the large differences in leaf cover and hence crop water demand. With ample N, drought decreased total water use from 312 mm to 200 mm. Water was extracted from below 1·8 m, with the water potential at 1·5 m estimated to have decreased to −2·0 MPa in the HD treatment by the end of the season. Smaller leaf cover with low N resulted in less water use, which was further decreased by drought from 200 mm to 110 mm. For the LD treatment much water at quite high potentials remained in the profile; soil water potentials at 0·5 to 1·0 m depth were estimated to be between −0·05 and −0·1 MPa for most of the season.

Leaf water potentials in HD plots were about 0·5 MPa lower than in HI plots in June and July. This difference was about equally divided between an increase in osmotic potential and a decrease in turgor. Relative water content/water potential curves indicated that the osmotic potential change was mainly associated with loss of cellular water and not with accumulation of osmotica. There were differences both in stomatal conductance and in leaf expansion rates, but measurements on mature leaves indicated no differences in cell wall elasticity between treatments.

Photosynthesis and photosynthetic efficiency. Photosynthetic light efficiency per unit flag leaf area, measured as the initial slope of light response curves of detached leaves in the laboratory, was not decreased by nitrogen shortage or drought when measured on mature leaves. However, efficiency did decrease more rapidly with age in the low N treatments where leaves senesced faster. Nitrogen shortage decreased carboxylation efficiency, measured as the initial slope of the relationship between photosynthesis and internal CO_2

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concentration, by 10 to 20% in irrigated crops, and P_{max}, the maximum photosynthetic rate measured at high light and ambient CO_2 concentration, was also smaller by 20 to 30% with the differences increasing as the leaves aged.

Water deficit decreased carboxylation efficiency by 10 to 30% in high N crops but had no consistent effect in the low N crops; confounding with leaf age and senescence complicates interpretation. Drought also decreased P_{max} in the high N crops by up to 40% but had no consistent effect on the low N crop.

Field measurements of the CO_2 and light response curves on leaves of intact plants were more variable than those made on detached leaves. Effects were generally similar, though the differences in carboxylation efficiency caused by drought in the high N crops were rather greater, being up to 50% as the season progressed.

Chlorophyll and RuBP carboxylase. Changes in light and carboxylation efficiencies and maximum photosynthesis rate were related to decreased amounts of chlorophyll and RuBP carboxylase per unit leaf area. Chlorophyll content was 55% smaller in the low N compared with the high N treatments; drought caused a 20% loss in the high N crops but had negligible effect on the medium and low N treatments. Carotenoids decreased similarly to chlorophyll suggesting that membrane components changed in proportion. Maintenance of efficiency at low light suggests that nitrogen deficiency does not affect the construction and organization of the thylakoids, and this is supported by the absence of effects on fluorescence induction curves. However, lack of N does decrease the capacity of the light harvesting system.

RuBP carboxylase decreased with nitrogen deficiency, by 25% and 40% in the MI and LI treatments, and there was also substantial loss of protein under drought, most in HD (40%) but also in LD (18%) suggesting that the minor stress may have affected protein production. Lack of enzyme would decrease the carboxylation efficiency, when RuBP regeneration was not limiting, and also the capacity of the system. (Lawlor; A. T. Day, Young, Croft, Cuminetti, Mitchell, Driscoll, Harrison, Powell with Johnston, Soils and Plant Nutrition)

Carbon and nitrogen metabolism: interactions with temperature and nitrate supply. Controlled environment experiments (*Rothamsted Report for 1982,* Part 1, 46–47) have given detailed information on the coupling between the processes of C and N metabolism and plant development, under different temperatures and NO_3^- supply conditions. Further analysis has brought out important points relevant to the effects of nitrate on crop growth.

The activity of enzymes changes as leaves age: that of nitrate reductase (NR) in particular may change by an order of magnitude between full leaf expansion and the onset of senescence. Nitrate supply and temperature both modify NR activity but there is no simple relation between activity and NO_3^- concentration in leaf tissue. Under cool conditions, NR activity is large and therefore NO_3^- concentration is small even with ample NO_3^- supply. However the lower growth rates at low temperatures correspond with slower protein synthesis and hence amino acid concentrations increase. This has implications for the use of tissue NO_3^- concentration as an indicator of plant N status. The concentration of free amino acids may be a more accurate indicator of N status at different temperatures.

Amounts of chlorophyll and the activities of enzymes of the CO_2 fixation cycle change in parallel as leaves age and with temperature or NO_3^- treatment, but NR activity does not change in proportion. This is consistent with a programmed expression of genes to provide an appropriate balance of enzymes at each stage of tissue development. These and other variations in the metabolic system are highlighted in the changes in plant constituents with NO_3^- or temperature treatment. Feeding with $^{14}CO_2$ shows that with more NO_3^-, particularly in cool conditions, more amino acids are made and synthesis of sucrose, and ultimately sucrose and starch concentrations, are decreased; the consequence is increased

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leaf growth and tiller production. With low NO_3^-, carbohydrates accumulate and tillering is inhibited. (Lawlor; Young with Keys, and Kendall, Biochemistry)

Variation in yield and quality of sugar beet. The amounts and patterns of nitrogen uptake by sugar beet can have considerable influence on the yield and quality of the harvested crop. Yield variation can be related to variation in the expansion of leaf area. Large differences in the thermal time required to expand unit leaf area index (LAI) during the early stages of growth have been observed; they appear to correlate with the nitrogen concentration in the leaf laminae, which ranged from 3·6% to 4·8% in crops grown at Broom's Barn and Trefloyne between 1978 and 1982. An increase of 1% in nitrogen concentration decreased the thermal time required to produce unit LAI by 75°C days, equivalent to 6–8 days at average spring temperatures. But large N uptake associated with large N% may increase amino-N content of the root and decrease sucrose concentration and hence lower the crop's value.

Soil N supply, nitrogen uptake and yield. Initial nitrogen uptake by fertilized crops at Broom's Barn and Trefloyne between 1978 and 1982 ranged from 2·3 kg N ha^{-1} d^{-1} in 1980 to 5·9 kg N ha^{-1} d^{-1} in 1981 and 1982 at Broom's Barn and at Trefloyne from 4·7 kg N ha^{-1} d^{-1} in 1980 to 5·4 kg N ha^{-1} d^{-1} in 1979. High initial uptake rates were associated with somewhat greater shoot N concentrations. There was no obvious relation between the initial rates of uptake and the amount of available nitrogen in the soil.

The differences in uptake can be associated with differences in the crop's demand for nitrogen, as determined by its growth rate. Simulations of the early growth of the fertilized crops grown at Broom's Barn between 1978–82 (p. 69), showed that two climatic factors, temperature and radiation, accounted for much of the variation in the early growth in four years, suggesting that, for these crops, nitrogen supply was less important. The 1980 crop grew more slowly than expected, and this suggests that edaphic factors may have been important for that crop.

Measurements of the total nitrogen within the crop-plus-soil system in 1980 showed a decrease of 60 kg N ha^{-1} from early June to mid-July. This compares with a smaller decrease in 1979 and an increase in 1981 and 1982. Simulations of soil N status in 1980 using a nitrogen leaching model (*Rothamsted Report for 1984,* 182) indicated that early irrigation and subsequent heavy rain were sufficient to have leached 60 kg N ha^{-1} out of the rooting zone.

Substantial losses of nitrogen can therefore occur when the crop is actively growing in June and July, with serious consequences for nitrogen uptake, nitrogen concentrations in developing leaves and the overall growth of the crop. There are two agricultural implications. First, there is a danger inherent in irrigating sugar-beet seedbeds to improve germination and establishment on light soils when heavy rain may follow. Secondly, the Soils and Plant Nutrition Department's nitrate leaching model, which performed well in the extreme conditions in 1980 and accurately predicted soil N status well into July, may have value as a guide to growers on when, and by how much, to adjust nitrogen fertilization. (Milford, Pocock; Brandram-Jones with Armstrong, Broom's Barn, and Whitmore, Soils and Plant Nutrition)

Nitrogen uptake, redistribution and quality. The concentration of amino-N in the storage root at the end of the season varies considerably between crops. In order to give sound guidance as to how to minimize levels of amino-N, it is important to know whether large concentrations are associated with late uptake of N in autumn or with large remobilization of N from the shoot. For the beet crops described above, the rate of nitrogen uptake in the autumn ranged from no net uptake at Broom's Barn in 1979 and 1980 to 0·6 kg N ha^{-1} d^{-1} in the other three years at Broom's Barn, and averaged 1·0 kg N ha^{-1} d^{-1} at Trefloyne. The

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crops had already taken up most of their nitrogen by August, when between 80 and 90% of the nitrogen was in the shoot. Nitrogen remobilized from the shoot to the storage root represented 80%, 50% and 30% of the net increase in nitrogen in the roots between the end of August and harvest in 1978, 1979 and 1980 respectively. In the other crops, continued uptake meant there were net gains in nitrogen in both root and shoot. Analysis of these data showed no good relation between either the extent of nitrogen remobilization from the shoot or the rate of late uptake of nitrate from the soil and the levels of amino-N in the harvested beet.

Amino-N levels were, however, closely related to total nitrogen uptake. For this limited range of crops, the relation was linear with a small increase in amino-N as nitrogen uptake increased to about 220 kg ha^{-1}. Inclusion of data from a further 80 crops for a wide range of soils and manurial conditions added an exponential increase at higher uptakes, and gave a well-defined relation, consistent between years and sites for healthy, drought-free crops. In crops suffering from drought or virus yellows, the proportion of total nitrogen accumulated as amino-N in the root increased as the severity of stress or disease increased. Amino-N therefore tended to accumulate when nitrogen uptake was excessive or growth was impaired. This suggests that where nitrogen is present in sugar beet crops in amounts exceeding those required for growth, the proportion that accumulates in the root is predominantly in the form of amino-N. (Milford, Pocock; Brandram-Jones with Armstrong, Broom's Barn)

Oilseed rape: leaf production, light interception and dry matter growth. Within the multidisciplinary oilseed rape experiment, leaf canopy expansion and light interception were studied in relation to dry matter growth of the crop. Light interception by the early sown crop increased rapidly to reach 50% by 29 September (45 days after sowing). The increase was much slower in the later sown crop, with 50% interception being reached by 23 December (109 days after sowing). Differences in temperature experienced account for most of this difference, as the equivalent intervals in thermal time were 690 and 570°C days (above 0°C) for the two sowings. The larger value for the early sown crop reflects its much smaller plant population (50 cf. 100 m^{-2}). The leaf appearance interval for the two sowings was identical at 82°C days. Greater winter damage in the early sown crop meant that, by March, green leaf area and light interception were quite comparable between sowings.

The mean efficiency with which intercepted radiation was converted to above ground dry matter was 1·53 g MJ^{-1} photosynthetically active radiation (PAR) for both early and late sown crops for the interval from 26 February to 30 March. This was when the leaf canopy was expanding and growth was largely vegetative. The two crops had the same mean conversion efficiency of 1·59 g MJ^{-1} PAR from 30 March to 11 June when growth was largely reproductive and flowering occurred. Higher efficiencies have been measured in other crops, but, for the first interval, the efficiency in rape was likely to have been less because changes in root dry matter were not determined and because low temperatures damaged leaves. In the later period, a substantial proportion of incident radiation was reflected by the flowering canopy. Measurements of the intensity and spectral distribution of radiation reflected and transmitted by the flowering canopy are being used to quantify this proportion. (Leach; Pearman, Mullen and Keirle)

A technique for counting and sizing plant cells. The dynamics of cell division and cell expansion in specific organs can indicate critical growth stages for nutrient availability, water stress etc. Measurement of cell number and size will enable growth studies to progress to the cellular level, e.g. in relation to accumulation of sucrose in sugar-beet roots, or the response of leaf growth to nitrogen timing.

A technique for the rapid counting and sizing of plant cells has been developed using a

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Coulter counter, model ZM, linked to an Apple microcomputer. The particles, suspended in an electrolyte, create voltage pulses in passing through the counting aperture. Pulse amplitude is related to cell volume so that the amplitude patterns can be analysed to obtain information on cell size/frequency distributions at a rate of 10–500 cells s^{-1} for concentrations of 100–5000 cells ml^{-1}.

Fast and efficient maceration of large numbers of samples has been achieved using 5% w/v aqueous chromium trioxide overnight followed by mechanical shearing. This produces good separation of cells, though some materials, notably cereal leaves, require filtering to remove vascular tissue. However, though live protoplasts with intact membranes can be accurately sized with the instrument, this chromic maceration modifies the electrical integrity of the cell membrane, resulting in underestimates of cell volumes. Corrections are possible but tedious, so alternative enzymic maceration techniques are being investigated. (Pocock)

Mathematical models of crop processes

Tiller production in winter wheat. A stochastic mathematical model for tiller production in winter wheat has been constructed that incorporates in its structure the principal characteristics of tillering physiology as expressed in the field: the inter-plant variability, particularly in the duration of tillering, the discrete nature of tiller appearance and the dependence of higher order tillering on the presence of the specific lower order tiller. The stochastic model is based on a stopped jump process, specified by its conditional jump rates, the conditional jump state distributions, and the probability distribution function for its stopping time.

This analysis has been tested on data from single plants of winter wheat sown on two dates in 1984. It was essential to allow for the finite distribution of tiller appearance times in assessing the statistical significance of any treatment; only differences of 50°C days or more showed any significance between treatments. Significant differences were indicated for the late sown crop in probabilities of emergence of specific tillers, resulting from differences in nitrogen timing. (Chalabi, Wood and W. Day)

Leaf area expansion of sugar beet. A stochastic dynamic model of the cumulative leaf area expansion in a field crop has been developed, with a structure that incorporates the variability observed in the field and with parameters that have a physiological interpretation and are easily computed. The model contains equations corresponding to area growth of each leaf (for leaves 4 to 20) in thermal time and each is characterized by four distinct mean parameters: thermal time at emergence, thermal time at maximum rate of expansion, maximum rate of expansion and maximum area.

The model was based on data from reference crops, grown with near standard husbandry, in sugar beet experiments at Broom's Barn during the seasons 1978–82 and 1984. Model parameters were estimated from data on the 1979, 1980 and 1981 crops and then cumulative leaf area from the model was tested against the observations. The performance of the model in predicting leaf area in the 1978 (for three sowing dates), 1982 and 1984 crops was then evaluated. Two modes of prediction were tested: the first mode used just temperature data; the second also used a single observation of the cumulative leaf area early in the season.

Much of the variability in leaf area expansion was accounted for, showing that a model based solely on temperature can form a valid basis for prediction. (Chalabi, W. Day and Milford)

Reality, observation and prediction. In mathematical models of biological systems, the observations must be defined functions of the processes formulated in the model, so that the mapping between the observed and real processes is well defined. This problem was formally considered in the tiller production model. Moreover a necessary condition for evaluating the

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effect of a treatment on a crop at any time in the season is that the model should be able to detect 'disturbances' in the 'natural' growth pattern. This criterion was satisfied in the model of tiller production and the approach could be easily extended to the sugar beet leaf area expansion model; this is important if decisions on whether the crop state is significantly displaced from its 'natural' pattern are to influence future treatments. The approach adopted in modelling leaf area expansion recognizes the importance of basing prediction on the statistical properties of the process and, where appropriate, taking account of observations of the current state of the process so that prediction can be operated online. It is believed that the mathematical approach adopted in these studies holds promise for further analytical dynamic models which are suited to field observations in agriculture. (Chalabi)

Early dry matter growth of sugar beet. Simple models of crop dry matter growth, based on an initial exponential growth phase followed by a linear phase, have been applied to spring-sown crops, e.g. by Greenwood, Draycott, Last and Draycott, *Fertilizer Research* (1984) **5,** 355–369. They assume that radiation and temperature variations have little influence on crop growth patterns. The reference crops from the sugar beet trials at Broom's Barn from 1978 to 1982 provide clear indications that this is not the case. Making a few simplifying assumptions about early crop growth, straightforward physiological principles about leaf canopy growth and radiation interception lead to the expression:

$$W_i = \Sigma\ A \,.\, R_i\ (\theta_i - \theta_0) + \text{constant}$$

where W_i is crop dry mass on day i, R_i is the incident solar radiation, θ_i the thermal time from sowing to day i, θ_0 the thermal time from sowing until leaf area starts to increase rapidly, and A is a constant.

This equation has been applied to the sugar beet data in the period up to leaf area index 1·5. It explains much of the variation in dry matter growth between years; 65 days after sowing actual dry masses varied by $\pm 1\ t\ ha^{-1}$ about a mean of around $1\ t\ ha^{-1}$. With the exception of the 1980 crop, the biggest deviation from our equation was $0{\cdot}3\ t\ ha^{-1}$. The 1980 crop values fall below the others, and this is probably because of excessive leaching resulting in inadequate nitrogen nutrition (see p. 66). Good definition of early growth is important to analyses of crop response to fertilizer because this is the period of maximum crop demand for N; shortfall of supply can restrict leaf expansion and hence total seasonal growth. (W. Day; Scott)

Aerobiology

Dispersal of naturally released fungal spores

Deposition of* Erysiphe graminis *in a barley crop. The conventional procedure for calculating deposition rates uses fall speed of individual spores and mean wind speed. Measurements of *E. graminis* deposits on different surfaces in a barley crop have shown that this approach significantly underestimates deposition. More than half the conidia were deposited in clumps of two or more spores which were more efficiently deposited than single spores, increasing deposition by as much as 50%. Deposition rates for single spores were consistent with the hypothesis that spores were predominantly removed in gusts (greater than $50\ cm\ s^{-1}$). Spores were probably shaken from leaves during movement caused by gusts rather than being blown directly from the leaf surface. As a consequence it is estimated that the typical distance spores travelled would have been only half that determined using conventional assumptions about deposition. (McCartney with Bainbridge, Plant Pathology)

Dispersal of spores from a rape crop. Spores of *Pyrenopeziza brassicae,* the cause of light leaf spot on oilseed rape and other brassicas, have been thought to be dispersed in rain-splash droplets and thus to travel only short distances. However, in an experiment this year,

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spores were caught on 'Rotorod' spore traps up to 4 m above and 20 m downwind of an infected rape crop. Deposition half-distances for downwind dispersal were about 8 m, too large for rain-splash alone. Comparing the times at which spores were trapped on a continuously operating (Burkhard) trap with periods of rain suggests that significant numbers of *P. brassicae* spores may be airborne for several hours after rain.

There was little disease until summer and most spores were caught during late June and July, a few weeks before harvest. The release of spores either in small water drops or 'dry', and their transport into the atmospheric boundary layer, suggest that they may have the potential to be dispersed over substantial distances. This may be important in the transmission of disease to other brassica crops, particularly vegetable crops which would be in the seedling stage during the period of greatest spore production. (McCartney; Lacey)

Modelling of splash dispersal. A technique was developed for measuring the initial speeds and directions of splash droplets from plant leaves. The formation of splash on horizontal barley leaves appears to be qualitatively and quantitatively different from that on liquid films or solid surfaces. Splash droplets from leaves tend to be ejected at slower speeds and shallower angles relative to the horizontal. Some were ejected below the horizontal especially when the incoming drop struck near the edge of the leaf. Small droplets tended to travel faster than large ones (maximum velocity about 10 m s^{-1}). (Macdonald, McCartney and Walklate)

Particle dispersion modelling. The Markov-chain simulation model for particle trajectories, based on Legg and Raupach (*Rothamsted Report for 1982,* Part 1, 175–176), has potential applications to the epidemiology of rain-splash and dry-dispersed fungal diseases, diffusion of pheromone vapour from spray droplets or insect lure, spray drift and passive insect dispersal in the atmospheric boundary-layer. In addition to mean particle slip corrections, the concept of turbulent particle slip has now been incorporated in order to extend the model to particles greater than 100 μm diameter.

Turbulent particle slip essentially represents the degree to which their inertia prevents particles from responding to fluctuations in wind speed. It is represented in the model as an attenuation of the random decorrelation component of the Markov process, and is quantified by deriving a low pass filter function from the solution of the momentum balance for a particle of known size and drag. Knowing the turbulence spectra in the atmospheric boundary-layer and mean velocity, and applying this filter function, mathematical closure of the model can be achieved.

Turbulence spectra in and above crop canopies of wheat and oats were determined in the field, and have given insight into the vertical spatial distribution of the turbulence correlations and their dependence on boundary-layer bulk flow parameters. (Walklate)

Staff and visiting workers

In April, K. J. Parkinson left after 20 years at Rothamsted to pursue commercial aspects of instrumentation. P. J. Welbank left in September after 28 years at Rothamsted and M. R. Keirle left in June. R. Cuminetti transferred to the Entomology Department to work on radar detection of aphids.

W. Day and G. F. J. Milford attended the symposium on 'Nitrogen metabolism in higher plants' in Groningen, Holland in April. D. W. Lawlor spent a week in Bordeaux working with Dr Prudet, and two weeks in Paris with Professor Champigny supported by an OECD Fellowship. He also presented a paper at the ICARDA/CNR meeting on 'Improving winter cereals for moisture limiting environments' in Capri.

This year Gillian Thorne was President of the Association of Applied Biologists.

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PUBLICATIONS

Broom's Barn Experimental Station

Research Papers

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