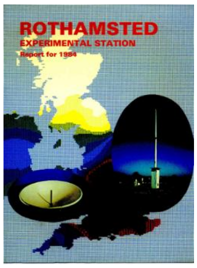
ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1984



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INTRODUCTION

This Division comprises Broom's Barn Experimental Station, the Rothamsted Farms and Field Experiments Section and the Physiology and Environmental Physics Department. At Broom's Barn multidisciplinary groups undertake investigations in crop husbandry, nutrition and protection which aim to help maintain and improve the efficiency and productivity of the UK sugar-beet industry. At Rothamsted the Division makes a major contribution to the multidisciplinary field experiments. The Head of Division chairs the Working Party for Field Experiments which takes overall responsibility for planning the Station's field programme and members of the Division play a prominent part on the Working Party and its constituent sub-groups. The Farms and Field Experiments Section are responsible for executing the programme.

Both at Broom's Barn and at Rothamsted the crop physiologists in the Division seek to bridge and help interpret parallel studies in agronomy, nutrition and crop protection. The physiologists and physicists of the Physiology and Environmental Physics Department investigate relationships between arable crop plants and their environment at levels from crop performance in the field to cell metabolism in the laboratory. The investigations require a quantitative and mechanistic approach to provide fuller basic knowledge of how physiological processes change in response to specific environmental factors. Throughout, the aim is to combine measurements and test ideas by means of

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simulation models. An essentially physics-based activity of the Department, in collaboration with the Crop Protection Division, is the aerobiology programme which studies how the aerial environment of a crop affects particle dispersal and disease spread. It is planned to extend these investigations to the deposition and distribution of crop protection chemicals applied as sprays to foliage.

BROOM'S BARN EXPERIMENTAL STATION

1984 and the growth of the crop. In marked contrast to the protracted sowing in 1983, almost 40% of the national crop was sown by 23 March, and, after a wet period that prevented further drilling in March, over 75% by 6 April; drilling was virtually finished by 17 April. Emergence from the March sowings was slow and a large area was affected by capping, many fields had only 50–60% establishment. Under wet conditions the new EB3 pellet gave better emergence from March sowings than the previous standard BB pellet. Establishment was better from sowings in the first half of April although some crops were badly damaged by bird grazing. Late April and early May were very dry and, where crops were sown in the third week of April, germination was often in two distinct phases making timely herbicide applications very difficult to achieve.

From mid-April on, temperatures in the West and North were higher than average giving rapid leaf expansion, while in East Anglia leaf growth was slow as a result of below average May and June temperatures. From temperatures measured at Broom's Barn day degrees above a base temperature of 3°C were calculated, and these results were used, with the aid of relationships described by Milford *et al* (*Annals of Applied Biology* (1985) **106,** 163–172), to predict the development of leaf area and ground cover. These predictions agreed well with values for ground cover measured throughout June and July in an experiment at Broom's Barn. Similar predictions were made for crops experiencing the temperatures of the West Midlands and Yorkshire. These results indicated that on midsummer's day beet crops covered an exceptional 40% of the ground in the West and North, compared with 27% in East Anglia, a near average figure which partly reflects the early sowing. On the assumption that the intercepted light in these three regions was converted to plant dry matter at a rate of $1{\cdot}85\,g\,MJ^{-1}$, then crops in East Anglia should have yielded approximately $1{\cdot}2\,t\,ha^{-1}$ less dry matter or about $0{\cdot}6\,t\,ha^{-1}$ less sugar throughout July than those from the other two regions. Samples taken from a random selection of fields in early August by British Sugar fieldmen suggested that regional differences in yield were of about this magnitude.

With over 77000 ha sown during March and below average temperatures until mid-April it was expected that a high proportion of plants would be vernalized, and an average of over 4% bolting was predicted for March sowings, based on the number of days after sowing when the air temperature did not reach 12°C. The British Sugar Specific Field Survey of 700 randomly selected beet fields showed that, in fields sown in March, there was only 0·88% bolting at the end of July and it was unlikely to reach the level forecast. It seems possible that the average temperatures in mid-April and the short period of much above average mean temperature in the last two weeks of the month devernalized some of the plants which would otherwise have bolted. Efforts are to be made to incorporate this year's experiences in a revised model of the effects of temperature on bolting.

In addition to bolters arising from seed sown this year, 36% of crops surveyed also had weed beet seedlings (originating from seed shed in previous years) when counted in June. In view of the warm weather during October which is likely to have ripened much viable seed, it is a matter of concern that, as in previous years, a third of the growers with affected fields took no control measures. The problem of weed beet seems likely to

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get worse under these circumstances, which persist despite circulating a new advisory leaflet and an 'action' postcard to all growers, talks on the subject, organizing a field workshop and producing a video film of bolter control to show at growers' meetings.

As in other recent years about half the national crop was treated at sowing with granular pesticides, principally to limit the damage caused by arthropod pests or by the ectoparastic nematodes associated with Docking disorder. Following the very dry late April, very little rain fell in the first three weeks of May, so soil conditions did not favour nematode activity. However, the end of May and the beginning of June were very wet and, in some areas, Docking disorder was reported. Damage was usually slight, partly because of the control given by the pesticides and partly because of the lateness of the nematode attack. The Specific Field Survey indicated that about 8400 ha of beet were affected by Docking disorder with an estimated total root yield loss of about 16200 t.

Nationally there has been a decrease in the use of soil-incorporated herbicides applied before drilling. Generally this has been associated with an increase in the use of residual herbicides sprayed on to the soil surface after sowing but before crop and weed emergence. These materials are more reliant on subsequent rainfall for adequate activity than those that have been mixed into the soil. This was illustrated in 1984 when dry conditions after all but the earliest drilling often reduced the initial activity of pre-emergence herbicides which led to the use of more post-emergence sprays for weed control in most beet-growing areas. However, the widespread use of repeated overall applications in low volumes of water allowed most weed problems to be solved, resulting generally in clean beet fields at the start of harvest in September.

At Broom's Barn, all the crop was sprayed at drilling with a pre-emergence residual herbicide. This gave satisfactory weed control where followed by two low-rate applications of a contact herbicide when the beet were emerging and being grazed by birds, and one of a herbicide with contact and residual action when the seedlings were larger and grazing was less severe. Where post-emergence herbicides were not used, late germinating weeds, particularly *Chenopodium album,* were a problem and required hand pulling.

Most of the problem samples sent to the Broom's Barn Plant Clinic in the early part of the season were due to adverse soil conditions caused by the cool, dry spring in East Anglia. No single cause could be found for most of these emergence and establishment problems, but many were associated with a period of low soil temperatures, and with high fertilizer concentrations in the seed zone. This occurred because there was insufficient rainfall to redistribute fertilizer applied at or near sowing, down the soil profile. Near the East Anglian coast, in particular in north-east Norfolk, poor uneven growth in June and early July was associated with cold dry weather with little sun. In several cases the roots were flattened, narrow and shrunken, due to hardness of the surrounding soil and lack of water. Recovery took place following rain and brighter, warmer weather. As usual some problems were associated with soil acidity, mineral deficiency and herbicides; of the pests, thrips damage was more common than usual.

Some manganese deficiency was found in 38% of beet fields at the end of May compared with 10% in 1983. The proportion of plants affected was also much greater, 7·9% deficient plants in 1984 compared with 0·6% in 1983. This increased severity in 1984 probably resulted from slow root development caused by cold, damp conditions at drilling, followed by a period of dry weather in the early stages of crop growth.

Unusually large numbers of *Myzus persicae* (146) were caught in the Broom's Barn 12·2 m suction trap during autumn 1983, and there was extensive colonization of autumn-sown oilseed rape and weeds known to be reservoirs of beet mild yellowing virus (BMYV) and the related beet western yellows virus (BWYV). This suggested that the beet crop in 1984 would be at a much higher risk from virus yellows than in recent years. However, a large number of ground frosts (70) were recorded at Rothamsted in January,

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February and March 1984 which, according to the forecast based on Watson *et al.* (*Annals of Applied Biology* (1975) **81,** 181–198), indicated a very low incidence of virus yellows both nationally (0·4%) and in the traditional 'yellows areas'. In the event, although virus symptoms were first reported in June, only 1·9% of the national crop was infected at the end of August and the highest local incidence of virus was only 5·9%, in the Ipswich factory area.

Green aphids were reported frequently in June on crops in all parts of the beet-growing region, which stimulated the issue of spray warnings by sugar factories in most areas. However, most of these aphids were *Macrosiphum euphorbiae,* an inefficient virus vector and, in retrospect, much spraying may have been done unnecessarily, especially as aphid buildup in unsprayed fields was prevented by the large numbers of parasites and predators present in the crop.

Black aphids, *Aphis fabae,* became locally abundant in late July in many areas, especially in central and northern East Anglia, where the largest numbers had been found on spindle bushes *Euonymus europeaus* in the spring. However, they were generally controlled by natural enemies, and insecticide treatment was only justified in a few fields.

The Root-crop Field Survey (*Rothamsted Report for 1983,* 50) again showed that BMYV was the main cause of virus yellows in 1984. Leaves collected in August from 703 plants throughout the beet-growing region, diagnosed by British Sugar fieldmen as being infected with virus yellows, were tested by enzyme-linked immunosorbent assay (ELISA) for beet yellows virus (BYV) and BMYV; 9% contained BYV, 47% BMYV, and 1% both viruses. No virus was detected in 43% of the plants suggesting that the level of virus recorded in the Specific Field Survey was overestimated. BYV, which has the most severe effect on yield, was found mainly in the Cantley, Bury St Edmunds and Ipswich factory areas, as in the previous three years. In the latter area only, where the greatest risk of virus infection occurs, a few growers who did not use a granular insecticide would probably have benefited from their use to control aphids early in the season. At present, these chemicals are only applied to 24% of the Ipswich factory beet crop compared to 50% nationally.

Migrations of *Myzus persicae* at Broom's Barn this autumn, indicated by autumn suction trap catches totalling 347, were even larger than last year. If the winter is mild, this will increase the risk of virus yellows infection in 1985, at least in East Anglia.

Downy mildew, which has not been prevalent since 1967, was widespread in the Spalding factory area where 37% of fields had some infected plants at the end of July. However, infection levels were low; 0·5% in the Spalding area and less than 0·1% nationally, compared with 5 and 0·7% respectively in 1967.

July and August were relatively dry but powdery mildew did not appear until late August, although it did then increase rapidly in some unsprayed fields. As in other recent years, a substantial proportion of the crop, particularly in southern East Anglia and the West Midlands, was sprayed with fungicide, mostly sulphur. Rust and *Ramularia* leaf spot were prevalent in a few crops late in the season. In one crop, where rust was first seen in mid-August, two sprays with fentin hydroxide greatly decreased rust incidence in October, whereas sulphur and triadimefon sprays did not.

Over much of the beet-growing area the summer was drier than average, and soil moisture deficits in some parts of eastern England reached approximately 200 mm by the end of August. This will have resulted in large responses to irrigation on sandy soils. However, because of local thunderstorms, the area around Broom's Barn experienced the wettest June since 1958 and this rain kept the land at field capacity until the end of the month. As a result the irrigation response here was only 4 t of roots ha^{-1}.

In spite of the shortage of summer rainfall over much of the beet crop, the average

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rates of leaf expansion in East Anglia early in the growing season and the rapid rates elsewhere have produced the second highest yielding crop on record which it is estimated will produce about 7·4 t of sugar ha^{-1} nationally.

Plant establishment

Insecticide seed treatments. All sugar-beet seed sown in the UK is currently treated with methiocarb at 2 g kg^{-1} seed to give some early protection against arthropod pests. Previous work suggested that carbofuran or carbosulfan could be used safely at higher rates, but gave little information on the relative insecticidal activity of these materials (*Rothamsted Report for 1983,* 45–46).

In 1984, further trials at nine sites tested methiocarb (2, 4 and 8 g a.i. 100000 $seed^{-1}$), bendiocarb (4, 8, 16 g), carbosulfan (4, 15, 30, 60, 90, 120 g), benfuracarb (30, 90 g), 'JF 9147' (8, 30, 90 g) and furathiocarb (4, 30, 60, 90 g) mainly in the new EB3 pellets. Although most of the trial sites were chosen because of a past history of seedling pest damage, severe soil pest attack occurred in only one; in that trial, at Nordelph, Norfolk, all treatments significantly increased seedling establishment, from 38% on the untreated control to, on average, 70%, but differences between treatments were not significant.

The trial at Broom's Barn tested the seed treatments with and without carbofuran granules (3 g a.i. 100 m^{-1}) applied in the seed furrow. Mean seedling establishment was better with carbofuran (71%) than without (67%) but there were no significant differences between seed treatments with or without carbofuran. However, phytotoxicity symptoms were observed and scored in May. High phytotoxicity scores were usually associated with the higher rates of insecticide seed treatments, especially carbosulfan (30, 60, 90, 120 g) and benfuracarb (30, 90 g); phytotoxicity was greater where carbofuran granules were used. However, the symptoms were transient and not visible later in the season.

In the trial at Llandrinio, Powys, serious damage to the foliage by flea beetle *(Chaetocnema concinna)* was observed in late April and scored for severity. Methiocarb (4, 8 g), bendiocarb (4, 8, 16 g), carbosulfan (15–120 g), benfuracarb (30, 90 g), 'JF 9147' (8, 30, 90 g) and furathiocarb (90 g) all significantly decreased damage, presumably as a result of systemic uptake, but methiocarb (2 g) and furathiocarb (4, 30, 60 g) gave poor protection.

Further evidence of systemic uptake and activity was obtained in two glasshouse experiments. One hundred aphids (*Myzus persicae* from an organophosphorus-susceptible strain) per treatment were caged on beet seedlings at intervals and the mortality assessed. The seedlings were grown from the same lots of seed as those pelleted for the field trials. In the first experiment, aphids were not killed on seedlings from seeds with pellets containing methiocarb (2, 8 g), bendiocarb (8 g), carbosulfan (30 g), benfuracarb (30 g), 'JF 9147' (30, 90 g), and furathiocarb (30, 90 g). However, carbosulfan (90 g) in the pellet caused high mortality of aphids caged on leaves up to 23 days after sowing. In the second experiment, testing fewer treatments, methiocarb (2 g) and benfuracarb (90 g) in the pellet were not active, but carbosulfan (90 g) in the pellet caused some mortality of aphids caged on leaves of seedlings 14 days after sowing.

The 1984 field trials, therefore, provided little guidance on the choice of insecticides and dose rates because of the relatively low levels of pest attack at most of the trial sites, although there were indications of slight adverse effects with some treatments in the absence of pest attack. (Winder)

Thiram steep. EMP (diethyl mercuric phosphate) steep treatment of sugar-beet seed was introduced in 1962, principally to control seed-borne *Phoma betae.* Since then, many

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other fungicides have been tested in the search for an equally effective, non-mercurial treatment. Thiram, applied as a dust, is widely used in Europe to control both seed-borne and soil-borne seedling diseases of sugar beet but was less effective than EMP steep in field tests at Dunholme before 1960. A prolonged thiram steep (0·2% suspension at 30°C for 24 h) was developed at the National Vegetable Research Station (NVRS) to control a range of seed-borne diseases of vegetable crops. This was as effective as, or slightly better than, EMP steep in experiments with sugar-beet seed in 1977 and 1978 (*Rothamsted Report for 1978*, Part 1, 63), but was not considered a practical commercial treatment.

Continuing pressure from the EEC to find an alternative to EMP steep as soon as possible, and present commercial interest in carrying out more complex physiological and fungicidal seed treatments, has prompted a re-examination of the thiram steep treatment. In 1983, experiments were started in co-operation with Germains UK Ltd, to test the effects on disease control of varying temperature and duration of thiram steep.

In two small-plot experiments in 1983 using a seed lot with 40% *P. betae* infection, EMP steep significantly increased seedling establishment, from 65 to 78% and from 45 to 72%. Thiram steeps at 0·2% a.i. for 6, 15 and 24 hours at 20°C or 30°C were all as effective as EMP, with no significant differences between treatments, and thiram applied as a dust also gave establishment that was not significantly inferior to EMP steep.

In a similar field experiment in 1984 using a seed lot with 50% *P. betae* infection, EMP steep increased establishment from 46 to 54%, and similar increases were given by 0·2% thiram steeps for 4, 8, 16 and 24 hours at 20 or 30°C. A high rate of thiram incorporated in the pellet was again equally effective.

These results suggest that the full thiram steep treatment recommended by NVRS for a range of vegetable crops including unrubbed multigerm red beet may not be necessary on rubbed and graded sugar-beet seed. Further experiments will be made, concentrating on conditions where seedling disease is likely to be severe (i.e. heavily infected seed sown early), in order to differentiate as well as possible between treatments. The effect of thiram treatments on soil-borne seedling pathogens of beet will also be tested. (Payne)

Seed quality studies. Each year the factors which affect plant establishment are discussed in this report. As the relative importance of individual factors varies from year to year and cannot be predicted, it is essential to select the seeds which will germinate and establish plants in a wide range of conditions. A study, started in 1981 (*Rothamsted Report for 1981,* Part 1, 71–72), sought to improve the prediction of the performance of individual sugar-beet seedlots as this is crucial when deciding which lots to discard and which to blend for commercial use.

Seedlots are currently assessed mainly on the basis of a standardized laboratory germination test; however, laboratory germination is sometimes poorly correlated with establishment in the field, so there appears to be a need for supplementary 'vigour tests'. An essential requirement in determining whether such tests are needed is the accurate measurement of performance of each seedlot in the field. Most previous investigations concentrated on the evaluation of vigour tests made in the laboratory, but in this study equal emphasis was given to tests made both in the field and under controlled conditions in the laboratory. The performance of 20 seedlots, with a range of laboratory germination of 80 to 95%, was assessed in field tests at seven sites in 1981; 10 of the seedlots were then chosen for further studies in 1982 and 1983.

At each site in 1981, there were large, significant differences in establishment between seedlots; there were also significant differences in the mean establishment between sites. In these field tests not only was the rank order of seedlots similar but, unexpectedly, the differences between seedlots remained constant at all sites. In the laboratory tests the

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rank order of seedlots was also similar but, more predictably, there were greater differences between seedlots as environmental stress increased (i.e. as mean establishment decreased).

Other studies have suggested that seed performance in field experiments can be modified by non-random factors such as post-emergence grazing. In 1982, this was tested by comparing establishment in unprotected and netted plots. Analysis of data from unprotected plots gave similar conclusions to those in 1981. However, it was also found that following early sowing, grazing by birds caused a greater reduction in the establishment of seedlots with high germination percentage than of those with low germination percentage. Thus, under some circumstances, a single count of seedlings in unprotected field experiments can give misleading estimates of the differences between seedlots and probably also between other treatments which affect the rate of emergence.

In 1983, further studies were made under protected conditions and there was good agreement between data from protected plots and in controlled environments. In plots protected from birds, establishment was well correlated with germination in the laboratory test and with emergence under controlled conditions ($r=0{\cdot}88$), suggesting that the case for vigour tests is less strong than seemed likely at the outset.

The results of three years' experiments have emphasized that small differences in laboratory germination are important as they can be associated with much larger differences in establishment in the field, particularly under adverse seedbed conditions. To detect these small differences requires considerable precision. The average standard error, measured at each of six laboratories, for the mean germination percentage of individual seedlots was $\pm 1{\cdot}89$ in tests with four replicates of 100 seeds. With seedlots of about 90% germination, most of the standard error is inevitable as it is a consequence of sub-sampling from the seed population. Thus much greater accuracy could not be achieved without much greater replication; however, minor improvements may be possible. The distinction between normal and abnormal seedlings, currently part of all laboratory germination tests, contributes to experimental error, and a less subjective discrimination, based on hypocotyl height warrants further study. (Durrant and Loads with Brown, Plant Breeding Institute and Bould, National Institute of Agricultural Botany)

Effect of cultivation technique on plant establishment. In a series of experiments at Broom's Barn from 1981 to 1984, different cultivation treatments in autumn, winter and spring were used to produce a range of seedbed conditions. Detailed measurements of several soil parameters (e.g. water content and potential, temperature, and impedance) were used to investigate the effect of weather on the physical condition of the seedbed, and the time course of emergence of sugar-beet seedlings was monitored.

In periods of wet weather the seeds sometimes became waterlogged, while in periods of dry weather germination was delayed and emergence was sometimes further impeded by the formation of a crust on the soil surface. These problems decreased seedling establishment and were not alleviated by any of the cultivation practices which were tested. Differences in seedling establishment between cultivation treatments were much less than those between seasons. The average final emergence varied from 50% in 1984 to 85% in 1981, but in any one year the range of treatment means was never greater than 10%. In years when the general level of establishment is low, this 10% would be important, but only with complete knowledge of the weather to come could the best cultivation technique be selected.

In each of the four years, seedbeds produced by various techniques in autumn or winter with no further spring cultivation gave average emergence or better. In 1984, a treatment was introduced in which seedbeds were prepared on a clay loam soil by

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ploughing with a furrow press attachment in the previous October. These were drilled with no further cultivation and gave average establishment. This system produces uniformly moist, undisturbed seedbeds and avoids causing wheelings before drilling which compact the soil and impede root growth. Furrow presses are now widely used, but their effect on seedbed structure must be further tested, especially on heavier soils, over a range of seasons. (Gummerson)

Environmental and nutritional aspects of crop growth and productivity

Sulphur nutrition. With the introduction of fertilizers with a high concentration of N, P and K, most of which contain practically no sulphur, and a gradual fall in the atmospheric SO_2 level, sources of sulphur for crop growth have recently declined. This raises the question whether crops are now adequately supplied with sulphur. Beet may be particularly sensitive to sulphur deficiency as it has a very high uptake. In trials carried out between 1978 and 1983 the uptake was 50–70 kg S ha^{-1} for crops given 125 kg N ha^{-1}. For high yielding crops, e.g. 1982 at Broom's Barn and 1979 and 1980 at Tenby in South Wales, uptakes as high as 100 kg S ha^{-1} were measured. Assuming that the beet tops are ploughed down as a green manure this represents an offtake via the roots of 20–50 kg S ha^{-1}.

In 1984 the effect of soil-applied sulphur on sugar yield and root quality was tested in trials on six farms in Norfolk and Suffolk, and at Broom's Barn. Sulphur was broadcast at 60 kg S ha^{-1} at or soon after drilling either as gypsum or micronized sulphur on the farm sites, or as micronized sulphur at Broom's Barn. Powdery mildew was controlled by 'Bayleton' sprays. The sites were chosen to give a range of soil sulphur levels representative of the region, varying from 8–41 μg SO_4-S ml^{-1}.

Seedling counts at Broom's Barn showed that the sulphur did not affect either seedling emergence or establishment so treatment yields were from similar plant populations. Growth analysis of plants lifted from 1·5 m^2 areas throughout the growing season showed no effect of treatments on yields of sugar or of top or root dry matter. This was reflected in the final harvest when sugar yields were 11·95 and 12·05 t ha^{-1} for crops grown with and without sulphur respectively. Root quality was the same for both treatments. Similar results were obtained from the commercial crops where, over the six sites, sugar yields averaged respectively 9·35 and 9·31 t ha^{-1} when supplied with gypsum and micronized sulphur and 9·34 t ha^{-1} without sulphur. Even on the site with the lowest sulphur status (8 μg SO_4-S ml^{-1}) where the greatest benefit from added sulphur would have been expected, no significant increase in sugar yield was observed when either type of sulphur was applied.

In this investigation the sugar-beet crop did not benefit from the addition of soil-applied sulphur. The inherent soil reserves and atmospheric supply of sulphur seem sufficient to satisfy crop demand. Data from the Central Electricity Generating Board estimates the annual sulphur deposition in East Anglia to be about 40 kg ha^{-1}. As deposition levels for the other beet growing regions of England and Wales are as high as, and in many cases higher than this, there is at present no justification for recommending sulphur as a soil-applied fertilizer for the beet crop. (Armstrong)

Fibrous root growth and soil water deficits. Previous experiments at Broom's Barn have investigated the effect of irrigation on water consumption, growth and yield of the sugar-beet crop. In 1983 these effects were re-examined in relation to the development and extent of the fibrous root system. To ensure differences in water supply, rainfall was kept off some areas of crop by using large mobile covers (19·5×5·5 m) which were only in position when it rained, and these areas were compared with a control crop which was irrigated from June to September to keep the beet as free from water stress as possible.

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The covers were used first to keep areas of beet rain-free for eight weeks during June and July (early deficit, ED), after which the stressed crop was irrigated to allow recovery, so that by the end of August the deficit was the same as in the control plots. The covers were then transferred to areas of beet which had previously been irrigated and a later drought period was imposed for eight weeks from 1 August (late deficit, LD). Plant growth, fibrous root length and soil moisture deficit (SMD) were measured at regular intervals throughout the season for each treatment.

The ED was imposed during the phase of most rapid growth of the beet crop. After four weeks of drying, the SMD in the top 40 cm of soil had reached 43 mm and the fibrous root density in this soil horizon was less than in the control plots. After six weeks the soil was so dry in this soil layer (SMD 55 mm) that many of the fibrous roots were dead or dying. Below 40 cm, moisture was more plentiful and root growth was less affected. Mean root densities of the ED and control treatments were 0·6 and 1·4 cm cm^{-3} in the 0–40 cm soil layer and 0·1 and 0·2 cm cm^{-3} in the 60–100 cm layer respectively. By the end of the ED period the SMD in the top 40 cm had reached 75 mm resulting in further root loss. The deficit over the whole soil profile was 140 mm. Irrigating the plots after the ED period stimulated new fibrous root growth in the surface 50 cm of soil. In the control plots the fibrous root system of the plants was more dense at depth than in the ED plots indicating that irrigation early in the season did not result in a shallow root system.

The LD was imposed after 70 mm of irrigation had been applied, the crop was well established and the fibrous root system had almost reached its maximum extent in the top 100 cm. At the end of the LD period the density of fibrous roots in these plots was lower in the top 30 cm of soil than in the control plots. Below this level there was little difference between treatments. Root densities in the LD and control plots were 1·3 and 2·2 cm cm^{-3} in the 0–30 cm horizon (SMD 54 and 28 mm) and 0·7 and 0·6 cm cm^{-3} in the 60–100 cm horizon (SMD 42 and 27 mm) respectively.

Measurements of actual water use (AE) were compared with the calculated potential water use (Penman potential evapotranspiration, PE) for both of the deficit crops and the control crop. In the first four weeks of the ED period, the incomplete leaf cover did not allow the crop to transpire at the potential rate; PE was 96 mm whereas AE was only 51 mm. During the last four weeks, when leaf cover had reached its maximum for the deficit period (70% leaf cover, at which maximum sugar-beet transpiration rates are possible) PE was 105 mm and AE 84 mm showing that the crop could not take water from the soil at the rate demanded by the atmosphere, even though water was extracted from the same depth as in the control plots (115 cm). In the first half of the LD period, PE was 82 mm but in the LD crop, which had previously been irrigated to maintain large soil water reserves and had roots below 120 cm, the AE was 96 mm, 17% above PE. During the final four weeks when PE decreased to 50 mm, AE was only 42 mm, indicating water stress. Because the soil remained very dry after the covers were removed from the LD plots, water use (16 mm) was still lower than evapotranspirational demand (23 mm). In both deficit treatments, plants responded to lack of rainfall by using more subsoil water than in the controls. A prolonged period of water shortage was less damaging to the sugar-beet crop later in the season because early irrigation had encouraged deep rooting, allowing the plants to extract large quantities of water from the soil.

When harvested in late October, sugar yields for the control, ED and LD crops were 12·0 (SE±0·10), 8·7 (SE±0·15) and 10·5 (SE±0·32) t ha^{-1} respectively. These results indicate that early water shortage is particularly detrimental to yield even when irrigation is applied later. Early irrigation, however, permits unrestricted growth with crops developing a deep and extensive root system more able to withstand late summer water

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shortages and resulting in a high sugar content in the roots (18·6% compared with 17·3% in the control and 16·5% in the ED). (Brown, Messem and Armstrong)

Plant density and light interception. The yield of sugar-beet crops is restricted by lack of foliage in early summer when the days are long and bright but much of the radiation, which would be converted to dry matter if intercepted by leaves, falls on to bare soil. Two obvious methods of increasing ground cover at this time of year would seem to be to increase the number of plants per unit area or to sow the crop earlier. During the last three decades beet has been sown progressively earlier in England, but further improvement is prevented by low spring temperatures which delay germination and stimulate bolting. Many experiments (Draycott & Durrant, *Journal of the International Institute for Sugar Beet Research* (1974) **6,** 176–185) have shown that increasing plant populations above 75000 ha^{-1} slightly increased dry matter yield but did not affect sugar yield. The amount of extra dry matter was small, and this was assumed to be the result of interplant competition decreasing crop growth rates. Certainly, very dense beet crops often look pale in mid summer, suggesting that the foliage is relatively inefficient. However, these effects have never been accurately measured, and no attempt had been made to quantify the extra light intercepted by dense crops in early summer.

Measurements of light interception and the efficiency of its conversion to dry matter and sugar were made in an experiment at Broom's Barn in 1983 comparing a conventionally spaced crop (80000 plants ha^{-1} in rows 50 cm apart) with two dense crops (138000 plants ha^{-1} in rows 38 cm apart and 160000 plants ha^{-1} in rows 50 cm apart). When harvested at the end of October the two dense crops produced, on average, 21·2 t ha^{-1} of total dry matter, only 0·95±0·380 t ha^{-1} more than the conventionally spaced crop. There were no significant differences in root dry matter or sugar yields. Throughout their growth the dense crops intercepted an average of 1410 MJ m^{-2} of solar energy, only 30 MJ m^{-2} more than the conventionally spaced crop. Thus there were no significant differences in the rates of conversion of light to plant dry matter.

Measurements of the size and longevity of individual leaves showed that leaf area per plant in the dense crops was not decreased by interplant competition until July. Despite this these crops only intercepted 120 MJ m^{-2} of solar radiation in June, an advantage of 20 MJ m^{-2}. In relation to the differences in plant population and the time of year at which it was expected to be of benefit, this advantage seems very small. A series of photographs showed considerable shading of the leaves of plants by their neighbours in the dense crops, even when light interception was as low as 15%. The close-row treatment, which had a more uniform plant distribution, was of little benefit in this respect.

In conclusion, the experiment showed that increasing the population of regularly distributed plants above the current recommendation of 75000 ha^{-1} had only a small effect on the interception of solar radiation early in the growing season. There were no significant differences in the rates of conversion of light to dry matter, and none of the extra dry matter produced by the dense crops was partitioned to sugar in the roots. (Jaggard and Glauert)

Diseases and pests

Factors affecting secondary dispersal of yellows viruses of sugar beet. Two aphid-borne viruses, beet mild yellowing virus (BMYV) and beet yellows virus (BYV) can seriously decrease yield in some years. Current advice on their control lacks precision, although it provides a useful guide to the optimum time to spray with insecticide and also indicates those areas and seasons in which spraying is not needed. Advice could be improved by taking account of the important differences between BMYV and BYV in transmission

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characteristics and effect on yield, and by identifying the factors which frequently cause large field to field differences in the incidence of yellows. As part of a collaborative project to improve advice on yellows control the most important components of secondary virus dispersal were studied with the aim of modifying spray advice to take account of field-specific factors.

After initial infection of sugar beet by yellows viruses introduced by alate *Myzus persicae,* secondary dispersal occurs mainly through their apterous progeny. Controlled environment studies revealed that movement of apterae between leaves on undisturbed plants correlated well with the interruption in nutrient flow which occurred when leaves changed from being net importers to net exporters of amino acids and sugars. Aphids were then forced to seek alternative feeding sites on younger leaves to satisfy their nutritional needs. This constant movement of aphids on a plant probably increases the likelihood of their becoming viruliferous because virus particles are more likely to be present in the younger leaves.

Interplant dispersal, and hence virus spread, may also be increased in this way, especially when the weather is turbulent and the plants are meeting within or between the rows. As the plants become larger however, interplant dispersal probably slows down due to the availability within individual plants of a larger number of young or senescing leaves which *M. persicae* prefer. Eventually aphid dispersal ceases when the plants are no longer favourable for aphid development, which, in this study, occurred 800–900 day°C above a threshold of 3°C after initiation of the first leaf.

To predict virus dispersal rates in the field a mathematical model of plant development was made. It is based on data from Milford (Physiology & Environmental Physics) on the relationship to temperature of leaf expansion, longevity and final leaf area. The model predicts trends in aphid movement by distributing a hypothetical aphid population between leaves of ages favourable for aphid colonization. When leaves die or become unsuitable, the aphids disperse to neighbouring plants. The model predicts that aphid dispersal between plants will peak at 400–500 day °C above the threshold of 3°C and then decline to zero at approximately 900 day degrees.

The model was tested in the field at Broom's Barn in 1982 and 1983 when the effects of plant growth stage on aphid and virus dispersal were examined on plots sown at monthly intervals from late March to late May. Both BYV and BMYV were introduced separately to uninfected plots using infective aphids, and subsequent aphid and virus spread was monitored. Virus spread was mapped visually and by using ELISA to determine virus infection in symptomless plants. Aphid populations peaked and declined at equivalent plant physiological ages rather than on the same time scale, confirming the laboratory studies. This resulted in decreased virus spread in the earliest sown plots, because the plants became unfavourable to aphids sooner. The pattern of infection by the two viruses also varied in a manner consistent with their persistence within the vector. The persistent BMYV spread further and was less aggregated than the semi-persistent BYV, but there was more rapid attenuation of BMYV spread as crops aged and became less suitable as aphid hosts.

Attempts are now being made to simulate virus spread using simple mathematical models which it is hoped will predict the likely progress and spread of infection given the time of inoculation, identity of virus and crop growth stage. Major improvement to the present spray warning scheme requires more information on the effects of the viruses on yield, development of means of monitoring the rate and timing of primary virus infection, and quantification of the role of field-specific factors in the development of virus yellows. (Jepson)

Beet western yellows virus in oilseed rape. The discovery, in oilseed rape crops, of a

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luteovirus which gave a positive reaction in ELISA with beet mild yellowing virus (BMYV) antiserum (*Rothamsted Report for 1982,* Part 1, 79), prompted studies on the identity of the virus, its ability to infect sugar beet, its occurrence in and effect on yield of oilseed rape crops, and the overwintering of the principal vector, *Myzus persicae,* on oilseed rape.

The virus was identified as beet western yellows virus (BWYV) on the basis of its host range which includes *Montia perfoliata, Capsella bursa-pastoris* and lettuce. Of five isolates from oilseed rape crops, three could not be transmitted to sugar beet while two were transmitted to between 10 and 50% of inoculated sugar-beet seedlings; the presence of BWYV in these beet plants was confirmed by further transmissions to indicator plants. This low rate of transmission implies that the danger of much direct movement of BWYV from oilseed rape to sugar-beet root crops in spring is small, although the virus was detected in 78 out of 80 randomly selected oilseed rape fields in England and Scotland in the spring of 1983, often in a high proportion of the plants.

A more detailed study of BWYV incidence and aphid infestation in a commercial crop of oilseed rape in Suffolk showed that *Myzus persicae* increased during October and November 1982 to 2·3 per plant (52% of plants infested) and then declined to undetectable levels in December and January. There was no resurgence in spring, possibly because this crop was sprayed with triazophos. The proportion of plants infected with BWYV increased from 5% in October to 52% by April.

In another study on an unsprayed oilseed rape plot (cv. Jet Neuf) at Broom's Barn in 1983, the proportion of plants infested with *M. persicae* rose from 1% one week after emergence in mid-September to approximately 100% during October, when an average of 12 aphids per plant were found. The proportion of plants infected with BWYV also increased, from 4% at the end of September to 95% by early January. *M. persicae* declined gradually during the winter and early spring to 0·2 per plant (6% plants infested) in early May before increasing again to 6·4 per plant (52% plants infested) in July. During June and July 16% of the *M. persicae* counted were alate nymphs.

The effect of BWYV on seed yield of oilseed rape was assessed in a field trial in an oilseed rape crop in Suffolk sown in autumn 1983. Virus infection was allowed to develop naturally in some plots, and in others aphicide sprays were applied to control the vector and thereby reduce levels of virus infection. Replicated plots 128 m^2 received no sprays, 10 pirimicarb sprays at 165 g a.i. ha^{-1} applied between 9 September and 1 December, or two pirimicarb sprays. The incidence of BWYV in each plot was assessed by ELISA prior to harvest and ranged from 12 to 100%. Seed yield was measured by ADAS, Cambridge, from a 62 m^2 area taken from the centre of each plot and moisture and oil content were assessed from sub-samples. BWYV-infection significantly decreased seed yield and oil content. (Smith)

Rhizomania. This disease, caused by beet necrotic yellow vein virus (BNYVV), has become a threat to the UK sugar-beet crop since its recent spread into northern Europe. In response to this, legislation was enacted in July, 1984, prohibiting the import of sugar-beet plants or unprocessed seed into Britain, except under licence. In addition a large-scale programme of sampling beet crops, and testing for the presence of BNYVV, was initiated in 1984, in collaboration with British Sugar and the MAFF Plant Health Division. Root samples were taken by British Sugar fieldstaff from 140 randomly-selected fields in August and tested for the presence of the virus at the MAFF Plant Pathology Laboratory, Harpenden, using the ELISA technique. Roots with rhizomania-like symptoms found throughout the growing season in other sugar-beet crops were also sent to the same laboratory for testing. To date, BNYVV has not been detected in any of these samples.

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At Broom's Barn, studies of the distribution of *Polymyxa betae,* the fungal vector of BNYVV, continued. Soil samples taken from 68 randomly-selected fields in August/ September, 1983 (*Rothamsted Report for 1983,* 51) were tested for the presence of the fungus by growing sugar-beet seedlings in them for four weeks in the glasshouse at about 20°C. Root systems were washed out and examined for infection with *P. betae* and *Olpidium brassicae.* In addition, crushed root extracts were used to inoculate leaves of *Chenopodium quinoa,* a wide-spectrum indicator plant for virus infection. *P. betae* was detected in 78% and *O. brassicae* in 87% of the soils. In many cases, root systems were so heavily infected with the cystosori of *P. betae* that they were visibly discoloured. In this preliminary survey the fungus was found in a higher proportion of light soils than heavy soils and more frequently in soils of intermediate pH than those of high or low pH in the range examined (5·3–8·2). Lesions on *C. quinoa* indicated the presence of soil-borne viruses in 15 of the samples, but none resembled the symptoms produced by BNYVV.

In 1984, soil samples were taken by British Sugar fieldstaff from 140 randomly-selected beet fields on two occasions. Samples collected in May are being tested at Broom's Barn for the presence of soil-borne viruses and to determine the population levels of *P. betae.* One half of each sample was air-dried for six weeks to eliminate free-living nematodes, and attempts will be made to identify viruses from sugar-beet seedling roots grown in these soil samples, wherever symptoms on *C. quinoa* are produced. A quantitative bioassay for estimating the number of infective propagules of *P. betae* in soils is being developed. Assessments of inoculum potential in soil samples taken from the sites in May and in August/September should yield information on the rate of build up in the growing crop. In this way the influence on inoculum potential of various recorded cultural practices, for example, the nature and extent of the rotation and the use of irrigation, as well as several soil factors (texture, pH), will be examined. (Payne, Smith and Asher)

The effect of resistant catch crops on the hatching of *Heterodera schachtii.* In some countries green manure crops, sown shortly after cereal harvest, are used to improve soil fertility. Cruciferous species such as *Raphanus sativus* ssp. *oleifera* (oil radish) and *Sinapis alba* (mustard) are often used in this way; however, most crucifers are hosts of beet cyst nematode *(H. schachtii)* and so might increase nematode populations if grown in infested soil. Nematode-resistant cultivars of some of these crops have recently been developed to remove this possible hazard, and their potential for controlling *H. schachtii* populations in England has been investigated.

A laboratory hatching test demonstrated that, at 20°C, 67–95% of *H. schachtii* eggs hatched in concentrated root leachates of four nematode-resistant cruciferous cultivars (oil radish cvs Pegletta and Ramses, white mustard cvs Emergo and Serval) and a susceptible cultivar (fodder rape cv. Emerald). Only 52% hatched in sugar-beet leachate, 25% in bare soil leachate and 21% in distilled water. The percentage hatch decreased as the root leachate was diluted. A further test confirmed these findings and demonstrated that at 15°C slightly fewer eggs hatched, at 10°C many fewer hatched and at 5°C virtually none hatched.

Field experiments investigated the effect of these cultivars, sown in September 1982 or August 1983, on populations of *H. schachtii.* Mean numbers of viable eggs 4–5 months after sowing a resistant cultivar were always less than under fallow but the decreases were only slight. There was little difference between the effect of the resistant cultivars and that of the susceptible cultivar, which, probably because of the late sowing and relatively cold and dry soil conditions, also appeared to act as a trap crop. Although the use of these cultivars is justified in fields infested with *H. schachtii* and in which catch

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crops are to be sown as a green manure, these trials gave little justification for the use of resistant varieties specifically as nematode-control measures. However, their effectiveness in decreasing nematode populations may be improved by earlier sowing, irrigation, or periods of prolonged rainfall. (Cooke)

Efficacy of granular pesticides in controlling Docking disorder. The application of granular pesticides to sugar-beet crops was first permitted on a limited scale in 1973. Subsequent surveys, based on information collected from about 700 randomly selected fields each year, showed that, by 1977, about 42% of the total sugar-beet area was treated; since then the proportion has remained steady at 43–50% (87000–100000 ha). Pesticides currently used include aldicarb, bendiocarb, benfuracarb, carbofuran, carbosulfan, oxamyl and thiofanox. The treated area includes most of the light, sandy soils at risk from Docking disorder, caused by the ectoparasitic nematodes *Trichodorus, Paratrichodorus* and/or *Longidorus*. Granular pesticides are also applied to control arthropod seedling pests, early aphid infestations, or simply as a general insurance.

Two separate surveys of disease incidence have, however, failed to demonstrate any decrease in the area of sugar beet affected by Docking disorder since the use of granular pesticides became widespread. From 1967–83, a survey based on monthly assessments by each British Sugar fieldman of the total amount of damage in his region, showed that the area affected remains closely correlated with May rainfall (in 1969 and 1983, years with similarly high rainfall, there were respectively 8110 and 8730 ha reported affected by Docking disorder); there was some indication that severity of damage has decreased (estimated yield loss 5·8 t ha^{-1} in 1969 and 4·3 t ha^{-1} in 1983). The second survey, initiated in 1979 and based on an annual examination of 700 randomly selected fields, ranked the years 1979–83 in the same order of severity of Docking disorder as the first survey but gave far greater estimates of the area affected (e.g. 20260 ha in 1983).

These findings contradict experimental evidence and growers' experience that yields of crops at risk from Docking disorder are usually greatly increased by pesticides in years with wet springs. This anomaly may result largely from the difficulties of diagnosing damage and estimating yield loss solely from an examination of growing crops—difficulties confirmed by the different results of the two surveys. However, it may also partly result from occasional incomplete control of nematode damage, possibly because of leaching of the pesticide by prolonged heavy rainfall.

Measurements of the vertical distribution of aldicarb in the soil in an experiment at Broom's Barn with three sowing dates showed that 12 days after application (during which there was 43·3 mm rainfall) most of the aldicarb residues were retained in the surface 10 cm of soil with 1·93 μg g^{-1} soil in the 5–10 cm layer. At 24 days after application (78·9 mm rainfall) the aldicarb residues were well distributed between 5–20 cm, and 60 days after application (158·1 mm rainfall) maximum concentrations of aldicarb residues were at 15–25 cm and even at this depth did not exceed 0·34 μg g^{-1} soil. These measurements agreed well with those predicted by the model CALF which simulates pesticide leaching (*Rothamsted Report for 1981,* Part 1, 134). Simulations based on spring weather patterns in 1979–83 suggested that nematode control would be seriously decreased only in years with exceptionally wet springs. In such years (e.g. 1983) predicted concentrations of aldicarb residues in the soil water were less than 3 μg ml^{-1} by 30 days after sowing; this is probably insufficient to control nematodes well. However, more accurate toxicity data for the nematode species concerned and more reliable survey data are required in order to understand fully the effects of leaching on Docking disorder control. (Cooke with Bromilow, Chemical Liaison Unit and Nicholls, Insecticides and Fungicides Department)

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Plant clinic. On average 136 sugar-beet problem samples were sent to Broom's Barn for help in diagnosis each year in the period 1980–83. The numbers varied from 94 in 1980 to 181 in 1983. Some were from growers, advisers or agrochemical companies, but most were sent by British Sugar fieldstaff. The primary purpose of the clinic is to use our specialist knowledge to diagnose and remedy growers' problems, but in addition the clinic helps keep us informed of the different and sometimes novel problems occurring in the field. It does not necessarily keep us informed of the frequency and severity of problems once they become recognizable by fieldstaff. Most samples come in the period mid-May to July when the crop is becoming established and, although this is the period of maximum field work at Broom's Barn, are dealt with within two days of receipt.

The problems change from year to year and as the season progresses. The commonest problems diagnosed during the period 1980–83 were: soil acidity (67 samples), Docking disorder (55), excessive concentrations of fertilizer salts in soil (54), *Aphanomyces* (47), herbicide toxicities (43), herbicide residues in the soil (4), trace element deficiency or toxicity (34), waterlogging and anaerobic soil conditions (30), blackleg etc., other than *Aphanomyces* (19), Barney patch etc. (19), soil pest complex (17), leatherjackets, cutworms, slugs, bibionids (15), capsids (15), root rots (12), unknown (40). (Winder)

Broom's Barn Farm

Cereals. All the winter cereals were sown between 19 and 26 September 1983. The autumn was very dry which made stubble cultivations difficult and consequently there was little chitting of volunteers from previous crops. This was most obvious in the wheat, which had many volunteer oats that were not controlled by the autumn-applied chlortoluron, although this herbicide controlled broad-leaved weeds well in both wheat and winter barley. Because of the low infectivity index for barley yellow dwarf virus no autumn aphicide was used, but all winter cereals particularly the barley, became infected with the disease to some extent, and this is reflected in the final yields. Spring barley was sown between 21 and 23 February and, with the winter oats, was treated with an ioxynil/benazolin/mecoprop mixture 'Springclene II'. 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 120 kg N ha^{-1} in two applications and spring barley 100 kg N ha^{-1} in one application.

The winter wheat and barley were sprayed early in April to control eyespot and mildew, and the wheat was treated with a straw shortener at the same time; the barley received a straw shortener in early May. The wheat was given a second fungicide spray in late June to control *Septoria,* and an aphicide was applied at the same time. The plots of wheat in the ICI-sponsored experiment on Dunholme needed an additional spray in early June due to a build-up of mildew originating from the artificially shaded areas. For the first time at Broom's Barn the oats required a fungicide in late April to control mildew and this was applied with the straw shortener. In mid-June the spring barley was treated, mainly for mildew, but also for *Rhynchosporium* and net blotch. By early summer all winter cereals looked well and despite thunderstorms, one very heavy on 20 June, very little corn lodged.

Harvest started on 27 July in the winter barley (cv. Igri) after spraying with diquat to dry off the many green ears in the crop; Windbreak yielded near to our average 7·1 t ha^{-1}, as it was least affected by barley yellow dwarf virus, but White Patch and Hackthorn yielded 6·6 and 6·0 t ha^{-1} respectively which reflects the levels of infection. Oats (cv. Pennal) on Flint Ridge and The Holt were not ripe until 9 August and both fields returned similar yields, 7·6 t ha^{-1}, although the soil on Flint Ridge is considerably lighter than on The Holt. The spring barley (cv. Triumph) was cut between 15 and 20

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August yielding 5·7–5·9 t ha^{-1} and the winter wheat followed immediately. Both wheat fields (cv. Norman) yielded more than any previous cereal crop at Broom's Barn; Dunholme, 2 t ha^{-1} above its previous best at 9·7 t ha^{-1} and New Piece 4·2 t ha^{-1} above its previous best at 10·7 t ha^{-1}.

Sugar beet. The first sowings were made in a short dry spell starting on 19 March. Ten days of rain delayed further field work until 3 April when, in a further three days drilling, 50% of the crop was sown. The showery weather in early April made it very difficult to complete the sowing of some experiments which in turn delayed the intended late sowings which were completed in early May. The early-sown areas were typical of many local fields except that the plant stand was better. The mid-April seedbeds had a very sharp moisture gradient with the surface drying rapidly, but fairly moist soil below. The depth of the moist layer was not uniform and, while some seeds were sufficiently far into this layer to remain moist enough for rapid germination and emergence, others, less deeply embedded in the moisture, dried out and lay ungerminated but viable until the rain in May when they gave good establishment. Aldicarb was applied in the seed furrow at drilling to decrease the risk of early virus infection, except where it would have interfered with experimental treatments.

Weed control was very difficult due to the varied sowing dates, the big difference in plant size within drillings and varying row widths. Most of the beet was band sprayed with 'Pyramin' at drilling, and this, with a combination of sequential herbicides, tractor hoeing, hand hoeing and hand weeding eventually controlled most of the weeds. Only one application of aphicide was required in early July except on specific experiments. Powdery mildew appeared late this year and the fungicide was not applied until early September.

Irrigation of the established crop started in the second half of July before a limiting deficit was reached. Most irrigation was required on Marl Pit, where it was necessary to avoid limiting deficits on four experiments. Approximately 9 ha of beet were watered, with total amounts applied varying from 50–120 mm according to the experimental requirement, soil type, etc. On Marl Pit the yield response to four applications totalling 60 mm was 4 t ha^{-1} of roots in early September.

Harvest started on 25 September in fairly wet conditions and persistent rain made conditions difficult especially on the hillside on Little Lane. The early sugar percentages were low, one down to 14·8%, but gradually increased. Yields averaged 43·0 t ha^{-1} clean roots at an average sugar concentration of 16·9%, ranging from 14·8% to 18·7%. Mean dirt and top tares were 15% and 5%. National yields averaged 45·8 t ha^{-1} at 16·4% sugar.

Livestock. During October and November 1983, 96 Friesian steers (average weight 398 kg) were bought and fed to appetite on a basic diet of one-third brewers grains and two-thirds beet pulp, plus 1 kg $head^{-1}$ day^{-1} 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 'Compudose' to increase liveweight gain. Although this is slightly more expensive than 'Ralgrow' (used last year), it is longer lasting and has no statutory period between implanting and slaughter, giving maximum benefit through the whole fattening period. The steers were sold between 13 February and 14 March, giving an average feeding period of 116 days per animal, which at the average selling weight of 552 kg gave a daily liveweight gain of 1·33 kg. (Golding)

Staff and visitors

W. N. Moore who, in 1938, was the first person appointed to Dr. Hull's staff at Hackthorn, Lincolnshire, retired in January from his responsibilities for the stores, vehicle

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and tarehouse. At the end of March, G. D. Heathcote retired after 32 years' service, the first ten in the Plant Pathology Department. P. V. Biscoe left during the year to take up a senior post in ICI's Agricultural Division at Billingham and A. W. Glauert left at the end of his research studentship. A. M. Dewar transferred from the Entomology Department to lead the work on aphid and soil pest control. M. J. C. Asher, from the Scottish Crop Research Institute, was appointed to a new post as mycologist specializing in soil fungi, particularly the fungal vector of rhizomania. On completion of her postgraduate studies, Helen Smith was appointed to a permanent post as Virologist.

Members of Broom's Barn Staff continued to be very involved in the work of the International Institute for Sugar Beet Research (IIRB), contributing to a rhizomania workshop at Colmar, France and to a Pests and Diseases Study Group meeting at Fuchsenbigl, Austria. W. E. Bray continued as Chairman of the IIRB Weed Control Sub-group and R. A. Dunning retired after 10 years as Chairman of the Pests and Diseases Study Group. R. K. Scott served on the Scientific Advisory Committee of the IIRB and members of staff attended the IIRB Winter Congress in Brussels and the Breeding and Genetics Group meeting in Denmark as well as study tours arranged by seed firms and agrochemical companies. D. A. Cooke made a study tour of European nematology research centres in June and A. M. Dewar visited the Sugar Beet Research Station at Bergen-op-Zoom in the Netherlands during February.

A Farm Walk at Broom's Barn in June was attended by some 520 growers and technical staff from British Sugar and other companies and organizations. Over 300 delegates from the European Beet Growers Congress, held this year in London, also visited the station in June. Many other smaller groups of visitors came from England and abroad (including France, USA, Poland, USSR) during the year including ones from chemical and seed companies, the Institute of Biology, and parties of students from the Netherlands and Germany, and from the Universities of East Anglia, Leeds, Newcastle and Essex. Dr. K. Veverka from the Institute for Plant Sciences, Prague worked with us for two weeks in September.

Training courses were organized for ADAS Sugar Beet Advisors, British Sugar field staff (Northern and Southern Groups), ADAS Special Interest Group (West Midlands), Beet Cyst Nematode Surveyors, ADAS Entomologists and MAFF Plant Health Inspectors. Members of staff gave many talks on a range of topics to do with sugar beet to agrochemical company representatives and to farmers meetings organized by British Sugar, ADAS, agricultural clubs, agrochemical companies and the local Agricultural Training Board. The station played an important part in the establishment of a SBREC working party on rhizomania of which R. A. Dunning was appointed Chairman and M. J. C. Asher Secretary.

Four winter scientific meetings were held at Broom's Barn. Exhibits were contributed to the CIBE congress, the Arthur Rickwood Experimental Husbandry Farm Open Day, the ADAS Sandland and Irrigation Demonstration, the Royal Show, Weed Beet '84 and the World Ploughing Competition. Several staff members contributed to the British Sugar Staff Conference at Stratford-on-Avon.

The work of Broom's Barn is undertaken for the Sugar Beet Research and Education Committee. W. J. Byford and D. A. Cooke assisted in compiling this report.

THE FARMS AND THE FIELD EXPERIMENTS SECTION

The services required of the Farms and the Field Experiments Section were little changed and continued to be primarily concerned with the planning, conduct and recording of the programme of field experiments. This 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 25 indoor meetings and made 15 field tours of experiments.) During the year the changing priorities of the programme led to the establishment of an Oilseeds Commodity Group and the closure of the Grass Commodity Group. The remaining functions of the latter were taken over by the Beans Group under the new title Legumes and Forage Commodity Group.

The total number of plots at Rothamsted and Woburn was 7285. Of these 4599 were managed by the Farms with yields taken from 3988 and 1310 were managed by the small-plot staff with yields taken from 442; on the remainder the work was divided between Farms, small-plot staff and scientific departments.

Weather

A wet January, with little snow but severe frost at times, was followed by an average February which allowed some early nitrogen top-dressing. March started dry but sowing barley and beans was soon interrupted by rain and was not completed until the end of the month. April was very dry, making it difficult to produce good seedbeds for potatoes on the heavier land. May was wet, June average and July dry, particularly at Rothamsted; winter barley harvest began at the end of the month.

At Rothamsted August was dry but at Woburn rainfall was a little above average. Despite this, grain harvest was completed at Woburn on 28 August, four days before completion at Rothamsted. September was wet but a start was made on potato lifting and oilseed rape and barley drilling was completed during the month. October became progressively wetter at Rothamsted and field work was frequently interrupted but Woburn had below average rainfall. November was a very wet month but potato lifting and winter cereal drilling were finished at Woburn and nearly so at Rothamsted.

Crops

Of the 335 ha farmed (259 ha at Rothamsted, 76 ha at Woburn), cereals occupied 205 ha, potatoes 17·7 ha, beans 12·1 ha and oilseed rape 8·9 ha. The remainder was grass, lucerne, fallow, access headlands, and a little maize, peas and sugar beet.

Wheat. There were 101·9 ha at Rothamsted and 14·9 ha at Woburn, almost all autumn-sown. Sowing was timely and the crop came through the winter well. Most crops after cereals were sprayed with a prochloraz, carbendazim, xylene mixture ('Sportak Alpha') in spring to control eyespot. Few crops were sprayed with a fungicide in summer because leaf diseases were few, but most received pirimicarb to control the abundant aphids.

The main cultivars were Avalon and Longbow with some Rapier, Stetson and Norman. All yielded very well; several fields yielded 10 t ha^{-1} with many plots giving substantially more. Flanders, retained for a final year on Broadbalk, yielded best (9·3 t ha^{-1}) after the two-year break. Although yields with farmyard manure alone were only a little better than with fertilizers (NPKMg) the combination of farmyard manure and spring nitrogen gave an average of 1·6 t more grain than fertilizers alone.

On the Factors Limiting Yield experiment (p. 23) Avalon yielded on average 10·4 t ha^{-1} following a break crop of oats and 8·2 t ha^{-1} following barley. Following oats, sowing on 18 October gave exactly the same yield as sowing on 20 September, but following barley later sowing increased yield from 7·5 to 8·9 t ha^{-1}. The timing of nitrogen applications had little effect on yield but increasing N from 160 to 230 kg ha^{-1} increased yield by 0·8 t ha^{-1}. Summer fungicide did not increase yield and a spring fungicide increased yield by only 0·2 t ha^{-1} after oats but by 0·6 t ha^{-1} after barley.

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In an experiment on the control of take-all seed treatment with triadimenol increased yield from 6·6 to 8·1 t ha^{-1} on a crop sown on 8 September but only from 7·4 to 7·8 t ha^{-1} when sowing was on 7 October.

In a trial comparing 10 cultivars Brimstone yielded most at Rothamsted but on the lighter land at Woburn gave one of the lowest yields. On this latter site Mission was best. Triticale, cv. Grace, was also included in these trials but gave poor results on both light and heavy land.

In the difficult autumn weather of 1984 many sowings were delayed, and although all the planned area was sown at Woburn some at Rothamsted, mostly after potatoes, on heavy soil, could not be drilled.

Barley. Of 19·7 ha autumn-sown most were of cvs Igri and Panda, with some Pirate in one experiment. Yields were generally good except on one field which followed winter barley and was severely infected by barley yellow dwarf virus despite ploughing-in stubble, as the aphid vectors survived on buried residues. The mean yield of Panda in the Factors Limiting Yield experiment (p. 28) was 9·1 t ha^{-1} and Pirate exceeded 10 t ha^{-1}. Igri yielded 8·6 t ha^{-1} on the Cultivation/Weedkiller experiment, 1·1 t more than in 1983. At Woburn Igri yielded on average 8·5 t ha^{-1} on the heavy land of the Minimum Cultivation and Deep PK experiment but in a fungicide experiment on the light land Maris Otter yielded only 7·6 t ha^{-1}.

Spring barley was sown on 44·9 ha. It generally did well at Rothamsted when it was sown in good time, established well, and benefited from adequate moisture in May and June; the main cultivars were Atem and Triumph. Although Triumph was very susceptible to mildew, and losses of over 1·0 t ha^{-1} were recorded on unprotected crops it yielded well when treated with fungicides and gave up to 6·4 t ha^{-1} on Hoos Barley, 1·5 t more than Georgie grown last year. In an experiment on insecticides and sowing dates the best yield was 8·9 t ha^{-1} when sown on 9 March and treated with omethoate ('Folimat'). Without insecticides the yields from sowings on 9 March and 13 April were 8·3 and 7·8 t ha^{-1} respectively.

At Woburn yields were more variable, but Triumph in the Ley Arable experiment yielded over 7 t ha^{-1}.

Winter barley for 1985 was sown by the end of September on both farms; some was sprayed with isoproturon to control weeds, but bad weather prevented completion of spraying.

Oats. The crop provides a break from wheat and barley. At Rothamsted cv. Pennal is grown but at Woburn the less common cv. Panema because it has resistance to cereal cyst nematode. Crops were not affected by diseases and Pennal yielded 7·5 t ha^{-1}. A small area of spring oats was grown, cv. Trafalgar, as a nurse crop for a grass ley but the yield and quality were both poor.

Beans. There were 12·3 ha equally divided between winter (Banner) and spring sown (Minden): almost all at Rothamsted.

A new series of annual experiments on winter beans compared all combination of three sowing dates (23 September, 19 October and 18 November), three seed rates (12, 24 and 36 seeds m^{-2}) and two methods of sowing (drilling and ploughing in seed). Ploughing in seed gave 0·2 t ha^{-1} more grain than drilling, without interaction with other treatments. There was a large interaction between seed rates and date of sowing; on the first date the largest mean yield (5·6 t ha^{-1}) came from the lowest seed rate, for the second date (5·4 t ha^{-1}) from the intermediate seed rate and for November sowing

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(5·3 t ha^{-1}) from the highest seed rate. (McEwen and Yeoman, Field Experiments Section, Moffitt, Farms)

Spring beans responded well to both irrigation and the control of pathogens (p. 34), the combined effect was to increase yield from 3·5 to 5·6 t ha^{-1}.

Oilseed rape. There were 8·9 ha, all at Rothamsted, slightly more than last year, and the experimental programme also expanded. Work on nitrification inhibitors and pollination continued and work was started on growth regulators and electrostatic spraying. The cv. used was Jet Neuf, direct drilled on 1 September 1983 and yields ranged from 2·8 to 3·5 t ha^{-1}.

Sowings for 1985 experiments were done on 15 August and 5/6 September, and the weedkillers, propyzamide+3,6-dichloropicolinic acid were applied.

Potatoes. There were 17·7 ha, mainly Désirée, Pentland Crown and King Edward at Rothamsted, Pentland Crown and Cara at Woburn. Planting conditions were much better than in 1983, although drier than ideal; the ridges dried out after planting and on the heavy land it was impossible to break clods adequately. Conditions were unfavourable for pre-emergence weedkillers and some crops were sprayed with metribuzin ('Sencorex') after emergence.

Crops were sprayed against blight and aphids with fentin hydroxide ('Duter') and pirimicarb ('Aphox'). Blight was not found but severe aphid damage (leaf curling and premature senescence) occurred on one field of Désirée on which aphicide was restricted for experimental reasons. All the earlier crops were desiccated with sulphuric acid (BOV), but wetter conditions later allowed a change to 'Reglone' (diquat). Lifting was frequently interrupted by wet weather but all plots and nearly all the non-experimental areas were completed in November.

Yields were greater than expected after the dry summer; some crops of Pentland Crown exceeded 60 t ha^{-1} gross at Rothamsted and gave up to 55 t ha^{-1} at Woburn.

Maize. A new series of annual experiments compared all combinations of three cvs (Bastille, Beaupre and Fronica), two sowing dates (11 April and 10 May) and with or without perforated polythene sheet at sowing. Bastille gave the largest mean yield of both forage (15·6 t D.M. ha^{-1}) and grain (7·6 t ha^{-1}). The earliest forage harvest (5 September) came from Beaupre sown on 11 April given polythene covering, about a month sooner than Fronica sown under normal practice (May, uncovered). Grain from all the earlier sowings was harvested on 24 October, two weeks before the later sowings. (Barnard, Field Experiments Section)

Grass. There was ample grazing early in the season and surplus grass was ensiled together with first cuts from experiments. It was scarce in the dry summer, second cuts were light and livestock needed supplementary feeding by later summer.

Cattle

One hundred and seventy-six were sold fat and 198 yearling steers bought.

Recording and retrieval of field data

All field operations, whether on experiments or on non-experimental land, are recorded daily by the Farm and the small-plot staff. These data are sorted to provide complete chronological records for each experiment and for each field. In addition similar lists of data-to-date are often needed during the year. A program has been developed for

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regular storage of data on cassette tape during the year using an Epson HX20 microcomputer. The Computing Unit transfers these data to the VAX for accessing by the database management system Datatrieve. Sorting data can be done readily using a Fortran program with Datatrieve routines. More general information retrieval is provided by interactive Datatrieve commands. (Yeoman with Legg, Thomas and Verrier, Computing Unit)

Visitors

The Field Experiments Section was responsible for just over 200 parties of visitors comprising about 2000 individuals. Most visited the field experiments as part of their programme. Nearly half the total number were students at schools, colleges or universities. Over 400 farmers visited, about 60 as members of the 'Friends of Rothamsted', and many came from overseas.

Staff

Farms. Jillian B. Curl and P. D. R. Styles were appointed.

Field Experiments Section. Myrtle E. Hughes retired after 44 years service, Jenny A. Davidson resigned and Mohinder K. Rumpal was appointed. J. McEwen gave four outside talks to groups of farmers and advisers on field beans. R. D. Prew gave four outside talks to similar audiences on the multidisciplinary wheat programme. He attended the Hungarian–British joint seminar on plant breeding and soil fertility held in Budapest.

PHYSIOLOGY AND ENVIRONMENTAL PHYSICS DEPARTMENT

For the purpose of this report the Department's programme has been divided into three areas: crop physiology, plant physiology and aerobiology. These are not clearcut divisions; the aim of the Department's work is to establish relationships between crops and their environment, by experimentation at levels from cell metabolism to crop performance and by defining models of biological and physical phenomena. We report here physiology studies in the laboratory and the field on wheat and sugar beet, and studies of the aerial environment of crops as it affects particle dispersal and consequently disease spread.

Crop physiology

The ultimate goal of our physiological research is to explain how physiological factors influence the yield of arable crops. Field study of crop performance is matched by efforts to produce models that describe the observations and that can be used either to analyse crop growth in other experiments or to predict responses to environmental or physiological changes. Much of the Department's research into the causes of yield variation in winter wheat and barley has been linked to multifactorial experiments that are described under Multidisciplinary Agronomy (pp. 23–28).

Yield variation in winter wheat

Modelling the wheat crop. The inter-institute exercise to develop a computer simulation model of the growth of winter wheat has involved four institutes—Long Ashton Research Station, Letcombe Laboratory, Plant Breeding Institute and Rothamsted Experimental Station. This project has sought to translate quantitative information about the performance of wheat crops into a computer program, and then test the model

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or its components against experimental data. The model forms a framework against which to explain variations between treatments, sites or seasons, and to assess likely consequences of variations in climate or physiological processes.

Some information used to define the parameters in the model was taken from the series of multifactorial experiments at Rothamsted. However other parameters defining specific physiological processes (e.g. photosynthesis) have come from studies elsewhere. We are now analysing the relationship between the model and the performance of these Rothamsted crops. Some analysis of tiller production is given below; differences in dry matter production between seasons are also being examined in terms of differences in light interception and effects of temperature on the efficiency of conversion of radiation to dry matter. (W. Day and Thorne; Scott with Rayner and Weir, Soils and Plant Nutrition Department, Dr. J. R. Porter, Long Ashton Research Station, and Dr. E. J. M. Kirby, Plant Breeding Institute)

The multifactorial experiments have shown consistent differences in the pattern of development between wheat sown in September and that sown in October. The mechanisms responsible are partly explained by the AFRC wheat model (Weir, Bragg, Porter & Rayner *Journal of Agricultural Science, Cambridge* (1984) **102,** 371–382). To test whether the same explanation would account for developmental patterns in a wider range of natural environments, Dr J. R. Porter of Long Ashton Research Station organized a study of the development of Avalon winter wheat sown on dates ranging from mid-September to mid-November at ten sites from Devon to Aberdeen, including Rothamsted.

The plots at Rothamsted sown on 15 September, 11 October, and 16 November 1983 reached the double ridge stage on 30 January, 22 March and 16 April respectively. Thereafter the later sown wheat developed more rapidly, decreasing the range of dates when a particular stage was reached: terminal spikelet, 9 April, 22 April and 4 May; anthesis, 14, 15 and 21 June; maturity 7, 10 and 13 August respectively. Later sowing decreased the number of leaves produced on the main stem (15·0, 12·1 and 10·5) but had only a small effect on the number of spikelets (21·8, 19·3 and 19·6). Leaves were initiated more slowly and spikelets were initiated more quickly with later sowing. With all sowing dates the grain filling period lasted 40–45 days and ended about the time of complete senescence of the flag leaf. The dates of each developmental stage predicted by the model from the weather were within seven days of the observed dates. Our data, combined with that from the other sites, will allow an extensive test of the model. (Wood; with Weir, Soils and Plant Nutrition Department and Dr J. R. Porter, Long Ashton Research Station)

Modelling tiller production. The tillering sub-model of the AFRC wheat model (Porter *Journal of Agricultural Science, Cambridge* (1984) **102,** 383–392) is based on various data including some results from the first years of multifactorial experiments at Rothamsted (1978/79 and 1980/81) and, like the rest of the wheat model, is intended to describe crops in which neither nitrogen nor water limit growth. It defines three phases: in the first, which lasts until the fourth leaf on the main stem appears, no tillers are produced; in the second phase, tillers are produced at a rate that is proportional to temperature, equivalent to one new tiller appearing in each interval between the appearance of consecutive leaves on the main stem; the final phase begins at the double-ridge stage on the main stem apex, after which no further tillers appear. Preliminary analysis of the data from six years' experiments for the mean number of tillers per unit area suggests that the start of tillering is quite well represented by the model. For nearly all the data on the early-sown (mid-September) crops the observed tillering rate was similar to that predicted by the model. However, for late-sown

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(mid-October) crops, higher tillering rates were much more common, and were associated with greater nitrogen supply. Most early-sown crops received no nitrogen during tillering, but in some years a few plots within the experiment did receive autumn nitrogen application and in these the tillering rate was usually higher. The late-sown crops received a variety of nitrogen treatments during tillering; the earliest and largest nitrogen applications gave the greatest tiller numbers, and with some treatments nearly all possible primary and secondary tillers appeared. Thus the AFRC sub-model which essentially only allows for production of primary tillers (i.e. tillers on the main stem), underestimates tillering rate in circumstances where nitrogen is not limiting growth. The end of tillering was not closely tied to double-ridge or any other growth stage and was not greatly affected by nitrogen treatment, although variations in tillering between plants did tend to show as earlier cessation of tillering with low nitrogen treatments.

Mathematical analysis of these observations must take into account the fact that tiller production is not a smooth function, but rather a series of step functions occurring in a variable way in a heterogeneous population of plants. We are analysing tiller production using a Poisson point process model, whose initial rate switches to zero after thermal time T. T is a random variable exponentially distributed with a parameter α that characterizes plant competition. The model describes the mean tiller numbers per m of row quite well, but further development is required to ensure that it models the process of tillering on individual plants realistically. (W. Day, Wood and Chalabi; Scott)

Tiller production, survival and growth. The appearance and death of individual tillers are being observed in order to elucidate the mechanisms controlling shoot number: the field studies reported here complement others made in growth rooms (*Rothamsted Report for 1983,* 61).

Regular observations on individual plants in the multifactorial experiment provided information about the appearance and death of particular categories of shoots whilst information about the weights and green areas of these categories was obtained at the first four sampling times and at maturity. In both September- and October-sown crops rapid death of tillers started at about the terminal spikelet stage, when stem extension started. In the September-sown crop the later-produced tillers died first and the proportion surviving decreased progressively the later the tillers had emerged. However, in the October-sown crop, fewer tillers that emerged in early January survived than would have been expected from their emergence dates and positions on the plant. This behaviour seemed to be associated with a period of low radiation and warm temperatures in late December, shortly before the group of weak tillers emerged, which could have restricted their growth before they became self supporting.

The only treatment that affected the times when production of tillers stopped and when death started was sowing date. An extra 40 kg N ha^{-1} applied at sowing increased tiller production by early-sown wheat in the autumn, giving an extra 286 tillers m^{-2} in early December, but tiller numbers for this treatment were no greater than for other treatments after the first part of the main early N had been applied in early February. With later sowing, autumn-applied N had increased the number of shoots by about 250 m^{-2} in the late February and April samplings, but none of these extra shoots survived to form ears. Nitrogen applied early in the spring (February and March) rather than late (March and April) delayed, but did not prevent, the death of some secondary tillers in early-sown wheat. In the later-sown crop, this early-applied N increased the maximum number of shoots by 600 m^{-2} but all these extra tillers died by mid-May. The shoots that survived were not adversely affected by competition from these additional ones. The dry weight of the main shoot plus the first two tillers in later-sown wheat given

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early N was greater in April (maximum shoot number), and similar in May, to the weight in wheat given N late.

In all these considerations of tiller production and survival it is important to remember the major contribution of the main shoot and the first two tillers to the economic yield. For both sowing dates, these three categories made up only just over half of the maximum number of shoots but they provided about 95% of the ears. When shoot number was at its maximum these categories accounted for about 85% of the dry weight and 70% of the leaf area index of the early-sown crop, and 80% of the weight and 90% of the leaf area in the late-sown crop. At maturity the contributions of the main shoot, first and second tillers to total ear number were: 55, 29, 13% respectively with early sowing and 52, 24, 22% with late sowing. The corresponding contributions to grain yield were 59, 27, 12% respectively with early sowing and 58, 21, 19% with later sowing. (Wood; Gray, Rainbow, Stevenson)

Effects of a compact subsoil layer on growth and yield. Among the sites on which wheat crops have been grown in the studies of yield variation, the sandy loam soil of the Cottenham series at Woburn is of particular interest because it has a compact layer at between 25 and 45 cm depth which has been shown to inhibit root growth (*Rothamsted Report for 1983,* 171). The effect of this restriction of root growth was investigated in a multifactorial experiment that included a comparison of normal ploughing to 25 cm depth with disruption of the compact layer using a Wye Double Digger. Wheat, cv. Avalon, was sown in September and treatments were applied in a factorial design to test the effects of breaking the compact layer, applying nitrogen in winter (35 kg ha^{-1} on 30 November and 35 kg ha^{-1} on 31 January), applying either 115 or 185 kg ha^{-1} of spring N either early (mostly in March) or late (mostly in April), and irrigating the crop. Autumn herbicide damage restricted the usable crop area and the precision of many observations, and final yields were obtained from hand-cut samples.

Neither emergence nor establishment of plants were affected by cultivation treatment but, by December, shoot dry weight, leaf area index and N uptake on deep cultivated plots were approximately 25% greater than with normal ploughing. Roots had then reached a depth of 80 cm on deep-cultivated plots, with 0·4 km roots m^{-2} of soil surface (12% of the total) below 40 cm, whereas virtually none had penetrated the undisturbed compact layer. The effects of deep cultivation persisted and, by the beginning of May, after all plots had received spring N, still increased dry weight by 33%, leaf area index by 52% and N uptake by 44%. At anthesis dry weight was increased from 1390 to 1560 g m^{-2} and leaf area index from 8·4 to 10·7, reflecting more and larger leaves per shoot as well as an increase in shoot number from 510 to 580 m^{-2}. Roots had then reached 190 cm on deep cultivated plots, with 26% of the total below 40 cm (10 km m^{-2}), whereas with normal cultivation no roots were below 120 cm and only 1·1 km m^{-2} were below 40 cm. Deep cultivation increased grain yield from 9·1 to 9·6 t ha^{-1} (85% dry matter and dry straw yield from 8·5 to 10·5 t ha^{-1} but did not interact with other treatments.

Cultivation treatment affected development as well as growth. With no winter N, the double ridge stage of apical development was reached on 7 February with deep cultivation and on 20 February with normal cultivation. This was probably a response to better availability of N, because the double ridge stage was also reached on 7 February with the autumn N treatment: there were no significant differences in soil temperatures between these treatments. This influence of nutrition on apical development will need to be considered when modelling crop development (see above).

Nitrogen applied during the winter increased crop weight and leaf area index at the end of February by over 60%, more than twice the benefit from deep cultivation. By the

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beginning of May, after all plots had received spring N, the effect of winter N had become less than that of deep cultivation. Thereafter the only significant effect was an increase of 1 t ha^{-1} in straw dry weight at maturity. The only significant effects of the spring N treatments were at maturity when late application compared with early and 185 compared with 115 kg N ha^{-1} each increased grain yield by 0·7 t ha^{-1} (85% dry matter). Grain yield with 185 kg N ha^{-1} given late exceeded 10 t ha^{-1}.

The potential soil moisture deficit increased steadily from 25 March to reach about 103 mm by 20 May: 113 mm of rain in the next 18 days reduced the deficit to 30 mm, after which it increased steadily to 205 mm on 2 August by which time the crop had senesced completely. Irrigation totalling 81 mm was applied in May, but even the unirrigated crop was able to find sufficient water, as water use (derived from soil water measurements with a neutron moderation probe) on unirrigated, ploughed plots did not fall significantly behind irrigated plots during the dry period in April and May. The greater water content of the irrigated plots at the onset of the heavy May rains would have resulted in greater drainage from the irrigated plots during those rains. A further 75 mm of irrigation was applied between anthesis and crop senescence and in this period measurements showed that both irrigation and deep cultivation increased leaf water potentials, and that irrigation increased photosynthetic rates slightly. Over the whole season, the crop used 30 mm more water from deep cultivated than from ploughed plots when not irrigated and about a further 40 mm when irrigated. The pattern of water extraction from the profile was consistent with that of root distribution. More water was extracted from the top 35 cm of soil above an undisturbed compact layer than with deep cultivation, but little from below 115 cm, whereas about 25% of total extraction on deep cultivated plots came from below 115 cm. Averaged over all treatments, irrigation did not increase grain yield significantly nor did it interact with cultivation, though it did increase straw dry weight of wheat given early spring N from 8·6 to 10·5 t ha^{-1}.

These observations on growth and yield, and the limited data on N uptake available at present, suggest that deep cultivation improved crop access to soil N during the autumn and winter and enhanced the uptake of fertilizer N applied in the spring, especially with the larger dressing: these effects could have resulted from a better root distribution. Fertilizer N given during the winter increased early growth as well or better than deep cultivation but the effects were less persistent. There was no evidence that the ploughed crop was more susceptible to drought but the likelihood of leaching in irrigated plots complicates interpretation. (Welbank; Keirle, Leach, Mullen, Parkinson with Barraclough, Darby, Doran, Penny, Smith, Weir, Widdowson, Soils and Plant Nutrition Department)

Variation in yield and quality of sugar beet. During the early stages of growth, air temperature is the main climatic factor and nitrogen the main agricultural input affecting leaf growth. Studies on a range of crops grown between 1978 and 1982 showed large differences in the thermal time required to expand unit leaf area index, with crops containing greater concentrations of nitrogen in their laminae having substantially faster rates of expansion (*Rothamsted Report for 1982,* Part 1, 79). However, excessive use of nitrogen lowers the quality and value of the harvested crop to the grower by decreasing sugar concentration and to the processor by increasing the content of amino-N. Recent surveys have demonstrated an inverse relationship between the grower's use of nitrogen and root quality measured at the factory (*British Sugar Beet Review* (1983) **51,** 15–17). To resolve these competing effects and to define optimum nitrogen fertilization requires a better understanding of what happens to nitrogen between its uptake as nitrate during the early stages of growth and its appearance in the nitrogenous constituents of the harvested roots.

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Influence of nitrogen fertilizer rates and timing on yield and quality. In 1982 a study was made of the responses in the growth, development and composition of the storage root to large perturbations in nitrogen supply at different stages of development. Crops were grown with no nitrogen fertilizer (N_0): with 125 kg N ha^{-1} applied either at drilling (N_{125}) or as a single top-dressing in mid-July (N_0^+): or with 125 kg N ha^{-1} in the seed bed and three top-dressings of 25 kg N ha^{-1} each in June, July and August (N_{125}^+). The N_{125}^+ crop produced the greatest root yield (91 t ha^{-1}) but had the lowest sugar content at 16·5% fresh weight whilst the N_0 and N_{125} crops had the highest sugar content (17·7 and 17·8% fresh weight) in yields of 72 and 86 t ha^{-1} respectively. The N_0^+ crop produced 84 t ha^{-1} with a sugar content of 16·5% fresh weight. Therefore the highest sugar yield was produced by the N_{125} crop (15·4 t ha^{-1}) followed by the N_{125}^+ (15·0 t ha^{-1}), N_0^+ (14·0 t ha^{-1}) and then the N_0 crop (12·7 t ha^{-1}). However the N_0 crop had a considerably lower amino-N content and lower root nitrate content than did any of the other crops (for amino-N 9·2, 15·8, 20·4 and 23·5 kg N ha^{-1} and for root nitrate 3·5, 4·1, 6·0 and 8·3 kg N ha^{-1}, in the N_0, N_{125}, N_0^+ and N_{125}^+ crops respectively).

The seasonal pattern of nitrate concentration in the plants under different treatments is influenced by both the nitrate uptake and its conversion to other nitrogenous compounds. In the N_0 crop, nitrate levels remained relatively constant at 1·7 kg N ha^{-1} throughout growth, except for transient increases after irrigation or heavy rains, until wet weather during the last three weeks of growth increased uptake from the soil and doubled the crop's nitrate content. In the N_{125} crop, nitrate levels increased to 4·8 kg N ha^{-1} during June, declined during July to 2·4 kg N ha^{-1} and remained constant at this level throughout the rest of growth. Therefore, towards the end of the season there was little difference in the root nitrate contents of the two crops. The N_{125} and N_0^+ crops were given the same amounts of fertilizer nitrogen (125 kg ha^{-1}) but at different times, one in the seed bed, the other as a top-dressing in mid-July. Levels of NO_3-N in the N_0^+ roots rose from 1·6 to 8·2 kg ha^{-1} soon after the large July top-dressing was applied and stabilized at 5·7 kg ha^{-1} during the rest of growth. These levels were almost twice those in the N_{125} crop. In the N_{125}^+ crop, the first top-dressing of 25 kg N ha^{-1} was applied in mid-June when the level of NO_3-N in the roots was rising. During the following four weeks more NO_3-N accumulated in the roots of the N_{125}^+ crop than the N_{125} crop. However, the increase was transient; the extra nitrate in the N_{125}^+ roots and much of that present in the N_{125} roots had disappeared before the second dressing was applied in mid-July. These changes in nitrate status are consistent with nitrogen accumulating in a transport or temporary storage pool prior to being translocated to the shoots or metabolized to other nitrogenous compounds. There were similar changes in amino-N contents.

This experiment has demonstrated two things. First, sugar-beet crops handle large influxes of nitrogen differently later in the season than during the early stages of growth. This has important consequences for impurity levels in the roots if nitrate becomes suddenly available late in growth, either because of its distribution within the soil profile or because of rainfall patterns. Secondly, the results indicate that it may be possible to define a stage in the crop's development before which split-dressings of nitrogen might be applied to improve leaf growth without a concomitant increase in nitrogenous impurities in the root. (Milford and Pocock; Dixey with Armstrong, Broom's Barn)

Plant physiology

Understanding causes of variation in field crop performance and identifying opportunities for improvement require basic studies of physiological processes, for which appropriate experimental techniques must be developed and tested.

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Application of nitrogen fertilizers increases the amount of chlorophyll and proteins in leaves (*Rothamsted Report for 1982,* Part 1, 176) but does not increase the light absorption coefficient or the rates of assimilation to the same extent as it stimulates growth of organs. We are examining the dependence of photosynthesis on light, CO_2, O_2 and temperature, and the effects of nitrogen nutrition on both photosynthesis of detached leaves and the growth and development of plant organs.

Fluorescence studies of photosynthesis. Increasingly the technique of measuring chlorophyll *a* fluorescence is being used to determine photosynthetic activity, and to give detailed information about the photosynthetic system. Measurement of chlorophyll *a* fluorescence at 685 nm indicates the energy state of the reaction centres of photosystem II (PSII) and pigments associated with it. Fluorescence reflects the rate of electron transfer from PSII to chemical acceptors, and the coupling between ATP synthesis and electron transport. To establish the relationship between fluorescence and photosynthetic activity we are measuring both fluorescence and CO_2 exchange in an open gas exchange system where CO_2 and O_2 concentrations can be altered rapidly.

Changing the CO_2 concentration from 0 to 300 or 1000 $\mu l\ CO_2\ l^{-1}$ induces characteristic transient effects on fluorescence and photosynthesis. Within 20 s fluorescence decreases and assimilation increases rapidly to large values (30 $\mu mol\ CO_2\ m^{-2}\ s^{-1}$ or more), after a further 20 s fluorescence rises and assimilation falls to less than one quarter of its peak value. There are then two or three damped oscillations in CO_2 fixation and fluorescence before a steady state is reached. Thus fluorescence is inversely correlated with assimilation under these conditions.

DCMU and phloridzin inhibit assimilation and increase fluorescence greatly. DCMU blocks electron transport from PSII to PSI in the thylakoids and phloridzin blocks H^+ flow through the ATP synthesizing enzyme CF_1: both compounds therefore cause a back-up of energy in PSII. Gramicidin and CCP decrease fluorescence and assimilation; they are known to allow H^+ leakage from thylakoids and to uncouple electron flow from photophosphorylation respectively. Hydroxylamine also decreases both fluorescence and assimilation in our experiments, probably by inhibiting water splitting.

On the evidence of these inhibitor studies and from the literature (Robinson & Walker (1981) In: *The Biochemistry of plants, Vol. 8, Photosynthesis,* Eds M. D. Hatch & N. K. Boardman, New York: Academic Press, 193–236) the transient changes in CO_2 assimilation and fluorescence caused by changing from 0 to 1000 $\mu l\ CO_2\ l^{-1}$ may be interpreted as due to different rates of enzyme reactions and ATP synthesis. In zero CO_2, the pool of RuBP is large and, when CO_2 suddenly becomes available, assimilation is very fast; the photosynthetic carbon reduction cycle becomes active and this drains the ATP pool. The ADP released stimulates increased ATP synthesis, increasing the H^+ flux out of the thylakoids and this, together with the reduction of $NADP^+$, allows rapid electron transport and decreases fluorescence. However, the decrease in ATP concentration that accompanies rapid photosynthesis inhibits phosphoglycerate kinase, slowing CO_2 assimilation and electron flow, and increasing fluorescence. As a consequence of these reactions having different time constants, rates of consumption and production of ATP and electron flow oscillate until a steady state is established, not at the maximum rates of photosynthesis or energy use, but at an optimum dictated by the characteristics of the system.

Increasing the oxygen concentration decreases both steady state fluorescence and assimilation, the former because electrons may be transported to oxygen or used in photorespiration and the latter because of photorespiration. In zero CO_2, the greater the rate of photorespiration the smaller the fluorescence, evidence that photorespiration or

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electron transport to O_2 decreases the energy load on chloroplasts. Under these conditions fluorescence and CO_2 assimilation are not linked.

Increasing the nitrate supplied to photosynthesizing leaves decreases fluorescence with little effect on assimilation, suggesting that nitrate reduction decreases the energy load on the chloroplast and increases the efficiency of light use. This will be further examined in conjunction with studies of the metabolism of wheat and sugar beet plants grown in solutions of different nitrogen concentration. The lack of a simple relationship between photosynthetic CO_2 assimilation and fluorescence in these studies, particularly under the influence of varying nitrogen nutrition, suggests that caution is required in interpreting fluorescence data obtained in less well defined circumstances. (Lawlor; Young, Kontturi, Mitchell, and Driscoll)

Growth, composition and photosynthesis of wheat and sugar beet leaves in relation to nitrate supply. Quantitative relationships between nitrate concentration at the root surface, and the growth and development of cells and organs are not well established. Neither are the effects of nitrate supply on the development of the photosynthetic system well understood, despite their potential importance in the achievement of rapid assimilation per unit of leaf area. A multi-channel recirculating hydroponic system has been constructed so that the effects of nitrogen on growth and leaf function can be studied at constant nutrient concentrations. In a series of experiments, spring wheat (cv. Kolibri) and sugar beet (line G) were grown in a growth room, at 20/15°C and $500 \mu mol\, m^{-2} s^{-1}$ photosynthetically active radiation, from the cotyledon stage for approximately one month at high (20 mM), medium (1·0) or low (0·1) nitrate concentrations.

After four weeks growth, the total leaf area of both wheat and sugar beet at the medium and low nitrate concentrations was 50 and 70% respectively less than at the high concentration. Leaves of wheat appeared one to two days later at low nitrate concentration than at high, whilst the appearance of sugar beet leaves was greatly delayed (e.g. by six days for leaf 13). Mature wheat leaves were shorter and to a lesser extent narrower at low concentration. Detailed observations showed that this was largely caused by a decrease in the rate of lamina expansion; the duration of expansion was slightly shorter.

Leaf size is determined by the number and size of cells and their arrangement in the mesophyll layers within the leaf. Cell number per unit area of wheat leaves increased from $1{\cdot}7 \times 10^7$ at high to $3{\cdot}0 \times 10^7\, cm^{-2}$ at low nitrate concentration but as the leaves were smaller the total number of cells was 30% less. Thus lowering the nitrate supply decreased cell division or survival. Cells were smaller at the medium and low nitrate treatments and the protein content in wheat decreased from 3 ng per cell (10% of dry matter) at high nitrate concentrations to 1·5 ng per cell (6% of dry matter) at both medium and low nitrate. The total dry matter per unit of cell water was larger and the osmotic potential lower ($-1{\cdot}7$ compared with $-1{\cdot}4$ MPa) in the smaller cells with lower nitrate possibly due to the greater concentration of soluble components. Protein and chlorophyll content per unit of fresh mass and leaf area of wheat were 50% less with low nitrate but the chlorophyll *a*/*b* ratio did not change, suggesting that thylakoid structure did not change although the amount of thylakoid membrane did. However, sugar beet grown at low nitrate concentration did have a smaller chlorophyll *a*/*b* ratio. The total carotenoid concentration of wheat was little changed by nitrate supply but that of sugar beet decreased as nitrate decreased.

Nitrate deficiency decreased photosynthesis; the decline in CO_2 assimilation was closely related to a decrease in chlorophyll and protein (50% of which is RuBP carboxylase). The maximum rate of photosynthesis in both sugar beet and wheat with

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high light and CO_2 was less at lower nitrate levels and the effects became larger as the leaves aged. Both photochemical efficiency and carboxylation efficiency were less. The response of photosynthesis to changing oxygen concentration in these experiments suggests that the RuBP carboxylase to oxygenase ratio was not changed by the nitrate concentration.

The lower photosynthesis and leaf area at low nitrate, and the consequent effects on dry matter growth, clearly result from effects on a wide range of physiological processes. Further analysis and future experiments will seek to identify the regulatory mechanisms that control leaf cell expansion and photosynthetic function. (Lawlor; Leach, Franklin, Plumb, Mitchell, Young, Driscoll, Pocock and Kontturi)

Measuring leaf boundary layer resistance. The leaf boundary layer extends from the leaf surface, close to which air movement is laminar and gas transfer is largely by diffusion, out to the fully turbulent region where mass transfer predominates. Since the resistance to gas transfer across the boundary layer is in series with the stomatal resistance of the leaf, the latter cannot be determined directly from measurements of leaf gas exchange, but only after subtraction of the boundary layer resistance from the combined resistance. Therefore determination of the boundary layer resistance is an important adjunct to studies of stomatal response and leaf gas exchange. The boundary layer resistance encountered within leaf cuvettes is often determined from measurements of the temperature and the rate of evaporation of water from wet filter paper placed within the cuvette. Humidity within the cuvette, the rate of gas flow through the cuvette and the filter paper area must also be known. Small errors in the temperature and humidity measurements lead to large errors in the resistance values.

A reappraisal of the energy balance of filter paper in an opaque cuvette has shown that the boundary layer resistance (r_a) can be determined by measuring just the relative humidity and air temperature in the cuvette. Experiments have confirmed the value of this new technique, which is much less sensitive to measurement error than is the conventional method. For example, with a nominal r_a of $0{\cdot}50\,m^2\,s\,mol^{-1}$ at 15°C, a 1°C error in air temperature would give rise to a 1·0% error in r_a (cf. 18%), and a 1% error in humidity a 4·0% error in r_a (cf. 6%). The other advantage of the new method is that relative humidity sensors are generally used within modern cuvettes—exactly what this method requires. (Parkinson)

Aerobiology

The physics of the aerial environment of crops controls many transfer processes that directly influence crop production, e.g. CO_2 and water vapour exchange, but also influences a number of other processes that can modify productivity, e.g. the deposition of spores and pollutants from above the crop on to leaf surfaces and the distribution of splash droplets (potentially containing spores) or spray droplets within the crop canopy.

Deposition of spores on to barley crops. The atmospheric dispersal of plant pathogen spores involves not only turbulent processes above the crop but also loss of spores by deposition on to the crop and on to the ground. The rate of movement of particles from the atmosphere to underlying surfaces is proportional to the concentration of particles just above the surface. The constant of proportionality is called the deposition velocity, v_g; it has units of velocity and depends upon particle size, the nature of the surface and on atmospheric turbulence. Downward transport of particles is enhanced by turbulent diffusion so that the deposition velocity of air-borne particles is generally greater than their sedimentation velocity in still air, v_s.

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We have determined deposition velocities above a barley crop under neutrally stable atmospheric conditions for a range of air-borne spores with sedimentation velocities from 0·05 to 4 cm s^{-1}. Deposition velocities for spores with v_s greater than 0·5 cm s^{-1} were about two to three times v_s while for smaller spores v_g was up to seven times v_s.

The measurement of spore concentrations in the turbulent air above crops is not straightforward as the efficiencies of suction traps depend on wind speed and direction relative to the trap. The deposit collected on passive spore samplers, such as freely exposed horizontal slides, depends on spore concentration and sedimentation rate but also on additional deposition caused by turbulence. If horizontal slides could be exposed in such a way as to eliminate turbulent deposition then the deposit would only depend on v_s and concentration, so that simple deposition measurements could be used to estimate concentration. During the above experiments spore deposits were measured on horizontal slides exposed in three ways: (a) openly on wire supports, (b) in large beakers protected by rain shields 10 cm above the rim and (c) between two large flat surfaces separated by a 10 cm gap. Traps (b) and (c) modified the air flow over the slide in such a way as to reduce turbulent deposition. Under neutrally stable atmospheric conditions the numbers of spores caught on traps (b) and (c) were about half those on freely exposed slides. However the deposit was still between 1·5 and 2 times that expected from sedimentation alone, suggesting that even under favourable conditions (neutral stability) the deposit was affected by atmospheric turbulence. It is clearly necessary to be cautious when attempting to estimate spore concentration from deposition measurements. (McCartney with Bainbridge, Stedman and Creighton, Plant Pathology Department)

Modelling splash dispersal of fungal spores. A mathematical model for predicting the trajectories of solid spherical particles in nonturbulent air (Chow, C-y (1979) *An introduction to computational fluid mechanics*. New York: John Wiley) has been modified to describe the flight of water droplets of diameter up to about 3·5 mm. The model was used to calculate the effect of initial speed and direction on the distance travelled by water droplets of a wide range of sizes. In experiments, the trajectories of droplets between 0·2 and 1·0 mm diameter, produced by vibration of a needle droplet generator, were recorded photographically in still air. The trajectories compared well with those predicted by the model when using the measured values of initial speed and angle of flight. Further experiments and modifications to the model are being made to account for the effects of moving air streams and turbulence on droplet trajectories. Calculations suggest that the turbulence within crop canopies may significantly affect the trajectories of droplets with diameters up to about 0·6 mm. (Macdonald and McCartney)

Disease development in mixtures of spring barley cultivars. The dispersal phase of disease development depends upon the physical characteristics of dispersal processes. By combining models of these processes with observations of disease spread in mixtures, we hope to define some critical factors controlling disease spread. Development of disease foci of *Rhynchosporium secalis* was investigated in 9×9 m plots of spring barley sown with either a susceptible cultivar (Apex) or with mixtures of the susceptible and a resistant cultivar (Koru) in the ratios 1:2 or 1:4. Each plot was inoculated at its centre with greenhouse-grown infected plants; at all subsequent assessments, disease incidence was found to decrease with distance from the centre of all plots and the rate of decrease was similar for the three treatments (half distance between 10 and 20 cm). The disease gradients were steeper than those observed in an earlier experiment with plots inoculated with *Erysiphe graminis* (half distances between 30 and 50 cm), (*Rothamsted Report for 1983,* 59). In the early stages of the epidemic, disease (% leaf area infected) decreased with height on the plant in a similar way in the three treatments. As the disease

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progressed, the decrease in severity with height diminished, and at the last assessment (towards the end of grain filling), disease incidence was similar on leaves 9, 8 and 7 in the mixtures, while there was slightly less disease on leaf 9 compared with leaves 8 and 7 in the susceptible plot. This contrasts with the development of *E. graminis* where a vertical disease gradient was observed throughout the epidemic.

Disease incidence in the mixtures was much less than in the susceptible cultivar plots, although the effect of the mixtures in reducing disease was somewhat less in this experiment than with *E. graminis* in 1983. A simple disease simulation model (*Rothamsted Report for 1983,* 59) suggested that disease development would be less affected by a mixture of cultivars for a disease in which spores were deposited close to the source. *E. graminis* spores are aerially dispersed and would be expected to travel farther than those of *R. secalis,* which are dispersed by rain splash. The preliminary analysis of these experiments suggests that the mode of spore dispersal may affect the performance of cultivar mixtures in controlling foliar diseases. (McCartney; Quayle with Fitt and Creighton, Plant Pathology)

Staff and visiting workers

During the year Heather Pellant retired after 45 years' service and B. K. French after 25 years. R. P. Scammell left in May on the termination of his temporary appointment and Hazel Gilmour left in September. N. R. Shah transferred to the Computer Unit in April and Corinne Quayle transferred to the Biochemistry Department in October.

Z. S. Chalabi, P. J. Walklate and T. Scott joined the Department and Janet Why, Maureen Lacey and Eileen Ward transferred from Soil Microbiology, Plant Pathology and Biochemistry Departments respectively. Fiona McNab, a SERC/CASE student jointly with the University of Essex, will be spending some time during the next three years working with D. W. Lawlor.

K. J. Parkinson gave a course of lectures on gas exchange measurements at the University of Umea, Sweden, from 16 to 23 May, and attended a NATO Advanced Study Institute on 'Agricultural Instrumentation' in Italy from 27 May to 6 June. W. Day organized a NATO Advanced Research Workshop on 'Wheat Growth and Modelling' held in Bristol from 9 to 12 April, and attended meetings as part of the EEC Climatology Programme in Brussels in January and in Sophia Antipolis, France, in October, and also visited the INRA Station de Bioclimatologie, Avignon.

M. Kontturi from the Institute of Plant Husbandry, Finnish Agricultural Research Centre, Jokioinen worked in the Department with D. W. Lawlor for three months.

This year J. Croft completed 20 years of meteorological observations at Rothamsted, and received the congratulations of the Meteorological Office.

PUBLICATIONS

Broom's Barn Experimental Station

General Papers

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Physiology and Environmental Physics Department

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