ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1983

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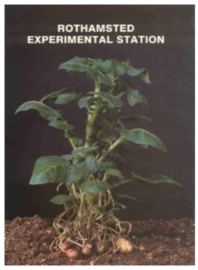

Agronomy and Crop Physiology Division

R. K. Scott

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AGRONOMY AND CROP PHYSIOLOGY DIVISION

STAFF
Head of Division R. K. Scott

Broom's Barn Experimental Station
Higham, Bury St Edmunds, Suffolk.
Telephone: (0284) 810363

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INTRODUCTION

The new grouping which constitutes this Division, Broom's Barn Experimental Station, the Rothamsted Farms and Field Experiments Section and the Physiology and Environmental Physics Department, entails the greatest realignment of previous programmes. The aim is to associate a stronger, unified effort in crop physiology with the agronomic elements of the Station's work. Since a crop physiologist was appointed in 1978 to the multidisciplinary research programme on sugar beet at Broom's Barn, the links with the physiology programme in the former Botany Department have strengthened to the point where there is now close collaboration at all levels from husbandry investigations in the field to studies at the cellular level in the laboratory. Increasingly the investigations on plant and crop physiology provide the interface for research programmes on sugar beet crop husbandry, nutrition and crop protection.

The formation of the Physiology and Environmental Physics Department by the amalgamation of that part of Botany which investigated plant growth and development, with the groups from the Physics Department studying plant physics and agricultural meteorology, will provide a focus for understanding the response of arable plants to the field environment. Investigations have centred on the consequences of changing the supply of water and nutrients to the plant, but a programme concerned with the dispersal of spores and spray drops in crops has also developed jointly with plant pathologists, and will in future provide the basis for wider links with those working on various aspects of crop protection. Throughout, the aim is to test ideas and combine measurements by means of simulation models.

Some members of staff in the Physiology and Environmental Physics Department and the Field Experiments Section devote much of their time to the well established multidisciplinary experiments on sugar beet, beans and wheat. Because of the need for similar information to help farmers optimize their systems, further multidisciplinary experiments are under way on barley and potatoes or are being planned for oilseed rape. The initiatives for these latter experiments have come from staff in other Divisions, but the Head of the Field Experiments Section and the Head of Division are closely involved in their planning as Secretary and Chairman respectively of the

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Working Party for Field Experiments. Where, in these experiments, growth and development can be monitored in relation to the whole environment they provide the opportunity for in-depth study of the effects of many factors and their interactions. The challenge is to measure and model in a coordinated effort by scientists from different backgrounds and disciplines, so that we are able to generalize as far as possible despite restricted replication over sites and seasons. It is here that the physiologists and physicists can especially contribute by taking a mechanistic and quantitative approach. In addition there will be under-pinning research projects, providing the basic knowledge of how physiological processes change in response to specific environmental factors.

BROOM'S BARN EXPERIMENTAL STATION

The year 1983 and the growth of the crop. Rainfall, which is always the dominant factor determining when the sugar-beet crop is sown, had a more adverse effect in 1983 than for many years. In every year since 1969 rainfall patterns during March and April have provided a two-week period in which favourable soil conditions have allowed 60–80% of the crop to be sown. In some years this period has been in late March, e.g. 1973, 1976, in others in late April, e.g. 1975, 1979. In 1983 no such period occurred and drilling was unusually protracted; although 10% of the crop was already sown by 18 March, 10% was still unsown on 18 May.

At Broom's Barn there was only 1·5 mm rain in the first two weeks of March but more than 16 mm every week for the next 10 weeks giving total rainfall for April and May over twice the long term average. Some beet was sown on 10 and 11 March, about 25% of our crop on 16 April and most of the remainder between 27 and 30 April, but operations could not be completed until late May. Plots sown in early March suffered considerably from bird grazing and others were affected by the continuously wet conditions following sowing. Detailed studies of plant establishment revealed that some seed lots appeared better able to tolerate wet conditions than others. Establishment from later sowing suffered less, but some crops were affected by *Aphanomyces cochlioides* although few failures or near failures were reported.

With some 30000 ha of beet sown during March, and cold, wet weather for several weeks thereafter, it was expected that a proportion of plants would be vernalized, and in early spring 4% bolting was predicted for Broom's Barn, taking into account the number of days after sowing when the temperature did not reach 12°C. In the event this was almost exactly the average level of bolting in several varieties sown at Broom's Barn in early to mid-March. Nationally, the British Sugar Specific Field Survey (based upon a detailed examination by British Sugar field staff of 700 randomly selected sugar-beet fields) showed 5·4% bolting at the end of August in these early-sown crops, probably the highest level for over 10 years. In the north of the sugar-beet growing area (Newark to York) some of the most bolting-susceptible varieties gave 35–42% bolting from early to mid-March sowings. The extent to which these observations can be explained on the basis of local temperatures is being investigated.

Much evidence was put before advisers and growers through Ceefax, courses, talks, articles and warning postcards to show that seed shed by bolters could lead to weed beet problems, and considerable pressure was exerted to persuade farmers to control bolters. About 28% of the 1983 crop area had weed beet from soil-borne reserves of seed, and a further 57% showed bolters from this year's sowing. Thus, of the total 200000 ha of root crop, about 168000 ha contained bolters. Control was carried out by hand pulling on 76000 ha, by machine cutting on 6000 and by chemical wiper applicators on 10000 ha. The warm weather during July and August was conducive to viable seed

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production on bolters which were not treated. It is disturbing that on 76000 ha no control measures were taken, indicating the limited extent to which advice based on results of our research on bolting is followed. In order to reinforce our evidence of the threat that bolters present, samples of plants have been taken from over 50 fields to determine the potential for seed returns to the soil.

Half the sugar-beet crop was treated with granular pesticides applied in the seed-furrow at sowing to control arthropod seedling pests, nematode damage which causes Docking disorder, early attacks of the aphids which transmit yellowing viruses or merely as a general insurance. Although experiments and experience have shown that these materials often limit pest activity, their effectiveness is decreased in a season such as 1983 when a very wet spring causes rapid leaching of the active ingredient to below the target area of the soil profile. The same weather enables the ectoparasitic nematodes which cause Docking disorder (*Trichodorus* spp., *Paratrichodorus* spp. and *Longidorus* spp.) to remain active throughout the period of seedling germination and early growth causing widespread damage.

Each year the Specific Field Survey assesses the extent and severity of Docking disorder. In 1983, it was estimated that 20300 ha were affected (a greater area than ever before) and that the yield loss was 67000 t of roots. This suggests that, although pesticides often prevent serious crop losses, further improvements in efficiency are needed.

The very heavy rainfall from mid-March to late May caused considerable movement of nitrogen fertilizer down the soil profile. Measurements made on light soils in April and May where 120 kg ha^{-1} had been applied in early March showed that only 28 kg N ha^{-1} were present in the top 25 cm and only 70 kg in the top 50 cm—quantities which are inadequate for fast growth in spring. Extra applications of nitrogen were recommended for these soils and experience this spring emphasizes the value of a policy of splitting nitrogen application, applying some in the seedbed followed by the major part as a top dressing at about the 4-leaf stage.

After the relatively poor start June, July and August provided a period of excellent weather for growth with total radiation receipts 20% greater than the long-term average. Despite being sown three weeks later this year, and the poor spring, our 'standard' crop grown with, as far as possible, identical management and irrigated to requirements, grew faster during July and August than in 1982, and by September the gap was closing after a large early season difference in growth.

July and August were dry, with only 44 mm of rain at Broom's Barn compared with a long-term average of 96 mm. In part, this offset the advantages of the bright weather, but wilting was not severe in our crops at Broom's Barn, because the air was relatively humid and the potential evaporation rates less than in a dry summer like 1976. Responses to irrigation reflected this; rainfall from June until August was 78 and 62 mm in 1983 and 1976 respectively, but in 1983 irrigation increased sugar yield by 20%, whereas in 1976 it more than doubled it. The open, generally dry autumn, led to excellent conditions for harvest and total sugar production was one of the largest on record.

Few *Myzus persicae* flew until the end of May when the long, wet period ended, and the numbers trapped in June were similar to the long-term average. The trap catch increased rapidly to reach a peak in the second week of July and then decreased by about 5% each week. None were trapped in early and mid-August and then few until the end of September when the catch was unusually large and crops of oilseed rape became infested. Very few wingless *M. persicae* were found on sugar beet at the beginning of June but the population increased rapidly to reach a peak in the first week of July.

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The relatively few frosts in January and February indicated the possibility of a moderate attack of virus yellows, 5·5% nationally, but March and April did not favour aphid multiplication and dispersal and the final long-term forecast based on the formula of Watson *et al.* (*Annals of Applied Biology* (1975) **81,** 181–198) was for only 1% infection overall at the end of August. However, the warm dry weather during late June and July led to rapid aphid multiplication and movement between plants, and the potential for yellows spread was increased by the lateness of many crops. Virus yellows began to appear in mid-July, but at the end of the month reports from most sugar factory areas were of only isolated plants or small patches of plants showing symptoms, except that in Essex the disease was then well established. Spread continued in August, in particular in parts of the Ipswich, Bury St Edmunds and Peterborough factory areas where, by the end of the month some 27% of the crop had over 20% plants infected and 5% over 60% infection. The national average infection of 6% was nearer to that indicated by the number of frosts in January and February than to the prediction based on the formula of Watson *et al.*

Short-term prediction and the issue of local spray warnings was made difficult in 1983 by the wide range of sowing dates due to the very wet May, which resulted in some crops being large enough to spray when others nearby had not yet emerged. The ELISA test applied to yellowed leaves taken from fields in which routine disease counts were made showed that a higher proportion of yellows infected plants contained the more damaging beet yellows virus (BYV) in 1983 than in 1981 or 1982. This must present a risk of a severe BYV outbreak in 1984 if the winter is mild.

Although the late summer was dry, the outbreak of powdery mildew was less severe than in previous dry years, e.g. 1980. Half the crop in East Anglia was treated to control this disease and in trials in commercial sugar-beet crops, yield increases of up to 15% were obtained indicating the potential profitability of much of the spraying.

Late in the season both *Ramularia* leaf spot and rust became common in many crops. These diseases have been more prevalent in recent years than ever before, apparently because of the relative susceptibility of some modern, high-yielding varieties. They usually only appear late in the season, from the end of September on, and it is doubtful whether they have sufficient effect on yield to justify their control with fungicides. However, in view of the benefits now obtained by spraying to control powdery mildew, which was also long thought to be of little economic importance, experiments have been started to test the effects of fungicides applied late in the season to control leaf spot and rust.

Comparison of wheat yields. In 1983 the weather during grain growth was very warm; mean air temperature at Broom's Barn was 17·2°C compared with 16·1°C in 1982. Since the duration of grain growth is temperature dependent, requiring about 690°C days above 0°C (*Rothamsted Report for 1982,* Part 1, 72), the crop in 1982 had an extra three days of grain growth and the final mean weights per grain for the September-sown crops of Avalon were 40·8 and 37·0 mg in 1982 and 1983 respectively. Similarly, for November-sown crops the grain weights were 41·9 in 1982 and 38·8 mg in 1983. Although individual grains were lighter in 1983, the overall grain yields for Avalon, sown on similar dates and with similar husbandry, were heavier, the September-sown crop producing 10·0 t ha^{-1}, 2·1 t ha^{-1} more than in 1982 while the November-sown crop yielded 8·2 t ha^{-1}, 0·5 t ha^{-1} more than 1982. These yields were heavier because in 1983 the crops grew very rapidly from mid-May to the end of July, as radiation receipts were 17% larger than 1982, and more grains were produced. In the September-sown crop grain numbers m^{-2} were 27 210 in 1983 compared with 19 300 in 1982; an increase that more than compensated for the lighter grain in 1983.

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Plant establishment

Interactions of insecticide, organic matter and rotation on sugar-beet establishment and on pest and beneficial arthropods. From 1980 to 1982 a field experiment was done at Broom's Barn in collaboration with the Entomology Department, forming one of a series organized by the International Organization for Biological Control (IOBC) on the integrated control of sugar-beet seedling pests; it followed another IOBC trial which ran on the same site from 1977 to 1979 (*Rothamsted Report for 1979,* Part 1, 58), ending with sugar beet on all plots. In the new experiment no insecticide was compared with γ-HCH incorporated overall at 1 kg a.i. ha^{-1} and aldicarb applied in the seed-furrow at 1 kg a.i. ha^{-1} both on continuous beet and, in 1982, on beet following two wheat crops which had not been treated with insecticide. Half of the plots within each of the four blocks, whether in wheat or sugar beet, received farmyard manure (34 t ha^{-1}) ploughed in during the previous autumn.

The effects of treatments on the number and activity of invertebrates were investigated by pitfall trapping; vertical polythene barriers between plots restricted the movement of soil-surface invertebrates across the experiment. Total soil-microarthropod populations were determined by soil sampling and the extent of pest damage was measured by counting the number of seedlings in sample lengths of rows (Table 1) and weighing samples of seedlings. The principal cause of poor establishment on the continuous-beet plots was feeding damage by adult pygmy beetles *(Atomaria linearis),* and differences in establishment between years were related to the number of *A. linearis* caught in pitfall traps during the first four weeks after sowing; this is when most damage occurs, much of it before seedling emergence. *A. linearis* is usually controlled effectively by crop rotation and establishment on the beet plots following wheat was much higher, even though they adjoined the continuous-beet plots.

TABLE 1

Effect of insecticide, farmyard manure (FYM), and crop rotation on seedling establishment

	1980	1981	1982	
	Beet after beet	Beet after beet	Beet after beet	Beet after wheat
No insecticide*	26	52	1	72
γ-HCH (overall)*	50	69	38	78
Aldicarb (seed furrow)*	41	73	64	78
Without FYM†	37	62	31	77
With FYM†	41	67	38	75

*Means of FYM and no FYM treatments
†Means of no insecticide, γ-HCH and aldicarb treatments

The small but consistent increases in seedling establishment given by FYM on the continuous-beet plots may be attributed to two factors. Firstly, the plants were larger for at least the first 10 weeks after sowing, whether or not serious damage from *A. linearis* occurred, and had therefore passed through the vulnerable stage more quickly. Secondly, fewer *A. linearis* were caught in pitfall traps on FYM-treated plots than on untreated plots in continuous beet, which suggests an effect on the mortality or reproduction of the pest.

The application of FYM may well have increased the mortality of the pest because some invertebrate predators caught in pitfall traps, e.g. *Bembidion* spp., the most

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frequently-trapped insect predators on FYM-treated plots were, by 1982, more than twice as numerous as on untreated plots. These increases in predator populations probably were associated with increases in the populations of Collembola and small Diptera where FYM was applied. Dissection of gut contents revealed that these were the principal prey of the adult beetles. While remains of *A. linearis* were not found in the gut of adult *Bembidion* spp., predation of *A. linearis* larvae by *Bembidion* larvae or other predators (e.g. Acari, or staphylinid larvae) is a possible explanation for the decrease in *A. linearis* trapped where FYM was applied.

The effects of insecticides on beneficial arthropods varied greatly. In 1980 and 1981 the number of *Bembidion* spp. caught in pitfall traps was considerably greater where γ-HCH was used, but there was no effect in 1982. Aldicarb had little effect on *Bembidion* spp. in 1980 and 1981, but in 1982 reduced the number caught to 33% of those on untreated plots. Gamma-HCH decreased the number of staphylinid beetles caught for some weeks after application, and this effect persisted longer in some years than in others. Slightly fewer linyphiid spiders were caught on γ-HCH treated than untreated plots but aldicarb had no effect.

Currently FYM is applied to about a quarter of the national sugar-beet crop. Its beneficial effects on plant establishment in this trial require future studies, but in practice, virtually all beet is grown in rotation and *A. linearis* is then only a pest in the late seedling stages when it has migrated from the previous year's beet fields. Insecticide treatment is essential to prevent serious loss of seedlings where beet is grown after beet; however, in this experiment neither insecticide then gave establishment as good as where beet was grown in rotation. (Thornhill)

The effect of *Aphanomyces cochlioides* on the survival and growth of beet plants. *A. cochlioides* is widespread in soils where sugar beet is grown and forms part of the complex of soil-borne fungi responsible for seedling damping-off. Under conditions of high soil temperature and abundant moisture, which may occur in late sown or re-drilled crops, attacks can sometimes be severe. Observations suggest that plant losses can occur for several months after emergence but that some infected plants may recover and survive to harvest. The effect on yield is not known, but we need this information in order to advise farmers whether to leave infected beet crops to harvest, or to plough them in and replace with crops other than sugar beet if possible. To obtain information on the effect of *A. cochlioides* on plant population and crop yield the fate of plants found lightly, moderately or severely infected at the 4–6 leaf stage was monitored through to harvest in crops in 1982–83. In addition, in 1982, the yield of a crop in which every plant was infected in late June was compared with that of a neighbouring crop drilled on the same day but free from attack by *A. cochlioides*.

Most uninfected or lightly infected plants survived to harvest whereas more than half the severely infected died; most within 21 days of the first observations, but a few during a further 23 days, or up to 2·5 months after sowing. The last plants to die had grown considerably, but leaves and crowns became detached from the roots at the site of the original lesion which had failed to expand with the surrounding tissues. The resulting symptoms closely resembled 'strangles'. At harvest infected roots were smaller and sometimes more fangy than healthy. This was particularly noticeable in the yield comparison of neighbouring infected and healthy fields. The average plant population in the infected field was 50000 ha^{-1} compared with 67000 ha^{-1} in the uninfected field. As well as being more fangy, roots from the infected field had a lower sugar percentage and the overall sugar yield was only half that of the unaffected field. The yield loss was probably increased by the greater weed competition in the gappy and initially slow growing infected crop.

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It is concluded that, when *Aphanomyces* is found in a beet crop at the 4–6 leaf stage, many plants are likely to survive to give harvestable roots. Of severely infected plants, where the hypocotyl is black and stringy, nearly half are likely to survive, and most lightly infected plants will survive. When the attack is severe the yield of the crop is much reduced, but because the disease is most common on late sown or redrilled crops it is often not diagnosed until June. At this stage in the season it is likely to be more profitable to leave a potentially low yielding sugar beet crop to grow on to harvest than to attempt to re-sow with another crop. (Payne)

Effect of soil physical factors on the germination and emergence of sugar beet. The results of experiments comparing the effects of various cultivation techniques on plant establishment are often difficult to interpret because of variations in weather during the establishment period. To make meaningful comparisons between different cultivations a set of soil measurements is required which can be used to evaluate the effect of a seedbed on establishment by predicting the time course of emergence given any subsequent weather. It is necessary, therefore, to identify and find ways of measuring the soil factors which affect germination and emergence and to define relationships between these processes and soil measurements.

Experiments in which seeds were germinated at various temperatures produced a family of germination-time curves. When germination was plotted against thermal time the effects of temperature were eliminated and the points fell approximately on the same curve. A similar analysis can be applied to water potential with data from experiments in which temperatures were held constant but water potential varied. Germination data from experiments in which both temperature and water potential change can be brought together in a single curve by plotting germination against the time integral of temperature above a base temperature multiplied by water potential above a base potential, defined as hydrothermal time. If other factors, such as poor aeration or fungal attack are affecting germination these would appear as departures from the usual curve and could be evaluated. Experiments measuring emergence in trays of fine soil have given similar results, but in order to produce a unique curve the percentage emergence has to be adjusted to allow for seedlings dying between germination and emergence. The final emergence is dependent on the water potential. In field conditions where the soil imposes appreciable mechanical resistance to emergence, account has also to be taken of soil impedance.

If it is assumed that the hydrothermal time to germination is a constant and that a sample of sugar-beet seeds contains seeds with a normal distribution of base temperatures and an independent normal distribution of base water potentials, then the time course of germination can be predicted from knowledge of the time courses of temperature and water potential, and from six parameters describing the sample of seeds. Difficulties arise in obtaining a representative and continuous measure of potential. In these experiments potential was derived from the amount of water absorbed by filter papers but the analysis has also been applied, with some success, to data from other experiments in which a variety of methods were used to control and measure water potential. The parameters describing the sample of seeds are the means and standard deviations of the base temperatures and the base water potentials, the hydrothermal time to germination and the percentage of viable seed. These parameters could be used as a basis for selecting seed lots for different conditions. They can also be used, with soil measurements, to predict the time course of emergence from a seedbed in non-waterlogged conditions. (Gummerson)

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Pellet structure and chemical additions. There can be substantial losses of plants after germination but before emergence (*Rothamsted Report for 1979,* Part 1, 57–58) often as a result of very wet conditions immediately after sowing, and damage by the 'soil pest complex' (springtails, millipedes, wireworms, etc.), even though the seed is routinely treated with methiocarb. In addition, these factors often retard the growth of the surviving plants. Results of experiments made under controlled conditions, suggest that pelleting sugar beet seed with a coating of fine clay as at present, increases the danger of waterlogging and probably lowers the activity of some of the pesticides which may be incorporated, while buffering the seed against possible phytotoxic effects of others. However, the attendant benefits of pelleting seed—seed placed more precisely by drills, and convenience as a carrier for insecticides, fungicides and nutrients—is considered to outweigh any advantages of a return to using unpelleted seed. A project has been started seeking to reduce pre-emergence losses and improve early growth through a better pellet structure and a more efficient pesticide seed treatment.

Mercury intrusion measurements by Newman of the Soils and Plant Nutrition Department indicate that pellet structures with widely differing porosity are available. Preliminary experiments suggested that relatively porous pellets made from mixtures of wood fibre and clay, were less detrimental under very wet conditions than pellets composed mainly of clay, but the magnitude of the improvement varied between seed samples tested. For example, in a study of 12 different bulks of seed in a test simulating very wet conditions, germination after 12 days at 15°C, averaged 43% with the present 'Filcoat' British Blend (BB) clay pellet and 70% with the best alternative European Blend (EB3), but with individual bulks the difference between pellet types varied between 5 and 46%. Similarly, emergence from very wet soil in a growth room at 5°C for 18 h and 15°C for 6 h, was 16% greater with EB3 than BB pellets but between bulks the increase varied from 3 to 33%. In a late-sown field experiment in wet soil in 1983, establishment was 5% better from EB3 than from BB pelleted seed.

Washing seed thoroughly before pelleting also increases its tolerance of wet conditions. In early-sown field experiments in 1983, washing seed increased establishment by 12% and incorporating calcium peroxide during pelleting gave up to 5% more plants. The possibility that including phosphate in the pellet might stimulate early root growth and also regeneration in the presence of root-damaging pests was also tested in field experiments; establishment was improved with one of the five varieties tested and seedling weight was greater with three varieties. (Durrant and Loads)

Methiocarb is currently incorporated in the clay pelleting material (BB) of all commercial seed used in the UK at 0·2% by weight of raw seed (approximately 2 g a.i. per 100000 seeds) as an insurance against attack by soil pests. It was chosen on the basis of field trials, in the period 1969–77, as the best available alternative to dieldrin which MAFF no longer allowed for seed treatment. The recent advent of several new insecticides, such as carbosulfan, which are possibly much less phytotoxic as seed-treatments than materials tested in the past, may allow higher dose rates to be used. Probable future changes in the composition of the pelleting material, have necessitated further testing because it is essential that the efficacy of the insecticide seed-treatment is maintained, or if possible improved. In earlier tests some insecticides, such as bendiocarb, were found to be unstable and to break down in the BB type of clay pellet; but it may be possible to use them in EB3 pellets which contain less clay.

Methiocarb at $2\,g\,kg^{-1}$ seed was compared with bendiocarb, carbofuran and carbosulfan at different rates, some relatively high, in laboratory germination tests and field establishment trials in 1982 and 1983. Several different pelleting compounds were used including the BB and EB3 types. The results suggest that carbofuran or carbosulfan may be used safely at dose rates which are high compared with the standard

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methiocarb rate or the dieldrin treatment it replaced. However, more field trials are necessary, particularly on pest-infested sites, to check efficacy and to determine optimum dose rates more precisely. In addition tests on treated stored seed are necessary to establish continued persistence of insecticidal efficacy and lack of phytotoxicity. Bendiocarb was found by its manufacturers to be unstable on BB pellets when tested in earlier trials, although it is used in some types of pellet in Europe. Our observations in one trial, that bendiocarb gave significant increases in plant establishment when incorporated in the EB3, but not in BB pellets, suggest that it may be sufficiently stable in EB3 pellets to be worth further testing. (Winder and Dunning)

Environmental and nutritional aspects of crop growth and productivity

Fibrous root growth. In 1982 a study was carried out to provide a description of the growth and distribution of the fibrous root system of sugar beet throughout the season. Soil cores were taken to increasing depths as the season progressed, roots were washed from them and the fibrous root density, expressed as cm of root per cm^3 of soil, was calculated.

The fibrous root density decreased with increasing depth down to 70 cm; at the end of June it was 2·0 cm cm^{-3} at 0–10 cm depth and 0·4 cm cm^{-3} at 50–70 cm. Thereafter, root density remained relatively stable in the soil layers down to 70 cm; the maximum recorded was 2·84 cm cm^{-3} on 20 September in the 0–10 cm layer. Below 70 cm the root density reached a maximum of about 0·5 cm cm^{-3} at the end of August, and subsequently changed little.

On this evidence, in comparison with winter wheat grown at Sutton Bonington in 1975 (Gregory *et al.*, *Journal of Agricultural Science, Cambridge* (1978) **91,** 91–102) the root system of beet is much less dense. For example, when the total dry weight of both crops was 1·2 t ha^{-1} the fibrous root densities in the 0–10 cm layer were 3·6 and 0·4 cm cm^{-3} and in the 30–40 cm layer 0·7 and 0·02 cm cm^{-3} for wheat and beet respectively. Even when the crops' total root systems were at maximum size there were large differences in densities; in the 0–10 cm layer 7·9 and 1·9 cm cm^{-3} and in the 30–40 cm layer 1·7 and 0·6 cm cm^{-3} for wheat and beet respectively.

These differences in root density could have important implications for water uptake, because at the time of maximum evaporative demand, typically June in East Anglia, the fibrous root system of beet is relatively poorly developed whereas the root system of winter wheat has reached its maximum size. Using measurements of changes in soil water content made at the same times and depths as the root measurements the water inflow rates were calculated for the different soil layers. Maximum inflow rates, 10^{-2} cm^3 water cm^{-1} root per day, were in the top 30 cm of soil. As the soil dried, rates of water uptake from deeper soil layers increased, each in turn reaching a maximum value before decreasing. In 1982 no water was extracted from below 100 cm. Inflow rates in the top 30 cm for beet were up to five times faster than those previously published for wheat (Gregory *et al.*, *Journal of Agricultural Science, Cambridge* (1978) **91,** 103–116), although below 30 cm the rates were generally similar. It appears, therefore, that sugar beet roots are capable of taking up water at faster rates to compensate for the less dense root system. Also, because the root system of beet is less dense, the average pathway for water movement from the soil to the root must be longer, but as inflow rates were consistent with rates of potential evaporation this does not appear to be a major resistance to uptake. (Brown)

Forecasting nitrogen fertilizer requirement of sugar beet 1982–83. This study, which aims to give growers more precise information each spring on the amount of nitrogen

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fertilizer required by the beet crop for maximum yield (*Rothamsted Report for 1980*, Part 1, 72), was continued in 1983. Four sites were selected, distributed throughout the beet-growing region (in Bury St Edmunds, King's Lynn, Newark and Kidderminster sugar factory areas), all on either sandy-loam or loam soil and the beet followed cereals. Potentially available mineral nitrogen in the topsoil (0–25 cm) was determined by a standard laboratory incubation technique and periodic measurements of mineral-N in this layer were made throughout the winter. In late February the subsoils were also sampled to determine the total amount of mineral-N in the profiles to 1 m depth. There was little difference between the sites and the average amount of mineral-N in the top soil was 23 kg N ha^{-1}, and in the subsoil 57 kg N ha^{-1}. These values were similar to those measured in recent years and indicate that there had been neither excessive leaching nor any buildup of soil mineral nitrogen.

Total winter rainfall, October to February inclusive, at the four sites ranged from 150 to 230 mm. At three sites the excess winter rainfall after the return to field capacity was near average but at Bury St Edmunds, it was above the long term average, with a total rainfall of 230 mm. Whilst the incubation test showed that there was more potentially available mineral-N at Bury St Edmunds and King's Lynn, the measured variations in mineral-N between sites were too small to identify real differences and fertilizer applications of 125 kg N ha^{-1} were recommended nationally to provide a total of about 200 kg N ha^{-1} available in the top metre of soil. At all sites fertilizer was broadcast on to the seedbed during March. The subsequent very heavy rainfall which occurred from mid-March to late May, for example 131 mm for Bury St Edmunds, caused considerable movement of nitrogen down the profile. Soil measurements made during April and May at two sites showed that even where 120 kg N ha^{-1} of fertilizer had been applied only 28 kg N ha^{-1} was measured in the top 25 cm and a total of only 70 kg N ha^{-1} in the top 50 cm. Research has shown that these quantities are inadequate for fast growth in the spring so an extra application of 40 kg N ha^{-1} was recommended to all growers on these light textured soils who had applied nitrogen fertilizer early.

Provisional yield results indicate that on the very coarse sand at Newark virtually all the fertilizer-N applied to the seedbed had been leached beyond the potential rooting depth. All yields were small and the recommended dressing of 120 kg N ha^{-1} gave a root yield of only 18·6 t ha^{-1}. However, this was increased to 37·4 t ha^{-1} by appplying an extra 60 kg N ha^{-1} in late May. At the King's Lynn site where excessive leaching also occurred during the spring, the best yield, 45 t ha^{-1}, was obtained where only 90 kg N ha^{-1} had been applied into the seedbed. The lack of response to the top-dressing treatments at this site must be attributed to the very low summer rainfall (less than 50 mm) in the area during June, July and August. This is less than one-third of the long term average and, in the absence of irrigation, curtailed both crop growth and uptake of the late applied N when demand for nitrogen by the crop was at its maximum.

At the Bury St Edmunds site irrigation was used and applying 90 kg N ha^{-1} into the seedbed and subsequently top-dressing with 30 kg N ha^{-1} on three occasions in May, June and July produced the best root yield (56 t ha^{-1}). The same net profit was obtained by applying 150 kg N ha^{-1} into the seedbed although this is a greater N requirement than was originally predicted in March.

At Kidderminster the nominal seedbed treatments were applied as split dressings similar to the procedure we are currently recommending to growers. With this technique the best beet yield (49 t ha^{-1}) was obtained with the recommended dressing of 120 kg N ha^{-1} of which 60 kg was applied at drilling and the remainder in early May.

This loss of nitrogen from the top soil layers caused by one of the wettest springs in the last 50 years emphasizes the value of splitting the fertilizer, applying some nitrogen on to the seedbed, followed by the major part as a dressing at about the 4-leaf stage. This

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practice is increasing and would have been of immense benefit to crops on the lighter soils in this extremely difficult season when much fertilizer was applied several weeks before the crop could be drilled. The practice of split dressings would also allow forecasts of nitrogen fertilizer requirements to be made at a later date, which would improve the prediction because any leaching or mineralization which may occur during March could be taken into account. (Last & Messem)

Remote sensing and crop growth. The growth rate of healthy beet crops is proportional to solar irradiance, S, the fraction of this that is intercepted by the foliage, f, and the coefficient of its conversion to dry matter, ε. This can be expressed in the form:

$$\frac{dW}{dt} = fS\varepsilon \qquad (1)$$

Because ε is a reasonably stable value, yield can be expressed as:

$$W = \varepsilon \int fS\,dt \qquad (2)$$

Over the beet-growing region of England, S changes little and thus the fraction of light intercepted is the major source of variation in yields. In collaboration with the Department of Physiology and Environmental Physics at Nottingham University, we have been evaluating a spectrophotometer designed to measure this fraction remotely, either from approximately 2 m above the ground or from an aircraft. The instrument, made by Macam Photometrics Ltd, measures the radiation reflected from the crop in the red (R : 600–660 nm) and near infrared (IR : 780–940 nm) wave bands and computes their ratio. The near infrared band is reflected strongly by leaves but their reflectivity is low in the red band because of absorption by pigments within the cells. In contrast, soils show a more gradual change in reflectivity across the spectrum. It has been shown (Kumar & Monteith (1981), In: *Plants and the Daylight Spectrum*. Ed. H. Smith, London: Academic Press), that this IR/R ratio is approximately linearly related to the proportion of light being intercepted by a green crop.

In a well-managed crop at Kennett, near Broom's Barn, IR/R ratios (r) were compared with measurements of f made with tube solarimeters and the following linear relationship, similar to that in other crops, was obtained.

$$f = 36{\cdot}9 \ln r - 3{\cdot}53 \qquad (3)$$

This crop was regularly sampled to measure crop dry weight and to determine the conversion coefficient, ε. This was then assumed to be the conversion coefficient of four commercial beet crops growing nearby. The fraction of light intercepted by each of these four crops was measured on several occasions throughout the season by a spectrophotometer mounted in the aircraft used by the ADAS Aerial Photography Unit. These values, and local values of incident radiation, were substituted into equation 2 to predict dry matter and sugar yields. The latter were predicted by assuming a harvest index, i.e. ratio of sugar to total dry matter growth, of 40%. The predictions, which ranged from 5·1 to 6·4 t ha^{-1} sugar, were within 15% of the yield estimated from small, hand-dug samples. In one case, where all the beet from the field could be identified when delivered to the factory, prediction was within 3% of the harvested yield.

Use of the spectral ratio meter to predict yields is being investigated further, but it is apparent that one aspect, the effect of stress and disease, needs special attention. A stress like nitrogen deficiency operates by reducing only light interception and not the efficiency of conversion (Armstrong *et al.* (1983) Influences of nitrogen on physiological

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aspects of sugar beet productivity. In: *Proceedings of the 46th Winter Congress of the International Institute for Sugar Beet Research,* pp. 53–61) and the method described above is wholly appropriate. In other cases, ε, or both f and ε, are reduced. Spectral ratio readings made in a virus yellows infected crop were lower than expected on the basis of measurements of intercepted radiation made with tube solarimeters. This suggests that the spectral ratio may be more closely related to $f\varepsilon$ than to f alone, and this will be investigated further where crops are diseased or affected by other known stress factors. (Biscoe, Clark, Jaggard with Dr M. Steven, University of Nottingham).

Photosynthesis of sugar beet treated with a growth regulator. A major limitation to beet yields is the failure to intercept light early in the season. However, experiments have shown no benefit by increasing the plant population beyond 75000 plants ha^{-1}, probably because of competitive shading effects later in the season which result in small root/shoot ratios. In cooperation with ICI we have been examining the feasibility of using a plant growth regulator (PGR), 'PP 333', to alleviate competitive effects with large plant populations. This regulator has been shown to increase photosynthesis per unit of leaf area and encourages the growth of many small leaves causing less mutual shading later in the season (Jaggard, Lawrence & Biscoe (1982) In: *Chemical manipulation of crop growth and development.* Ed. J. C. McLaren. London: Butterworths).

In 1982 crops of beet were grown with normal (75000 plants ha^{-1}) and high (150000 plants ha^{-1}) populations; the latter with and without the application of PP 333. The mobile gas-exchange system (*Rothamsted Report for 1982,* Part 1, 76–77) was used to measure canopy photosynthesis throughout the season in conjunction with frequent harvests of small areas of crop for growth analysis. Large areas of crop were harvested at the end of the experiment for accurate yield determinations. Exceptionally favourable spring weather greatly accelerated early-season growth causing much less 'wastage' of available sunlight by normal density crops, so high density crops did not obtain an early-season advantage. No differences in yield between treatments were found, the small root/shoot ratio characteristic of high plant populations was not observed, and although PP 333 caused the required visual effects on morphology it did not affect overall growth or yield. The photosynthesis-light response (PLR) curves, measured using the gas-exchange equipment, were similar for all treatments and the change with time was as expected (Glauert (1983) *Carbon exchange of a sugar-beet crop through a season,* Ph.D. Thesis, University of Nottingham). The only difference was that the decrease in photosynthesis at high light intensity (>500 W m^{-2}) began later in the season for the PP 333 treated crop, a result that is consistent with laboratory studies.

Uninterrupted dawn-to-dusk measurements of photosynthesis showed a large, diurnal hysteresis in the PLR curves, the rate of photosynthesis being 15–20% faster during the morning. This hysteresis was observed only on days when the ambient vapour pressure deficit was larger than 1·0 kPa and was probably caused by a large resistance to water movement in the plant because the soil water deficit was kept small by irrigating. Avoiding this hysteresis may be a future PGR target. (Biscoe and Glauert)

Diseases and pests

Powdery mildew control in years of heavy and light attack. The benefits, sometimes substantial, of controlling *Erysiphe betae* in beet crops were demonstrated in experiments from 1975 to 1979 (*Rothamsted Report for 1979,* Part 1, 64). From 1980 on, the use of sulphur sprays for this purpose was actively promoted both by British Sugar and by the suppliers of sulphur, and its use increased rapidly from 15% of the crop in East Anglia in 1980 to about half treated in each of the years 1981–83, although mildew

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was then less prevalent. The programme of experiments was continued in order to monitor the economic response to sulphur sprays over a series of years and to test further if the optimum time for spraying differs from year to year. In each year from 1980 to 1983 there was one experiment at Broom's Barn testing the effect of applying a single spray on different dates, and several carried out by British Sugar, comparing a more limited range of spray dates, and with some plots sprayed twice.

In 1980 infection was early and heavy, but from 1981 to 1983 the disease seldom appeared before mid-August and it developed relatively slowly. At Broom's Barn in 1980, the best mildew control and the largest yield increases (12%) were given by sprays in the first half of August. Later sprays were less effective, particularly with the susceptible variety Nomo. Although in mid-September there was a clear visual difference between the severity of infection on Nomo and on the less susceptible Sharpe's Monobeet, sprays in early August gave similar yield increases in both. In 1981 and 1982 yield increases from spraying were less at Broom's Barn (about 6%) and the timing of a spray on Nomo was not critical, sprays from late July to early September giving similar yields. In 1983 sprays did not increase yield although some mildew spread occurred in September and October.

In all the British Sugar trials in 1980 sprays increased yield; on average by 12%, but by 19–25% in three trials where the disease appeared and the first sprays were applied at the end of July or in early August. In 1981 and 1982 sulphur sprays increased yield in most British Sugar trials. Although few of the increases were significant, the trend was constant indicating that the extensive commercial spraying in these years, was, on balance, profitable. In 1983 the difference between sites was particularly marked. In two trials in Essex and south-east Suffolk mildew spread was marked by mid-August and sprays increased yield, in one case by 12%, whereas in two further trials in Norfolk where no mildew was found, sulphur sprays did not increase yield.

The overall conclusions of the series of experiments on mildew control from 1975 onwards are as follows. In most years spraying sugar beet with sulphur is profitable over a large part of East Anglia. When the disease appears and spreads in late July or early August yield increases may be very great. When the disease increases rapidly, timing a single spray to coincide with the period of most rapid spread is critical, particularly in the more susceptible varieties, and it is possible to spray too early as well as too late. In years of moderate or low powdery mildew attack, timing of the spray is of less importance and a routine application in late July or early August will usually be satisfactory. The value of spraying twice with 10 kg ha^{-1} of an 80% sulphur formulation is doubtful. In some trials two sprays gave a bigger yield than one but in others beet sprayed twice yielded less than that sprayed once, suggesting possible slight phytotoxicity. (Byford)

Beet yellowing viruses

Root-crop Field Survey. The field survey started in 1981 (*Rothamsted Report for 1981,* Part 1, 77) was continued in 1982 and 1983, using ELISA to determine the incidence of beet yellows virus (BYV) and beet mild yellowing virus (BMYV) in the root crop. In 1982 the survey was extended from East Anglia to include 11 British Sugar factory areas in the eastern part of the country. While making regular disease counts in randomly selected fields, factory fieldmen sent to Broom's Barn a leaf from the first plant they counted as infected with virus yellows in each of the ten random counts made in the field. Leaves from symptomless plants were also sent as controls. In total leaves from 1112 plants with yellowing symptoms were tested during the season; 57% contained BMYV and 8% BYV. In 1983 207 fields were selected from all factory areas to give the best possible distribution of sites across the beet growing areas. Leaves from

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1388 plants with yellowing symptoms were tested; 61% contained BMYV and 19% BYV. The incidence of BYV was higher in 1983 than in 1981 or 1982, particularly in East Suffolk and Essex. If conditions in the 1983/84 winter favour the survival of the virus and its aphid vector, then the 1984 root crop could be at greater risk from infection with BYV than for some years.

During the three years of the survey the fieldmen's counts of plants with apparent symptoms of yellowing viruses overestimated the incidence of plants actually containing the viruses by approximately 25%. This suggests that in years of low virus incidence, the Specific Field Survey (now in its 38th year) may somewhat over-estimate the incidence of virus yellows. The ELISA survey has been used to locate farms in East Suffolk and Essex where severe outbreaks of virus yellows occur consistently; as a result work is in progress on the role of oilseed rape and stubble turnips in the epidemiology of BMYV in these areas. (Smith and Hinckes)

***Heterodera schachtii/Polymyxa betae* Survey.** In 1983 Broom's Barn, in cooperation with British Sugar, initiated a survey to monitor two soil-borne pathogens which are thought to constitute a future threat to the UK sugar-beet crop.

Readily detectable populations of beet cyst nematode *(H. schachtii)* occur in about 20% of fields in the Fens and up to 5% of fields in other beet-growing areas. In the past serious crop damage and rapid increases in nematode populations were limited by enforced restrictions on crop rotation. These restrictions no longer remain (*Rothamsted Report for 1982,* Part 1, 81), the area of oilseed rape (an alternative host of *H. schachtii*) has increased, and beet growing tends to be concentrated on lighter soils; these factors combine to increase the risk of damage by this pest.

During 1983 we became aware of an increasing threat from a disease so far not recognized in this country. The soil-borne fungus *Polymyxa betae,* thought to be relatively common in UK soils, is the vector of beet necrotic yellow vein virus (BNYVV) which causes a very severe disease of sugar beet known as rhizomania. The disease was first seen in Italy in the late 1950s; it appears to be spreading slowly northwards through Europe and has now been recognized in northern France and the Netherlands. The aim is to impose strict controls on imported plant material from infected areas on the continent to help exclude it from the UK. Work is planned to determine whether the ecological requirements of the disease will allow it to become established and damaging in England and, if so, to formulate a programme for its control should it appear. A survey has been started to investigate the distribution of *P. betae* and to test for the presence of BNYVV in plant material grown in soils infested by the vector.

In its first year the survey will comprise a bioassay of soil samples collected in August/September from randomly selected beet fields (one field per British Sugar fieldman, about 70 in all). Sugar beet seedlings are being grown in subsamples of the test soils contained in transparent plastic containers at about 20°C; cysts and females of *H. schachtii* are visible through the walls of the container and will be counted after 10 weeks' growth. Other subsamples of soil, mixed with silver sand and kept at near field capacity, will be used to grow seedlings for 3–4 weeks at about 20°C; the fibrous roots will be examined for the presence of *P. betae.* When *P. betae* is found plants grown in the infected soil will be checked for the presence of BNYVV using *Chenopodium quinoa* as a test plant. (Cooke, Payne and Smith)

Broom's Barn Farm

During the year some improvements were made to the roads and ditches. Modification to the irrigation plant involved installing a two-stage pumping system, the first stage to

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raise water from the borehole, the second to distribute it around the farm. The system is now much more versatile and able to power reel irrigators without an additional diesel pump in the field.

Cereals. To avoid volunteers in subsequent crops all cereal stubbles were again ploughed. The winter wheat and barley were drilled between 20 and 27 September 1982. One field of oats was sown on 16 October 1982 but the autumn rains prevented sowing of the other field until 3 February. The wheat and barley looked well through the winter but were checked by a spell of very frosty weather in late February. Three of the four fields were sprayed with chlortoluron post-emergence, to control broad leaved weeds, wild and volunteer oats, and with cypermethrin to prevent the spread of barley yellow dwarf virus. Wet conditions prevented spraying of the fourth field. The autumn sown oats suffered from herbicide damage because heavy rain washed the terbutryne, which was applied pre-emergence, into the root zone. February sown oats established well over most of the field. A fine spell in early March gave the opportunity to sow all the spring barley and to apply the first half of the nitrogen top dressing to the winter cereals. The weather then prevented any further landwork until mid-April when the herbicide programme on the winter barley was completed and a fungicide was applied to control eyespot on all the winter barley and winter wheat; a straw shortener was also used on the wheat. Herbicide treatment of the late-sown oats and spring barley and all the remaining N top-dressing was done in late April. The total N levels (kg ha^{-1}) were: winter wheat 184, winter barley 140, winter oats 121 and spring barley 92. The wheat was sprayed twice (mid-May and mid-June) to control *Septoria* and a small amount of mildew, and in early July to control aphids. The spring barley was treated in early June for mildew, *Rhyncosporium* and net blotch. The weather prevented application of a straw shortener to winter barley. Harvest started with winter barley on 20 July followed, after a short break, by autumn sown oats which were ready on 3 August, then continued uninterrupted to completion on 19 August. The yields (t ha^{-1}) of winter wheat (Norman) 8·8–9·2 and winter barley (Igri) 7·2–7·4 were again good but the winter oats (Peniarth) 4·6–4·9 and the spring barley (Triumph) 3·9–5·5 were disappointing. With the exception of the wheat, the higher yields were from the lighter soils, probably because of the difficult working conditions on the heavier soils in the wet autumn and spring.

Sugar beet. The first few sowings were done on 10 and 11 March in a short dry spell but no further work was possible until 16 April, when about 25% of the crop was drilled. Most of the remainder was sown between 27 and 30 April, leaving only the intended late sowings, but more rain prevented completion until late May. The very early sown areas emerged slowly, suffered considerable bird damage, and had a low plant population. The remainder emerged well, and plant stands were almost complete. Of the total area 63% was treated with granular insecticide at drilling to decrease the risk of early virus infection. To control weeds most of the crop was band sprayed with chloridazon at drilling and later sprayed overall with one-third rate phenmedipham. On some areas wet conditions delayed spraying, tractor and hand hoeing and some fat hen had to be hand pulled later in the season. One aphicide application controlled aphids well and there was little spread of yellows despite its introduction on some experiments. Powdery mildew was seen in early August but a sulphur spray in the middle of the month gave satisfactory control; in a small unsprayed area every plant became infected. In the earliest sown plots 2–9% of plants bolted but the remainder of the crop was virtually bolter-free. Irrigation was used extensively from late June to early September, a total of 115 mm being applied to much of the crop.

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Harvest started on 30 September and continued in near ideal conditions until the end of November when heavy rain made completion much more difficult; it finished on 15 December. Yields of roots were better than expected after the late start and averaged 42·7 t clean roots ha^{-1} at an average sugar concentration of 16·4% ranging from 15·0% to 17·7%. Mean dirt and top tares were 9 and 3%. National yields averaged 38·3 t ha^{-1} at 16·2% sugar.

Livestock. In October and November 1982, 67 Friesian steers and 32 cross-bred heifers were bought and fattened in the yards on a ration of one-third brewers grains and two-thirds beet pulp with added minerals, which was fed *ad lib.* Clean straw was always available. A small amount of barley was also fed to the steers. All were sold between 14 February and 22 April 1983; the heifers live through the market and the steers on a deadweight basis. The Friesian steers again gave a higher gross margin than the heifers on this feeding system. The yards were restocked in autumn 1983 with 96 Friesian steers. (Golding)

Staff and visitors

J. Iwanicki, who joined the staff at Dunholme Field Station in 1949, retired at the end of October from his responsibilities for the glasshouses, meteorological recording and caretaking. A. W. Glauert and D. L. Moir were awarded Ph.D. degrees by Nottingham and Newcastle Universities respectively.

Members of Broom's Barn staff took an active part in the work of the International Institute of Sugar Beet Research, contributing to a session on Nitrogen Fertilizers at the 46th Winter Congress in Brussels, to the Summer Congress in Denmark and the Breeding and Genetics Group meeting in France. R. A. Dunning served on the Institute's Scientific Advisory Committee and attended, as Chairman, a meeting of the Pests and Diseases Study Group in Austria at which it was decided to set up a 'Correspondence Group' on rhizomania. Broom's Barn made a major contribution to an Association of Applied Biologists' meeting at Cambridge in January on Pests, Diseases, Weeds and Weed Beet in Sugar Beet; R. A. Dunning organized a session at the International Congress of Plant Pathology at Brighton in November.

An Open Day at Broom's Barn in June was attended by some 250 farmers, and technical staff from the sugar beet and related industries. Four winter scientific meetings were held at Broom's Barn and the Station contributed exhibits to the Spring and Autumn National Sugar Beet Demonstrations near Newmarket, to 'Wheat '83' held near Cambridge and to the Arable Marquee at the Royal Show. P. C. Longden organized a Weed Beet training day for ADAS officers and D. A. Cooke a training day for Ministry of Agriculture cyst-nematode surveyors. Several members of staff contributed to an ADAS sugar-beet training course at Stafford in December. Members of staff gave talks on a variety of topics to agrochemical company representatives and to farmers' meetings organized by British Sugar plc, ADAS, agricultural clubs, agrochemical companies, etc. Groups of visitors during the year included the NFU Sugar Beet Committee, the 9th International Sugar Consultants' Forum and students from the Universities of Essex, East Anglia (2 parties), Leeds, Newcastle and Wales (Bangor).

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

THE FARMS AND THE FIELD EXPERIMENTS SECTION

The complementary service provided by the Farms and the Field Experiments Section for those requiring field experiments is emphasized this year by a joint report.

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The main responsibilities of the Rothamsted and Woburn Farms continued to be the physical conduct of most of the field experimental programme together with maintaining currently non-experimental land in a suitable condition for future experiments. The small-plot staff of the Field Experiments Section had similar responsibilities at Rothamsted for experiments and land under their management. Much of the Section was concerned with planning the programme, via secretaryship of the field experimental committees, providing field plans and other documents needed by the Farms and, with the Statistics Department, preparing the annual publication 'Yields of the Field Experiments'. The Section continued to have a major commitment to the multidisciplinary experiments and provided team leaders and some staff for those on winter wheat and grain legumes. Both Farms and Field Experiments Section originated some individual research.

The programme of field experiments is controlled by the Working Party for Field Experiments whose membership during the year was: E. Lester, later succeeded as Chairman by R. K. Scott, D. C. Griffiths, G. Inions, A. E. Johnston, R. Moffitt, A. W. Neill, W. Powell, 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 subcommittees held 21 indoor meetings and made 16 field tours of experiments.

The total number of experimental plots at Rothamsted and Woburn was 7692, an increase of 323 on the previous year. Of these 4863 were managed by the Farms, who took yields from 3993, 1381 were managed by small-plot staff, yields taken from 626; on the remainder the work was divided between Farms, small-plot staff and scientific departments.

Weather

A season of contrasts began with a mild January, in which the last of the winter wheat was sown and some winter barley was sprayed with weedkiller and fungicide. A very cold February followed with persistent snow. March started dry, allowing sowing of beans and some cereals in good conditions but there was much rain towards the end of the month. Both April and May had about twice the average rainfall, the remaining cereals were sown late and crop spraying and potato planting were extremely difficult.

Drier weather in June allowed silage and haymaking to be completed under good conditions and a warm, humid and showery July followed in which all winter barley, oilseed rape and oats were harvested. A superb August brought an exceptionally easy harvest which was completed by 25 August. Dry weather persisted, making stubble cultivations difficult amd delaying germination of volunteer cereals. A period of rain beginning on 10 September enabled cultivations, drilling and potato harvest to be done in good time. All field work was completed by the end of the year.

Crops

Of the 338 ha farmed (262 ha at Rothamsted, 76 ha at Woburn) cereals occupied 202 ha, potatoes 20·5 ha, beans 15 ha and oilseed rape 6·5 ha. The remainder was grass, fallow, access headlands with a little swedes, peas and maize.

Wheat. There were 56·2 ha at Rothamsted and 15·2 ha at Woburn. The Woburn crop was all autumn-sown but Rothamsted had 8 ha of Broom spring wheat following autumn crops which failed. Sowing in the 1982 autumn was difficult and protracted and establishment of crops sown after 11 November was generally erratic although some sown in a drier spell in January established well. Weedkiller application in autumn was

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also difficult; much was done in spring using isoproturon mixed with a broad-leaved herbicide which proved very effective.

The main varieties were Aquila and Avalon but a little Flanders was retained on three long-term experiments for continuity. A wide range of yields was recorded. In contrast to 1982 Avalon did well but Aquila, except on the poor soils of Woburn, was less satisfactory. The best yield of Flanders on Broadbalk was 7·9 t ha^{-1} after potatoes, compared with 8·7 t last year.

As usual some of the best yields came from the Factors Limiting Yield experiment (pp. 21–25) which gave yields in excess of 10 t ha^{-1}. The same experiment showed a benefit from following an oat break, rather than barley, of 1·9 t ha^{-1}, a benefit of September *vs* October sowing of 0·4 t ha^{-1} when following oats but a loss of 0·6 t ha^{-1} when following barley and a benefit of 0·6 t ha^{-1} from summer fungicides. Another experiment gave further information on the pattern of loss for continuous cereal growing. A first wheat gave 8·0 t ha^{-1}, a second 5·8 t ha^{-1} and continuous 7·8 t ha^{-1}.

The variety trials again gave good yields. At Rothamsted Norman and Longbow yielded over 10 t ha^{-1} and Avalon, Avocet and Fenman were almost as good. Aquila and Flanders gave about 9 t ha^{-1} at Woburn, where Norman yielded only 7 t ha^{-1}. Generally there was little foliar disease on most crops and potential losses were not great although some fungicide spraying was done. There were, however, losses from root diseases as the Factors Limiting Yield experiment showed.

Sowings of the 1984 crop were done in good conditions. Pre-emergent weedkillers have been applied where possible but pressure of work led to some post-emergence sprays in November.

Barley. There were 29·5 ha autumn-sown and 79·2 ha spring-sown. The main autumn-sown variety was Igri, spring-sown varieties were mainly Triumph and Atem with Georgie retained on the Classicals for continuity.

The autumn-sown crop was generally good. Field yields of Igri were about 6·6 t ha^{-1} and the same variety in the Factors Limiting Yield experiment (pp. 27–31) gave yields in excess of 8 t ha^{-1}, with large benefits from controlling leaf diseases particularly on the September-sown crop (0·3 t ha^{-1} from 'Baytan' seed dressing, 1·0 t ha^{-1} from four applications of foliar fungicides between January and May). Benefits from 'Terpal' growth regulator were greater on the October than the September sowing (0·6 *vs* 0·2 t ha^{-1}). The Cultivation/Weedkiller experiment gave a mean yield of 7·5 t ha^{-1} with a small increase of 0·2 t ha^{-1} from using the 'Paraplow' on direct drilled crops. A conventional subsoiler gave no yield increase on any of the cultivation treatments. On the heavy land at Woburn the Minimum Cultivation and Deep PK experiment gave a mean yield of 7·3 t ha^{-1}.

The season did not suit spring barley as drilling was protracted, beginning in March and finishing in April. Seedbed nitrogen was leached and a top dressing of 60 kg N ha^{-1} was given to most of the crop. Early-sown crops yielded well but the later sowings suffered. Georgie grown on Hoosfield gave a maximum of only 4·9 t ha^{-1} because, although sown on 9 March, nitrogen could not be applied until late May. In the variety trial at Rothamsted Kym gave 7·1 t, Atem 6·7 and Triumph 6·2 t ha^{-1}; in the companion experiment at Woburn only Atem exceeded 5 t ha^{-1} but Triumph in the Woburn Ley Arable experiment gave some yields in excess of 7 t ha^{-1}. At both Rothamsted and Woburn there was a benefit of over 1 t ha^{-1} from sowing in early March compared with mid-April.

Leaf diseases were generally not serious, foliar fungicides gave increases of only about 0·4 t ha^{-1}.

All autumn sowings for 1984 were made in good time and sprayed with either

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chlortoluron or methabenzthiazuron weedkillers. One field has also been sprayed with prochloraz fungicide.

Oats. There were 9·4 ha of autumn-sown Peniarth at Rothamsted and 6·7 ha of Panema at Woburn. Sown late in difficult conditions 3 ha at Rothamsted were redrilled to spring wheat. A small area on a very heavy field at Rothamsted being prepared for a subsequent wheat experiment could not be autumn-sown and the spring variety Orlando was used.

Field beans. There were 15 ha of Throws M.S. winter and Minden spring beans, grown at Rothamsted only. Weeds were well controlled by propyzamide plus simazine on the winter crop, simazine alone on the spring crop. Both crops matured early because of the dry weather and were harvested in mid-August, interrupting cereal harvest.

Winter bean yields were a little better than in 1982. An experiment on the control of chocolate spot *(Botrytis fabae)* gave a mean yield of 3·5 t ha^{-1} with little effect from benomyl sprays. Fuller control of pests and pathogens (p. 32) increased yield from 3·6 to 4·0 t ha^{-1}. Spring beans were sown in good time but suffered from pests, diseases and the summer drought with a yield range from 3·2 t ha^{-1} from unirrigated plots without pathogen control to 5·4 t ha^{-1} with irrigation and pathogen control (p. 32).

The 1984 winter bean crop was sown at the end of September using, for the first time, seed of the variety Banner, treated with a proprietary mixture of carbendazim and thiram. The problems experienced in previous years of drilling beans treated with fungicide were overcome by fitting an agitator to a Massey Ferguson drill.

Oilseed rape. About 6·5 ha were grown, mostly autumn-sown Jet Neuf. The small experimental programme was concerned with pollination and control of pests and diseases. A mean yield of 3·3 t ha^{-1} was obtained.

Potatoes. There were 20·5 ha, mainly Désirée and King Edward with a few Pentland Crown at Rothamsted, Pentland Crown and Cara at Woburn. Planting began in mid-April but was frequently interrupted. Seedbeds were poor for later-planted crops, particularly on the heavy soils, which were consequently more prone to the summer drought. Where possible irrigation was used and on one field on heavy land at Woburn, where the seedbed was cloddy, this prevented the loss of the crop.

Weeds were controlled with a mixture of linuron and paraquat applied pre-emergence. Serious blight was threatened and the crop was sprayed with mancozeb once and then with seven sprays of fentin hydroxide. Haulm pulverizing followed by desiccating, with either B.O.V. or 'Reglone' was delayed this year to take advantage of favourable growing weather in September. Fortunately the weather remained generally favourable for lifting and the crop was in store by early November.

Most unirrigated crops at Rothamsted and Woburn gave total yields of tubers in the range 21–33 t ha^{-1} with a maximum of 43 t ha^{-1} from the Rothamsted rates of P and K to the Subsoil experiment. Samples taken from irrigated crops at Rothamsted indicated yields of both King Edward and Désirée in excess of 50 t ha^{-1}.

Grass. There was ample grass in early season but the ground was too wet to carry cattle and turning out was delayed. Accordingly an early silage cut was taken at Rothamsted before grazing, and cattle at Woburn were transferred to Rothamsted and a hay cut was taken before they returned.

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Grazing was short for a period in August but this was remedied by rain and warmth in September.

Cattle

One hundred and seven fat cattle were sold from both farms and 147 yearling steers bought.

Buildings and equipment

The 20 t mechanical weighbridge was becoming rusty and unsafe and has been replaced by a larger load cell bridge.

The grain drier at Rothamsted has been extended to give a further 160 t of storage.

Land

Work by the County Council on the Redbourn By-pass began in August and 3 ha have been lost. Fortunately most of this is low lying river grazing and scrub woodland but one arable field has been divided and is now of little use for field experiments. Topsoil has been removed from a further 2·5 ha of grazing land to permit the tipping of surplus excavated soil. After grading and return of the topsoil it is intended that about 2 ha of this will again be usable for grazing.

Visitors

Nearly 7000 visitors attended the two Open Days at the end of June and the majority included a tour of the farm and field experiments as part of their insight into the work of the Station. During the rest of the year the Field Experiments Section was responsible for 200 visiting parties comprising about 1700 people, nearly all visited the field experiments, about three-quarters of them as part of a programme which included the scientific departments. About a third of our visitors were from overseas but most came from UK universities, research institutes, colleges and schools. We were pleased to see the number of visiting farmers nearly doubled to 250, about half of them as members of the 'Friends of Rothamsted' (p. 13).

Staff

Farms. The Hon. Andrew H. Joicey left in February and G. Inions replaced him in May. A. W. Neill, B.E.M., retired in November after 35 years' continuous service at Woburn. Brenda Simpson retired on 31 December after 30 years' service. J. Pickles resigned and M. Herring transferred from Woburn to Rothamsted. R. Moffitt gave an outside talk to a local farmers' group.

Field Experiments Section. Melanie G. Drake and J. J. Stephens resigned and were replaced by Jenny A. Davidson and R. Norrish (on transfer from Soils and Plant Nutrition). J. McEwen gave three outside talks to farmers on our research programme on field beans. R. D. Prew attended a meeting of the Anglo-French Collaboration Group on Cereal Production in Paris, and gave talks on our wheat programme to the Essex and Herts ADAS Winter Cereals Conference and to three outside farmers' groups. Together with F. V. Widdowson (Soils and Plant Nutrition) he organized the Rothamsted field experiment display at the RASE 'Wheat '83' event and was one of those demonstrating to the 10000 visitors.

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PHYSIOLOGY AND ENVIRONMENTAL PHYSICS DEPARTMENT

The Department was formed on 1 January by the amalgamation of parts of the previous Physics and Botany Departments. It brings together expertise and active research on the physical environment of crops, and on the physiological response of crop plants to that environment. A large part of the programme is directed towards understanding the performance of field crops, and the constraints on crop yield.

The studies of the physical environment of crops are primarily concerned with the dispersal of spores or spray droplets in crops. Collaborative work with plant pathologists is vital to this programme which has ranged from studies of turbulent diffusion theory appropriate to spore transport to practical studies of disease development in field crops. This year, measurements of disease have been made in the field on both single varieties and mixtures of susceptible and resistant varieties, and these results will be compared with computer simulations of disease spread.

The physiological responses of winter wheat to a wide range of agronomically important factors continue to be an important research area. This work is reported in the Multidisciplinary Agronomy section of the Report. Aspects are also studied in more detail by experiments on plants in pots, using controlled environment facilities to apply well defined treatments, e.g. differences in temperature and irradiance that affect development and growth rates respectively. These detailed studies will provide valuable information in our attempts to interpret field crop response. Other detailed studies have been on wheat response to nitrogen and to drought. In both cases measurements of leaf growth and photosynthesis rates were important components, and for drought a computer simulation model has been developed to define the factors controlling dry matter growth.

Studies of sugar beet physiology are done jointly with Broom's Barn Experimental Station. They seek to understand the physiological controls to leaf growth and to sugar accumulation in the roots, and how these processes are important in determining the crop's productivity.

Underlying all the studies of physiological performance in the field is a need to understand the mechanisms at an organ or cellular level. Studies of metabolism in wheat plants subjected to water stress have revealed that photosynthetic carbon assimilation is more affected than oxygen evolution, and that in severely stressed plants a contributory mechanism is inhibition of ATP synthesis and hence ribulose bisphosphate formation.

Microclimatology and aerobiology

The objective of this work is to develop and test theories of dispersion within crop canopies. This involves experimentation in the wind tunnel and in the field, and has benefited from collaboration with the Plant Pathology Department concerning spore dispersal and consequent disease development.

Disease development within crops. Early development of foliar disease in crops is often patchy when it results from low levels of inoculum distributed randomly in the crop. The rate of disease increase is determined by the speed with which the patches, or foci, enlarge and intensify, and this speed is a function of the gradient of spore deposition around infected plants. A simple mathematical simulation model of disease development around foci was developed to assess the importance of spore deposition gradients. The model incorporates values of the leaf area available to the pathogen, lesion growth rate and the age of lesions when spore production starts (latent period) in addition to the deposition gradient. Lesion area and the spore production rate for individual plants are calculated on a daily basis. Crop leaf area and deposition gradient

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are assumed constant but the model could be extended to include changes in these with time.

The simulations indicate that the total amount of leaf area diseased in a patch is independent of the deposition gradient until about 30% of the available leaf area in the focus has been infected. Subsequently the likelihood of multiple infection, i.e. of spores landing on already infected tissue and not contributing to further infection, increases. With shallow gradients spores are spread further and multiple infection is less likely, with the result that a greater total amount of leaf area and a greater number of plants are diseased. Progressively shallower gradients produce more disease (after several generations) until spores are lost from the perimeter of the crop.

The use of crops composed of multilines or mixtures of cultivars has been suggested as a means of decreasing disease. The model indicates that mixtures can be expected to be more effective against diseases when gradients are shallow; enhancement of disease by greater outwards spread is more than offset by slower disease intensification through loss of spores by deposition on to resistant plants. (McCartney)

The effect of mixtures on the development of disease patches was investigated in the field. Widely separated plots measuring 9×9 m were sown with either a variety of barley (Koru) susceptible to powdery mildew *(Erysiphe graminis)* or a mixture of susceptible and resistant (Atem) varieties in the ratio 1:2 or 1:4. The experimental plots were surrounded by the resistant variety. Each plot was inoculated at its centre with greenhouse-grown infected plants when the crop was about 10 cm tall. The pattern of disease which developed round each plant was assessed frequently until the crop was fully grown. Preliminary analysis shows that disease developed predominantly on susceptible plants with the result that total disease in the mixtures was much less than in the pure stand. Additionally, disease on infected plants in the mixtures was less than that in the susceptible plots. Disease gradients were still discernible in the mixtures 13 weeks after the initial inoculation; disease had reached the edge of the susceptible plots by then, but they were not uniformly diseased. Thus mixtures may substantially reduce both the amount of disease and the rate of growth of disease in foci. A full analysis of the results will include comparison with predictions using the computer simulation. (McCartney and Quayle, with Bainbridge and Creighton, Plant Pathology Department)

Deposition gradients. Analysis of deposition patterns of 20 μm diameter droplets released from a point source at half crop height in a barley crop (*Rothamsted Report for 1982*, Part 1, 174) was completed. The decrease in deposition rate away from the source was well described by an exponential law, and gradients, expressed as half distances, varied both in time and with height in the canopy. Gradients were steeper at mid-crop height than at ground level especially when the crop was fully grown; at that time the measured half distances were about 40 cm at mid-crop height compared to between 100 and 250 cm at ground level. The steepest gradients were measured when the crop was short, before stem extension, when half distances were about 40% less than those for either a seedling crop or a fully mature crop. Analysis suggests that the steeper gradients in the short crop were caused by the more efficient trapping of droplets that results from higher leaf area density and higher wind speed in the crop. (McCartney and Quayle)

Wind structure within crops. Wind speed frequency distributions measured within and above a barley crop were highly skewed towards higher wind speeds and could be well described by either an extreme value distribution or a log normal distribution. Profiles of the skewness and kurtosis of the distributions were similar to those measured within a sorghum canopy by Dr R. H. Shaw, University of California, Davis. Analysis

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showed that fast gusts of wind occur within barley and sorghum canopies, which have quite different structures, and it is probable that they occur in most crops. Thus time-averaged wind speeds are likely to be inadequate for the interpretation of discrete events occurring within crop canopies if there is significant non-linearity in the dependence of the event on wind speed. (McCartney)

Modelling spore dispersal in crops. Turbulent dispersal theory employing Markov chain simulation of fluid particle trajectories (*Rothamsted Annual Report for 1982,* Part 1, 175–176) was used to calculate the dispersal of fungal spores. It was shown that the theory could be applied to spores which are liberated only when wind speeds exceed a given threshold, i.e. in gusts, a situation for which conventional theory is inadequate. The model results suggest that deposition gradients for gust-released spores are steeper within a few metres of the source but at larger distances gradients are similar to those for continuously released spores. (Legg)

Work has started on a mathematical model to describe the dispersal of fungal spores in splash droplets during rain. Use will be made of the results from rain tower experiments and previously developed diffusion models for dry dispersed spores. (McCartney and MacDonald, with Fitt, Plant Pathology)

Crop and plant physiology

Our studies of plant processes and crop growth are directed towards an understanding of how crops respond to environmental conditions, including drought and nitrogen nutrition, and how these responses determine productivity. To achieve these objectives requires experimentation both in the field and under controlled environment conditions, and the measurement of changes in overall plant size and of components of the plant down to the level of concentrations of specific metabolic products.

Current investigations concentrate on leaf growth, tillering and photosynthesis of wheat, and leaf growth and sucrose storage in sugar beet. Much of this work is being brought together through simulation models of plant processes and crop growth.

Sugar beet: leaf growth. Earlier reports demonstrated how the production of total dry matter and sugar depended on the amount of solar radiation intercepted during growth and emphasized the importance to radiation interception of the expansion of the leaf canopy early in the season. At this time, air temperature is the main climatic factor and nitrogen the main agricultural input affecting leaf growth (*Rothamsted Report for 1979,* Part 1, 60). The increase in leaf area index (LAI) tends to be a linear function of thermal time (the daily accumulation of temperature above a base temperature) and this allows the effects of specific treatments on leaf canopy growth and radiation interception to be compared quantitatively in crops grown on different sites and in different seasons. Studies in a range of sugar beet crops grown between 1978 and 1982 showed large differences in the amounts of accumulated temperature required to expand unit LAI, with crops containing greater concentrations of nitrogen in their laminae having substantially faster rates of expansion (*Rothamsted Report for 1982,* Part 1, 79).

An experiment was done in 1982 to test whether the nitrogen contents of leaves and the rate of increase of LAI could be manipulated by additional dressings of nitrogen given at the time of most rapid leaf expansion. Changes in area, weight and composition of specific leaves were compared in crops given 0 or 125 kg N ha^{-1} in the seed bed and in a crop given 125 kg N ha^{-1} in the seed bed followed by three top dressings of 25 kg N ha^{-1} early in June, July and August. Giving the crop 125 kg N ha^{-1} compared with none greatly affected the increase of LAI by increasing the rate of expansion and

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final area of individual leaves. The top dressings of 25 kg N ha^{-1} had no effect even when applied while leaves were still actively expanding. The nitrogen applied in the seed bed increased the nitrogen content of individual leaves. The content increased linearly as leaves expanded, reached a maximum just before expansion was completed, and thereafter steadily declined. Two-thirds of the nitrogen present at full expansion was subsequently lost from the 10th and 15th leaves in the crop given 125 kg N ha^{-1} but in the crop given no nitrogen fertilizer only half the 10th leaf's nitrogen was lost and none from leaf 15. Nitrogen is usually remobilized from leaves of other crops at the onset of leaf senescence. In sugar beet the loss starts much earlier, often 5–6 weeks before senescence is visible, and occurs without affecting leaf appearance. Nitrate and amino-nitrogen were less than a tenth of the total nitrogen present in leaves and changes in their amounts were small relative to changes in total nitrogen, so protein–nitrogen was probably remobilized. Top dressings of nitrogen altered neither the total amounts of nitrogen in the laminae nor the amounts of nitrate or amino-N. They did not prevent or delay the loss of nitrogen from leaves. Sugar beet leaves therefore need a certain amount of nitrogen, probably as protein, to grow to full size, but not necessarily as much to maintain their photosynthetic function. Nitrogen accumulated in individual leaves during their growth may therefore act as a reserve for the later growth of the plant. This is consistent with an earlier observation that much of the nitrogen contained in sugar beet crops at harvest is taken up early in growth. (Milford; Burgoyne and Pocock with Armstrong, Broom's Barn)

Winter wheat: leaf growth. Drought can decrease the green leaf area available to intercept radiation by changing the time of leaf appearance, the rate and duration of leaf expansion and the start and rate of senescence, though the relative importance of these components will differ between crop species. Gallagher (*Journal of Experimental Botany* (1979) **30,** 625–636) has shown for cereals that leaf appearance and growth are functions of thermal time. The leaf growth of the 'Avalon' winter wheat crop grown on the rain shelter site in 1982 (*Rothamsted Report for 1982,* Part 1, 176–178) has therefore been analysed as a function of chronological and thermal time above a base temperature of 0°C.

The time of leaf appearance (first emergence from the preceding leaf sheath) was unaffected by the drought treatments, as was found with spring barley in 1979 (*Rothamsted Report for 1981,* Part 1, 180). The rate of leaf appearance was a linear function of thermal time and required about 100°C days for each leaf which is considerably greater than for the barley (70°C days per leaf). In both the spring barley and the winter wheat, the main effect of drought was on the size and longevity of later leaves (numbers 6 to 9 in barley, 11 to 13 in wheat). Drought reduced the final lamina length in winter wheat due to a slower rate of lamina exension (e.g. leaf 12; irrigated, 21·5 mm day^{-1}, unirrigated, 18·5 mm day^{-1}) but did not change the duration of extension. The green leaf area of the unirrigated crop was further decreased because leaves 11 and 12 senesced 5 days earlier and there was a more rapid senescence of leaf 13 (31·4 mm day^{-1} cf. 19·7 mm day^{-1}). (Leach)

Winter wheat: tiller survival. Ear number is an important determinant of yield in winter wheat and may be greatly affected by the proportion of tillers surviving to form ears. The causes of variation in this proportion in crops given ample nitrogen are not fully understood. In 1982, increased radiation during any part of the tiller death phase increased growth but only increased ear number when given late, just before the first three primary tillers had begun to die (*Rothamsted Report for 1982,* Part 1, 23–24). As tillering is an aspect of development it is likely to respond to temperature. Tiller survival

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was studied in 1983 in relation to changes in development rate, induced by different temperatures, and in growth rate, induced by changed radiation. Avalon winter wheat was grown outdoors in microplots using 9 cm square pots (*Rothamsted Report for 1981*, Part 1, 59–60) with a plant density of 247 m^{-2}. Batches of plants were moved to growth rooms for the environmental treatments for periods of 3 weeks starting at the double ridge, terminal spikelet or two- to three-node stage, when plants had on average 4·5, 4·4 or 2·7 shoots respectively. The growth rooms conditions were day/night temperatures of 13/9 and 9/5°C in factorial combination with photon flux densities of 475 and 235 μmol quanta (400–700 nm) m^{-2} s^{-1} and with daylength the same as outdoors. After treatment plants were returned outdoors until maturity.

Plants developed faster in the warm room than in the colder room, having one to two more florets per spikelet immediately after treatment and reaching anthesis 2–7 days sooner. During period one, warmth caused faster leaf expansion, greater dry weight, but faster death of tillers. By maturity these effects had disappeared or even been reversed. Warmth during periods two or three increased the death of tillers and decreased growth; growth rate was slightly less during treatment, but greatly decreased after anthesis even though treatment had ceased. At maturity grain yield was much less for plants treated at the warmer temperature because there were fewer ears with smaller grains and fewer grains per spikelet, in spite of the increase in florets per spikelet observed during floret initiation. Plants given bright light in period one weighed more and had retained more tillers immediately after treatment than plants given dim light, but the differences disappeared by maturity. Bright light in period two, and especially in period three, resulted in a permanent increase in dry weight, improved tiller survival and hence more ears and greater grain yield. The temperature and light intensity treatments rarely interacted.

These results indicate the importance of the main period of stem extension (two-node stage to the boot stage), when competition for assimilates between and within shoots is likely to be severe, in determining the components of grain yield. Further analysis should help to clarify the physiological mechanisms involved. (Wood, Thorne; Keirle, Mullen, Pearman, Rainbow and Stevenson)

Winter wheat: Effects of nitrogen on growth, photosynthesis and water relations. Some of the physiological responses of winter wheat (cv. Avalon) to different amounts of nitrogen fertilizer were measured in the field this year. Three nitrogen treatments were compared: low (none); medium (40 kg ha^{-1} on 3 March+26 kg ha^{-1} on 21 March); high, (40 kg ha^{-1} on 3 March+55 kg ha^{-1} on 21 March). The dates of nitrogen application were just before and after the double ridge stage (10 March). The crop was sown on 15 October 1982, basal phosphate and potassium were applied to the seed bed, and propiconazole was used to control brown rust.

Grain yields were not significantly affected by N: low 7·39, medium 7·68, high 7·09 t ha^{-1} (85% dry matter). When compared to the high nitrogen crop, the low nitrogen crop had more ears (652 cf. 580 m^{-2}) but fewer grains per ear (23·9 cf. 30·9) and per unit area of ground ($1{\cdot}6\times10^4$ cf. $1{\cdot}8\times10^4 m^{-2}$); the grain mass was larger (41·0 cf. 34·0 mg) and the maximum lamina area index substantially smaller (4·3 cf. 8·0). The interval between the appearance of individual leaves was 100°C days (base temperature 0°C) and was not affected by nitrogen. Application of nitrogen increased the final size of laminae 7 to 12 (flag), leaf 11 showing the largest differences in length between the low and high nitrogen crops (224 cf. 300 mm). Senescence of leaves started at the same time in all crops but was complete in those with low nitrogen a few days before those with high nitrogen. More than 90% of incident radiation was intercepted in the three crops from anthesis through the major part of grain filling so the energy available for assimilation in this period was similar. A difference in above ground leaf dry mass, which developed in the early stage of leaf expansion when the high nitrogen crops intercepted more light, persisted until maturity. Stem dry mass was similar in all treatments. At final harvest total dry matter was 17·3, 18·6 and 19·0 t ha^{-1} from the low, medium and high nitrogen crops respectively.

Photosynthesis of the youngest fully expanded leaves was measured in the laboratory on five occasions, using detached leaves with the severed edge in water. Measurements were made at saturating light with increasing carbon dioxide concentration or at saturating CO_2 with increasing light. Oxygen evolution was also measured with increasing light at saturating CO_2. Compared to the low nitrogen crop, leaves of plants from the high nitrogen crop were more efficient in CO_2 assimilation and oxygen production at all levels of irradiance and all concentrations of CO_2 up to saturation. Stomatal conductance was unaffected by nitrogen treatment when measured in the laboratory. Measurements in the field showed a 10% greater conductance in high compared to low nitrogen crops. Chlorophyll content of the youngest fully expanded leaves was measured at the time of maximum LAI to be 0·40, 0·60 and 0·55 g m^{-2} in low, medium and high nitrogen crops respectively. The lower efficiency of photosynthesis per unit area of leaf in the field crop with deficient nitrogen contrasts with the limited effect of nitrogen on young wheat plants grown in controlled environments (*Rothamsted Report for 1982,* Part 1, 46–47). Photorespiration of flag leaves of high and low nitrogen crops was measured in the field on leaves that were photosynthesizing at a constant rate in a $^{12}CO_2$ concentration of 330 $\mu l\ l^{-1}$ in air. The photorespiration rate was calculated from the difference between the uptake of $^{14}CO_2$ and $^{12}CO_2$ during the first 2 min of exposure to $^{14}CO_2$. Photorespiration was 20% of net photosynthesis at 22°C and 29% at 32°C and was not affected by nitrogen. At this time net photosynthesis at large photon flux was 5·5 and 4·7 μmol quanta (400–700 nm) m^{-2} s^{-1} at 22°C and 32°C respectively. Dark respiration, measured in the field on whole plants enclosed in gas exchange chambers, was up to 15% greater with high nitrogen than with low nitrogen. Respiration adjusted for the effect of temperature decreased through the night, suggesting that it was limited by the supply of available substrate.

With the wet spring, the soil water deficit was no greater than 20 mm until late June; the calculated deficit then increased steadily to 208 mm by mid-August. There was no difference in leaf water potential of the youngest fully mature leaf between nitrogen treatments. The potential, measured near midday, was −0·8 MPa on 18 May and steadily decreased to −1·5 MPa in August. To determine if nitrogen treatment affected tissue water balance or cell elasticity, osmotic potential and turgor pressure of excised leaves were measured as a function of relative water content (RWC). Leaves were saturated with water and water potential measured during dehydration. Osmotic potential, and therefore turgor, were derived from plots of the reciprocal of water potential against RWC. In early June the osmotic potential of leaves from low nitrogen plots was smaller than from other treatments, but later in the season the potentials were similar (about −1·3 MPa); at the turgor loss point (about 0·9 RWC) osmotic potential was −1·5 MPa. The calculated elastic modulus of tissues was 7–8 MPa at 1·1 MPa turgor, increased to 15–20 MPa as turgor decreased to 0·5 MPa and decreased to zero with loss of turgor.

The low nitrogen crop was able to produce a large leaf area so that for much of the season light interception was similar to the high nitrogen crop and, despite the smaller photosynthetic efficiency with low nitrogen, yield was also similar. The low nitrogen crop had sufficient nitrogen to produce a similar number of ears to the high nitrogen although inadequate nitrogen during ear development and growth may have caused the smaller number of grains per ear. With greater biomass and greater dark respiration,

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the high nitrogen crop may have been unable to produce enough assimilate to fill grains as well as the low nitrogen crop. (Lawlor, Parkinson; Clarke, Croft, Cuminetti, A. T. Day, Driscoll, Harrison, Leach, Mitchell, Shah, Uprety and Young)

Spring wheat: leaf photosynthesis under water stress. Spring wheat (cv. Kolibri) was grown in nutrient solution and stressed by single additions of polyethylene glycol 4000 (−0·5, −0·8, −1·0, −1·5 MPa osmotic potential) for 8 h in darkness at 20°C. This decreased leaf water potential measured in the light from −0·5 MPa in control plants to −1·8 MPa in the most severely stressed plants. The fifth fully expanded leaf was exposed to a photon flux of 600 μmol quanta (400–700 nm) m^{-2} s^{-1} for 4 h in approximately 400 $\mu l\ l^{-1}$ CO_2. After this initial treatment CO_2 exchange was measured with increasing irradiance at saturating CO_2 or with increasing CO_2 at saturating irradiance.

When the leaf water potential decreased to below −0·7 MPa, photosynthesis was markedly smaller at all photon fluxes and at all CO_2 concentrations; at −1·8 MPa photosynthesis stopped and leaves respired in the light. Stress decreased the initial slope of the relationship between CO_2 uptake and the calculated sub-stomatal cavity CO_2 concentration, indicating an increased 'mesophyll resistance', i.e. inhibition of the photosynthetic mechanism. Stress also decreased the maximum rate of photosynthesis. At saturating CO_2 concentrations, the maximum rate of oxygen evolution was decreased in all stress treatments but the initial slope of the photon flux response was decreased only at −1·8 MPa. The ratio of CO_2 assimilated to O_2 evolved at saturating irradiance and CO_2 was about 1·0 for leaves of control plants, increased to 2·5 at −1·5 MPa and much more at −1·8 MPa. Carbon dioxide assimilation is therefore more affected by stress than is O_2 evolution and the associated electron transport. This is also shown by the pyridine nucleotide (NADPH and NADH) concentrations in stressed leaves. These concentrations have been determined, after rapid freeze clamping, by the method of Carrier and Neve (*Photosynthetica* (1979) **3**, 323–331); NADPH was constant whilst NADH increased with severe stress. Adenine nucleotides (ATP and ADP), measured on TCA extracts by the luciferin/luciferase method, changed with stress; ATP decreased and ADP increased. Thus the ratio of ATP to reduced pyridine nucleotides fell drastically. The amount of RuBP in stressed leaves decreased as would be expected if ATP supply were limiting for the photosynthetic carbon reduction cycle. Inhibition of photophosphorylation may be a primary effect of stress (Boyer & Younis (1983), In: *Effects of stress in photosynthesis,* Eds Marcelle, Cliysters & van Poucke, The Hague: Martinus Nijhoff, 35–44). Sucrose content of leaves, measured by gas liquid chromatography (GLC), decreased with stress probably due to consumption in respiration. Organic acid concentrations were measured by GLC: some, e.g. citrate and glycollate, accumulated and others, e.g. glycerate, decreased. Total amino acids increased 20-fold and proline five-fold in stressed leaves. The data suggest that rapid, severe water stress inhibits ATP synthesis and therefore ribulose bisphosphate formation and, as a consequence, CO_2 assimilation. Electron transport and O_2 evolution are less inhibited; reductant (NADPH) concentration remains constant. However, the accumulation of NADH may be a consequence of an increasing ratio of respiration to CO_2 assimilation at severe stress. Sucrose consumption and changes in the concentrations of organic acids may also be related to a flux of material into the Krebs cycle. Accumulation of amino acids is probably linked to the change in the ratio of respiration to assimilation and to the observed high level of cellular reductant. (Lawlor; Driscoll, Khanna-Chopra and Mitchell)

Winter wheat: modelling the effect of drought on growth. In the 1981/82 winter wheat

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drought experiment at the mobile shelter site (*Rothamsted Report for 1982,* Part 1, 176–178) information was recorded to allow the simulation of crop growth using a computer program.

For this simulation model the crop canopy temperature was derived from an energy balance calculation using the daily screen maximum and grass minimum temperatures, total solar radiation and the daily crop evaporation estimated from the neutron probe readings. The calculation indicated that the unirrigated plots were consistently warmer (on average by 0·8°C) than the irrigated. Hourly radiation was calculated from the daily total assuming a sinusoidal variation through the day. Light penetration into the canopy was assumed to decline exponentially with increasing LAI. The extinction coefficient (0·56) was derived from field measurements of visible radiation above and below the canopy in the period before ear emergence. Leaf and stem areas used in the model were derived from the measurements made of LAI and the sizes of individual leaves. Because few measurements were available for the light interception by ears, a separate model was used which treated them as upright opaque cylinders uniformly distributed at the same height above the leaves. The interception by ears predicted in the model was confirmed by measurements made in the field in 1983 which showed a maximum interception of 27%. The simulation provides the average hourly light intensity on the ears and leaves in the canopy.

Photosynthesis of leaves is described by a sub-model that includes five parameters determined from field measurements:

1. Photochemical efficiency, with a value of 0·05 independent of treatment, leaf age and temperature up to 30°C.
2. Mesophyll conductance to CO_2 transfer, independent of treatment and temperature but decreasing with leaf age from a maximum value of 2·5 mm s^{-1}.
3. The photorespiration fraction, increasing with temperature with a Q_{10} of 1·3.
4. Day respiration (the net photosynthesis measured in the dark) increasing with temperature with a Q_{10}=1·3 and decreasing with leaf age.
5. Stomatal conductance, which differed between treatments only for leaves 12 and 13. It increased with irradiance to a maximum value of 7·5 mm s^{-1} (for both leaf surfaces in parallel).

For ears, photochemical efficiency for the unirrigated treatment was 40% higher than the irrigated, the photorespiration fraction was negligible and day respiration had a Q_{10} of 1·7.

The hourly net photosynthesis of the ears and leaves is calculated in the model. It is summed to give the net canopy photosynthesis during daylight, from which the night respiration of the canopy is then subtracted. This respiration is based on measurements made in the field and is dependent upon crop mass, age and temperature (Q_{10}=2·2). The net assimilation is then converted to dry matter (using a standard factor of 1·65 to convert CO_2 to dry matter) and partitioned between tops and roots. The changes in dry weight can then be compared with the measured dry weight increases in successive periods. There was close agreement between the model and final measured dry weight, e.g. irrigated measured 2063±248, predicted 1984 g m^{-2}; unirrigated measured 1901±228, predicted 1964 g m^{-2}.

Causes of differences between treatments were studied by replacing the values of one parameter in the model of the irrigated crop with the values for the unirrigated crop, and vice versa. Factors studied by this exchange have been leaf area, stomatal resistance and temperature. Drought decreased maximum LAI from 5·3 to 4·5 and shortened the duration of green area. Exchanging leaf area values increased the irrigated yield by 5% and decreased the unirrigated by 1%: radiation absorption was scarcely affected but the

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larger leaf area was associated with a larger respiration. In the model respiration of leaves was related only to age and temperature because the field results showed no relation to radiation or previous photosynthesis. Therefore increasing leaf area without significantly increasing light interception resulted in decreased net assimilation. These results indicate that LAI was supra-optimal in the irrigated treatment. Interchange of stomatal resistance depressed the irrigated yield by 6% and enhanced the unirrigated by 2%. Temperature exchange depressed the irrigated yield 3% and enhanced unirrigated by 2%.

In summary, the small decrease in yield of the unirrigated treatment was due to the increase in stomatal resistance coupled with a small temperature effect opposed by the smaller more efficient leaf area. (Parkinson; Lawlor, Leach and Scammell)

Instrumentation

During the past year, although no completely new instruments have been introduced, improvements have been made to leaf chambers and porometers. A new humidity/temperature/light sensor circuit has been produced that fits into porometer and leaf chamber handles. An equally small microprocessor circuit is being developed to be interfaced to a 16 digit by 2-line alpha-numeric display so simple messages can be given to the operator. Memory capacity has been increased to allow storage of results and these can be transferred later to a printer for which the interface has been developed. (Cuminetti; French, Harrison and Shah).

Staff and visiting workers

Until mid-November, R. K. Scott was acting Head of the Department. W. Day took up his appointment on 14 November, returning to Rothamsted after two years at Long Ashton Research Station. At the beginning of February, B. J. Legg left to take up the post of Head of Horticultural Engineering Division at the National Institute of Agricultural Engineering. He had been at Rothamsted for 16 years and had contributed substantially to many aspects of the research in the Physics Department. During the year Gillian Tuck resigned after 10 years, Helen Stevenson and Alison Rainbow were appointed. A. C. Grace also left. O. Macdonald joined the Department in October to study for a higher degree on the dispersal of splash-borne fungal spores.

D. W. Lawlor spent five weeks at the Indian Agricultural Research Institute, New Delhi on a United Nations Development Programme Consultancy relating to plant photosynthesis and stress physiology. He also attended the Organization for Economic Cooperation and Development meeting on 'Climate and Biosphere Interaction' at the University of Osnabrück, West Germany from 21 to 24 March 1983 and presented a poster at the 6th International Congress on Photosynthesis in Brussels in August. G. N. Thorne, with other AFRS staff, attended a meeting in Paris with staff of Institut Technique des Cereales et des Fourrages and Institut National de la Recherche Agronomique to discuss current cereal experimentation. H. A. McCartney gave a paper at the 6th Conference on Biometeorology and Aerobiology and attended the 16th Conference on Agricultural and Forest Meteorology, Fort Collins. He also visited the Department of Land Air and Water Resources at the University of California, Davis and gave a Departmental Seminar.

Dr R. Khanna-Chopra, from the Water Technology Center of the Indian Agricultural Research Institute, New Delhi, spent six weeks in the Department under the Royal Society's exchange agreement with the Indian National Science Academy, working with D. W. Lawlor on stress physiology. Dr D. C. Uprety of the Division of Plant Physiology, Indian Agricultural Research Institute, New Delhi, spent four

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months in the Department as a United Nations Development Programme trainee, working with D. W. Lawlor on the Mobile shelter experiment on nitrogen responses of winter wheat.

PUBLICATIONS

Broom's Barn Experimental Station

Theses

MOIR, D. L. (1983) *Some effects of beet cryptic virus on sugar beet.* Ph.D. Thesis, University of Newcastle.

GLAUERT, A. W. (1983) *Carbon exchange of a sugar-beet crop through a season.* Ph.D. Thesis, University of Nottingham.

General Papers

ARMSTRONG, M. J. & DRAYCOTT, A. P. (1983) Prospects for improving use of nitrogen fertilizer for the grower. *British Sugar Beet Review* **51(2),** 9–12.

ARMSTRONG, M. J. & DRAYCOTT, A. P. (1983) Prospects for improving use of nitrogen fertilizer for the grower. In: F. O. Licht: *International sugar economic year book & directory.* G5–G10.

BISCOE, P. V. & (DAWSON, R. G.) (1983) Cereal production systems. In: *Fream's agriculture.* Ed. C. W. R. Spedding. London: John Murray, pp. 471–493.

BISCOE, P. V. & JAGGARD, K. W. (1984) Measuring plant growth and structure. In: *Instrumentation for environmental physiology.* Eds B. Marshall & F. I. Woodward. Cambridge: Cambridge University Press.

BISCOE, P. V. & WILLINGTON, V. B. A. (1983) Role of physiology in the production of heavy wheat yields. In: *Yields of cereals course papers 1983.* Stoneleigh: Arable Unit, National Agricultural Centre, pp. 37–44.

BISCOE, P. V. & WILLINGTON, V. B. A. (1983) Environmental effects on dry matter production. In: *The nitrogen requirement of cereals.* MAFF/ADAS Reference Book No. 385. London: HMSO, pp. 53–65.

DUNNING, R. A. (1983) Rhizomania—a threat to the UK crop? *British Sugar Beet Review* **51(3),** 53–54.

(FRANCIS, S. M.) & BYFORD, W. J. (1983) *Peronospora farinosa* f.sp. *betae. CMI Descriptions of Pathogenic Fungi and Bacteria No. 765.* Kew: Commonwealth Mycological Institute.

LONGDEN, P. C. (1983) Weed beet—the latest picture. *East Anglian Farmers' Guide* January 1983, 3.

SCOTT, R. K. & (ALLEN, E. J.) (1983) Root production systems. In: *Fream's agriculture.* Ed. C. W. R. Spedding. London: John Murray, pp. 508–522.

WILLINGTON, V. B. A. & BISCOE, P. V. (1983) Effects of nitrogen on the growth and development of winter wheat. In: *The nitrogen requirement of cereals.* ADAS/MAFF Reference Book No. 385. London: HMSO, pp. 131–132.

Research Papers

ARMSTRONG, M. J., MILFORD, G. F. J., BISCOE, P. V. & LAST, P. J. (1983) Influence of nitrogen on physiological aspects of sugar beet productivity. In: *Proceedings of the 46th Winter Congress of the International Institute for Sugar Beet Research, Brussels,* 53–61.

COOKE, D. A. (1984) The relationship between numbers of *Heterodera schachtii* and sugar beet yields on a mineral soil, 1978–81. *Annals of Applied Biology* **104,** 121–129.

COOKE, D. A. (MATHIAS, P. L.), CHWARSZCZYNSKA, D. M. & (COPPOCK, L. J.) (1983) Comparison of methods of assessing field populations of *Heterodera schachtii. Plant Pathology* **32,** 339–343.

DRAYCOTT, A. P., LAST, P. J. & WEBB, D. J. (1983) Effect of time and method of nitrogen fertilizer applications on available soil nitrogen, on seedling establishment and growth, and on yield of sugar beet. In: *Proceedings of the 46th Winter Congress of the International Institute for Sugar Beet Research, Brussels,* 293–303.

https://doi.org/10.23637/ERADOC-1-23

DURRANT, M. J., PAYNE, P. A. & (MCLAREN, J. S.) (1983) The use of water and some inorganic salt solutions to advance sugar beet seed. I. Laboratory studies. *Annals of Applied Biology* **103,** 507–515.

DURRANT, M. J., PAYNE, P. A. & (MCLAREN, J. S.) (1983) The use of water and some inorganic salt solutions to advance sugar beet seed. II. Experiments under controlled and field conditions. *Annals of Applied Biology* **103,** 517–526.

JAGGARD, K. W. (WICKENS, R.), WEBB, D. J. & SCOTT, R. K. (1983) Effects of sowing date on plant establishment and bolting and the influence of these factors on yields of sugar beet. *Journal of Agricultural Science, Cambridge* **101,** 147–161.

LAST, P. J., DRAYCOTT, A. P., MESSEM, A. B. & WEBB, D. J. (1983) Effects of nitrogen fertilizer and irrigation on sugar beet at Broom's Barn, 1973–78. *Journal of Agricultural Science, Cambridge* **101,** 185—205.

(MCGOWAN, M.), ARMSTRONG, M. J. & (CORRIE, J. A.) (1983) A rapid fluorescent-dye technique for measuring root length. *Experimental Agriculture* **19,** 209–216.

THORNHILL, W. A. (1983) The distribution and probable importance of spiders of the family Linyphiidae living on the soil surface of sugar-beet fields. *Bulletin of the British Arachnological Society* **6,** 127–136.

TURNBULL, P. E. & BISCOE, P. V. (1983) Avoiding the effects of herbicide damage caused by weather variables in sugar beet. *Aspects of Applied Biology 4, Influence of environmental factors on herbicide performance and crop and weed biology*. Wellesbourne: Association of Applied Biologists, pp. 545–552.

(STEVEN, M. P.), BISCOE, P. V. & JAGGARD, K. W. (1983) Estimation of sugar-beet productivity from reflection in the red and infra-red spectral bands. *International Journal of Remote Sensing* **4,** 325–339.

Field Experiments Section

GENERAL PAPERS

DYKE, G. V. & PREW, R. D. (1983) Beans in crop rotations. In: *The faba bean* (Vicia faba L.)*: a basis for improvement.* Ed. P. D. Hebblethwaite. London: Butterworths, pp. 263–269.

LESTER, E. & PREW, R. D. (1983) A multidisciplinary approach for evaluating the factors that affect cereal yields. In: *The yield of cereals, Proceedings of an International Seminar, Cambridge and Stoneleigh, 1983.* Ed. D. W. Wright. London: Royal Agricultural Society of England, pp. 79–84.

PAPER IN ROTHAMSTED REPORT, PART 2

MCEWEN, J., JOHNSTON, A. E., POULTON, P. R. & YEOMAN, D. P. (1984) Rothamsted Garden Clover—Red Clover grown continuously since 1854. Yields, crop and soil analysis 1956–1982. *Rothamsted Experimental Station Report for 1983,* Part 2, 225–235.

RESEARCH PAPERS

JENKYN, J. F., DYKE, G. V. & TODD, A. D. (1983) Effects of fungicide movement between plots in field experiments. *Plant Pathology* **32,** 311–324.

JENKYN, J. F., FINNEY, M. E. & DYKE, G. V. (1983) Effects of nitrogen fertilizer and tridemorph on mildew, growth and yield of spring barley 1975–77. *Journal of Agricultural Science, Cambridge* **101,** 517–546.

PREW, R. D., CHURCH, B. M., DEWAR, A. M., LACEY, J., PENNY, A., PLUMB, R. T., THORNE, GILLIAN, N., TODD, A. D. & WILLIAMS, T. D. (1983) Effects of eight factors on the growth and nutrient uptake of winter wheat and on the incidence of pests and diseases. *Journal of Agricultural Science, Cambridge* **100,** 363–382.

Physiology and Environmental Physics Department

GENERAL PAPERS

ARMSTRONG, M. J., MILFORD, G. F. J., BISCOE, P. V. & LAST, P. J. (1983) Influences of nitrogen on physiological aspects of sugar beet productivity. *Proceedings of 46th Winter Congress of the International Institute for Sugar Beet Research, Brussels,* pp. 53–61.

https://doi.org/10.23637/ERADOC-1-23

DAY, W. & LEGG, B. J. (1983) Water relations and irrigation response. In: *The faba bean (Vicia faba L.): a basis for improvement.* Ed. P. D. Hebblethwaite. London: Butterworths, pp. 217–231.

DAY, W., PORTER, J. R., WEIR, A. H., RAYNER, J. H., BRAGG, P. L. & KIRBY, E. J. M. (1983) Modelling the growth of wheat. In: *Better British wheat.* Eds J. Hardcastle & R. Sutherwood. London: ARC, pp. 34–35.

(ELLIOTT, M. C., HOSFORD, D. J.), LENTON, J. R., MILFORD, G. F. J., POCOCK, T. O., (SMITH, J. I., LAWRENCE, D. K. & FIRBY, D. J.) (1984) Hormonal control of storage root growth. In: *Growth regulators in root development.* Eds M. Jackson & P. Stead. British Plant Growth Regulator Group Monograph No. 10, pp. 25–35.

LEGG, B. J. (1983) Movement of plant pathogens in the crop canopy. *Philosophical Transactions of the Royal Society of London* **B302,** 559–574.

THORNE, G. N. & WOOD, D. W. (1982) Physiological behaviour of the cereal crop. In: *Yields of cereals course papers 1982.* Stoneleigh: Cereal Unit, National Agricultural Centre, pp. 12–22.

THORNE, G. N. (1982) Growth and development and the environment. In: *Opportunities for manipulation of cereals productivity.* Eds A. F. Hawkins & B. Jeffcoat. British Plant Growth Regulator Group Monograph No. 7, pp. 204–209.

RESEARCH PAPERS

BAINBRIDGE, A. & MCCARTNEY, H. A. (1983) Gradients of spore deposition and implications for disease development. *10th International Congress of Plant Protection, Brighton, 1983,* p. 947.

DAY, W. & PARKINSON, K. J. (1982) Application to wheat and barley of two leaf photosynthesis models for C_3 plants. *Plant, Cell and Environment* **5,** 501–507.

LAWLOR, D. W. (1983) Metabolism and energy supply of plants under stress. *Journal of the Science of Food and Agriculture* **34,** 945–946.

LAWLOR, D. W. (1982) Integration of biochemical processes in the physiology of water stressed plants. In: *Effects of stress on photosynthesis.* Eds R. Marcelle, H. van Clijsters & M. Poucke. The Hague: Martinus Nijhoff, pp. 35–44.

LEGG, B. J. (1983) Turbulent dispersion from an elevated line source: Markov chain simulations of concentration and flux profiles. *Quarterly Journal of the Royal Meteorological Society* **109,** 645–660.

(LEUNING, R.) & LEGG, B. J. (1982) Comments on 'The influence of water vapour fluctuations on turbulent fluxes' by Brook. *Boundary-Layer Meteorology* **23,** 255–258.

MCCARTNEY, H. A. & BAINBRIDGE, A. (1983) Deposition of 20 μm diameter droplets close to a point source within a barley crop. In: *Proceedings of the 6th Conference on Biometeorology and Aerobiology. Fort Collins, Colorado, 1983.* Boston: American Meteorological Society, pp. 40–43.

PARKINSON, K. J. & DAY, W. (1983) The influence of water stress on photosynthesis in a barley crop. In: *Effects of stress on photosynthesis.* Eds R. Marcelle, H. van Clijsters & M. Poucke. The Hague: Martinus Nijhoff, pp. 65–74.

PREW, R. D., CHURCH, B. M., DEWAR, A. M., LACEY, J., PENNY, A., PLUMB, R. T., THORNE, GILLIAN, N., TODD, A. D. & WILLIAMS, T. D. (1983) Effects of eight factors on the growth and nutrient uptake of winter wheat and on the incidence of pests and diseases. *Journal of Agricultural Science, Cambridge* **100,** 363–382.

(RAUPACH, M. R.) & LEGG, B. J. (1983) Turbulent dispersion from an elevated line-source: measurements of wind-concentration moments and budgets. *Journal of Fluid Mechanics* **136,** 111–137.

THORNE, G. N. (1982) Distribution between parts of the main shoot and the tillers of photosynthate produced before and after anthesis in the top three leaves of main shoots of Hobbit and Maris Huntsman winter wheat. *Annals of Applied Biology* **101,** 553–559.

https://doi.org/10.23637/ERADOC-1-23