ROTHAMSTED RESEARCH

Report for 1971

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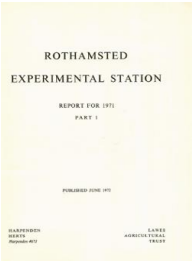

Plant Pathology Department

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PLANT PATHOLOGY DEPARTMENT

J. M. HIRST

The inconvenience of the deep excavations made along three sides of our building during 1971 was considerable, but as the year ends and a new building emerges we can contemplate the relief that our share of it will bring and be grateful to the contractors for impeding our work as little as possible.

Properties of viruses and virus diseases

Molecular weights of virus proteins. When proteins of some viruses of the potato virus Y group, (potato virus Y, henbane mosaic virus, tobacco etch virus, turnip mosaic virus, bean yellow mosaic virus and pepper veinal mottle virus) were examined by electrophoresis in SDS-polyacrylamide gels, each showed a major component, of molecular weight 30–35 000 daltons, but this was usually accompanied by variable amounts of smaller components. None of these viruses is known to contain more than one major structural protein, so the multiple bands on gels probably reflect proteolytic attack on the virus particles, either in the host or during purification. Our estimates for tobacco etch virus (31 000 daltons) differs from the estimate by Damirdagh and Shepherd (*Virology* (1970), **40**, 84–89) of 22 000 daltons for the molecular weight of the protein made from chemical analysis. Whereas size estimates by electrophoresis are unaffected by the presence of several components, chemical analyses are suspect unless made on homogenous preparations. (Carpenter)

Potato virus X (PVX). During storage or brief exposure to trypsin, PVX becomes modified so that the size of the protein from disrupted particles, estimated by the SDS-polyacrylamide gel electrophoresis method, is 25 000 instead of the 30 000 daltons from unaltered particles (*Rothamsted Report for 1970*, Part 1, 121). Trypsin must rupture at least one peptide bond in each protein subunit and if fragment(s) amounting to 5000 daltons are lost then the weight of the whole virus particle would decrease by 6–7 $\times$ 10^6 daltons (16%) and its surface would be considerably altered. However, because non-covalent interactions are important in virus structure, fragments formed by protein chain cleavage may be retained with little detectable change in the particles. As PVX is often regarded as the 'model' flexuous rod virus particle, it seemed important to find how the properties of the virus particle are affected by altering its protein, especially as the earlier studies must often have been done on mixed forms of the virus.

Mapping the position of peptides formed by proteolytic enzymes acting on the virus and its protein showed that brief trypsin attack on the virus particle removes a single large neutral polypeptide from the N-terminal end of the protein subunits by cleavage at an exposed lysine residue. The virus degrades naturally to the small molecular weight form by cleavage at the same point. The released fragment can be recovered from the supernatant solution after pelleting the modified virus particles. Amino acid analyses of the modified and unmodified proteins, and of the fragment, show that the fragment is composed predominantly of serine and threonine, although the protein as a whole is not unusually rich in these amino acids. Many of these hydroxylated amino acids must be on the surface of unmodified particles and their interaction with borate ion may be the means by which this buffer dissolves precipitated virus. The modified virus has a

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greater electrophoretic mobility at pH 7·0 in free solution and in polyacrylamide–agarose composite gels, thus although the loss of the neutral peptide cannot change the total net charge on the virus it alters the net surface charge, perhaps by exposing previously buried charged groups. The sedimentation coefficient of modified virus is about 5% less than that of unchanged virus but within the range 110–120 S previously obtained for the virus. The UV absorption spectra of the two forms are identical, a result consistent with the lack of aromatic amino acids in the fragment. In the electron microscope the two forms appear very similar so electrophoresis is the only method by which they can bedistinguished.

Modified virus particles are about half as infective as the intact form.

The serological behaviour of the forms has not been compared in detail but the fragment of the protein that is removed seems not to behave as an antigenic determinant.

PVX reacts with amino group reagents such as dansyl chloride, and investigating these derivatives shows that there is at least one other reactive amino group in addition to the trypsin-sensitive lysine. Occasionally during purification the virus becomes irreversibly pigmented, perhaps because the amino groups react with the products of host polyphenol oxidase activity. (Carpenter)

Henbane mosaic virus. Several isolates of henbane mosaic virus were examined in the electron microscope and particle lengths estimated. When extracts were made in water, the particles were either straight and about 900 nm long, or flexuous and about 800 nm long. The type depended to some extent on the species and age of the host plant, on how long it had been infected and the temperature at which it was grown. However, extracting leaves in solutions containing magnesium ions (0·05*M*) always gave straight 900 nm particles, whereas extracting in solutions containing ethylenediaminetetra-acetate (0·05*M*) always gave 800 nm flexuous particles, regardless of the species and age of the host plant. Similar morphological differences were found with pepper veinal mottle virus or bean yellow mosaic virus extracted in the two solutions. Particle length is a character widely used to identify and group plant viruses, so it is important to know that the morphology of some viruses depends on the extracting medium. (Govier and Woods)

Virus diseases of tropical crops

***Cocoa necrosis virus* (*CNV*).** This virus precipitated with an antiserum to a strain of tomato black ring virus (TBRV) isolated from tulip; the relationship is distant and CNV may be considered a serotype of TBRV. When the two nucleoprotein components of CNV were separated by rate zonal sucrose density gradient centrifugation, the 130 S component was very infective, whereas the 102 S component had little infectivity and did not appreciably enhance the infectivity of the 130 S component when mixed with it. These properties support the suggestion made last year that the vector of CNV may be a nematode. (Kenten)

Cowpea mild mottle virus. A disease common in cowpeas in Southern Ghana was found to be caused by a seed-borne virus with straight particles 650 nm long. It was not transmitted by any of five aphid species tested but was by mechanical inoculation of sap. Soyabean and french bean are systemic hosts suitable for propagating the virus, and the necrotic lesions on inoculated leaves of *Chenopodium quinoa* are useful for its assay. The virus does not precipitate with antisera to potato virus S, carnation latent or narcissus latent viruses and seems to be a new member of the potato virus S group. (Kenten with Dr. A. A. Brunt, Glasshouse Crops Research Institute)

***Viruses infecting Taro* (Colocasia esculenta).** Two diseases of Taro in the Solomon Islands, 'Bobone' from which plants apparently recover and 'Alomae' a lethal disease,

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may be caused by viruses. Electron microscopy of extracts of diseased plants showed three types of virus-like particle, 750 nm flexuous rods, small bacilliform particles 140 × 30 nm and large bacilliform particles 280 × 55 nm. Both bacilliform particles have always been present in 'Alomae' plants, sometimes with the 750 nm rod. 'Bobone' plants have never shown the small bacilliform particles but always the large bacilliform particle alone or with the 750 nm rod.

The 750 nm rod is transmitted in the non-persistent manner by *Myzus persicae* from 'Alomae' diseased leaves to apparently healthy Taro plants, in which it causes leaf distortion and severe mosaic. The severity of symptoms gradually diminishes on new leaves, until 3–4 months after infection, they are symptomless, and virus cannot always be detected by electron microscopy of leaf dip preparations. (Kenten and Woods)

Potato mop top virus (PMTV)

Relationship to tobacco mosaic virus (TMV). In nature PMTV is transmitted by zoospores of *Spongospora subterranea* the fungus that causes powdery scab of potatoes. PMTV can also be transmitted mechanically, with carborundum, to leaves of tobacco (var. Xanthi-nc) in which it produces local necrotic rings or lesions. Sap from infected tobacco leaves contains only few particles, most of which are defective, usually because the protein uncoils from one end. Virus sediments when sap is centrifuged for 15 minutes at 9000 g and can be eluted from the green pellets with 0·5*M* borate buffer, pH 7·5. Preparations were purified by clarifying the borate extract first with ether, then with carbon tetrachloride and concentrating the virus by centrifuging the clarified preparation, first, for 2 hours at 100 000 g and then in sucrose density gradient columns.

In appearance and antigenicity PMTV and TMV seem related. Particles of PMTV vary in length but are most commonly 250–300 nm or 100–150 nm but only 300 nm particles are infective. The two viruses have similar width and pitch of the protein helix. An antiserum with a titre of 2048 against PMTV had a titre of 8 against TMV, and an antiserum with a 1600 titre against TMV had a titre of 5 against PMTV. Plants infected with TMV were partially protected against infection by PMTV. (Kassanis, Woods and White)

Development of local lesions of potato mop top virus (PMTV). The number of lesions caused by PMTV in *Chenopodium amaranticolor* depends greatly on the isolate and the environment. In trying to explain this, plants were variously treated before inoculation and then incubated in different controlled environments. In all experiments, plants grown in the glasshouse were compared with glasshouse plants kept dark for 36 hours before inoculation and, in one experiment, also with plants shaded by muslin for the previous two weeks. Leaves, dusted with carborundum, were rubbed with sap from tobacco infected with a Scottish isolate of PMTV that usually produced lesions on *C. amaranticolor*. Inoculated plants were incubated at 15° or 20°C in cabinets lit for 12 hours/day with 32 000 lux or shaded to give 16 000 lux.

The results emphasised that the problem is complex but some in Table 1 show how environmental factors can interact to determine lesion formation. Experiment 1 compared the 4th, 5th and 6th-formed leaves on plants differing by three or four unfolded leaves, i.e. leaves of different age but on different plants. There were many more lesions on young than on old leaves. The greatest effect of temperature was that lesions appeared sooner at 20° than at 15°C. Darkening made lesions fewer on young plants but more on old plants at 15°C, and had little effect at 20°C. Young plants, not pre-darkened, had more lesions when shaded but young plants that were darkened had fewer lesions and their number was little affected by shading. In experiment 2 pre-darkening increased lesion numbers even more, but light intensity after inoculation had little effect. In

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TABLE 1

Effect of pre- and post-inoculation treatments on numbers of lesions on C. amaranticolor

Experiment	Pre-inoculation treatments		Total numbers of lesions of all types on the leaves indicated Post-inoculation treatments: 15° Full light	15° Shade	20° Full light	20° Shade
1 (leaves* 4, 5, 6 Feb.)	Young plants	Not darkened	199	299	229	278
		Darkened	163	199	200	177
	Old plants	Not darkened	20	61	28	86
		Darkened	109	91	31	54
2 (leaves* 5, 6 March)		Not darkened	269	230	149	242
		Darkened	343	376	377	284
3 (leaves* 7, 8, 9 April)	Open glasshouse	Not darkened	177	121	231	159
		Darkened	336	224	312	288
	Muslin	Not darkened	98	25	203	178
		Darkened	224	126	241	205

* Leaves numbered from the 1st node above the cotyledons

experiment 3, growing plants under muslin decreased, pre-darkening increased and post-shading decreased lesion numbers. The effect of growing under muslin was greater when plants were incubated at 15°C. Some of the differences between experiments may have been caused by the considerable changes in day length and light intensity in the glasshouse during January–April when the plants were raised. (Macfarlane)

Transmission of viruses

Aphid transmission of virus from sap extracts. In experiments on the role of 'helper' viruses in aphid transmission (*Rothamsted Report for 1970*, Part 1, 121), aphids acquired potato aucuba mosaic virus by feeding on virus extracts through artificial membranes, provided they had fed first on a leaf infected with the 'helper' virus (potato virus Y). Potato virus Y (PVY) has now been transmitted with aphids fed on virus extracts. Aphids first fed on PVY-infected leaves, which had been irradiated with UV to prevent transmission of infective virus, and then fed on an infective PVY extract through an artificial membrane, transmitted PVY acquired from the extract. We and others had previously failed to transmit viruses of the PVY group by feeding aphids only on an extract, but we have now succeeded by using extracts of infected leaf in 0·1*M* ammonium acetate buffer containing chelating agents and 15% sucrose. Virus was often transmitted when 0·01*M* ethylenediaminetetra-acetate and 0·01*M* sodium diethyldithiocarbamate were included as chelating agents and the pH of the extracting fluid was about 8·7 but further experiments are needed to decide which of these reagents is necessary, their optimum concentrations and pH. There were more transmissions from extracts centrifuged for 15 minutes at 8000 *g* than from uncentrifuged extracts. Transmissions were fewer from extracts kept for 24 hours at 4°C than from fresh extracts, but experiments with extracts centrifuged for 80 minutes at 105 000 *g* or with phenol extracts suggest that aphids acquire whole virus and not free RNA. (Govier and Kassanis)

***Tobacco necrosis virus* (*TNV*) *and* Olpidium brassicae.** The mechanism of transmission was studied again using single sporangial isolates of the fungus. Roots bearing ripe zoosporangia are macerated in 0·5*M* mannitol, which prevents discharge, a single sporangium is then isolated by micropipette, and transferred to dilute nutrient solution in which lettuce plants are growing, when the sporangium discharges its zoospores. We

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confirmed that TNV particles become attached to the surface of the body and flagellum of the transmitting zoospore. (Macfarlane, Kassanis and Woods)

Soil-borne oat mosaic virus. Oats sown in soil, once air-dried, from the Welsh Plant Breeding Station, Aberystwyth developed mosaic after growing for three months in a 16 hour 'day' at 15°C and night temperature of 10°C. Transmission by nematodes, which rarely survive drying, is therefore improbable. Biotrophic fungal parasites in the oat roots were *Lagenocystis* (= *Lagena*) *radicicola*, *Polymyxa graminis*, and *Olpidium brassicae*. *O. brassicae* was easily isolated and then propagated but seems not to transmit the virus. This confirms previous experience with an infested soil from Devon. (Macfarlane)

Virus diseases of brassicae. Spraying Brussels sprouts (Roem van Kloosterburen) up to three times with 'Metasystox' (in June, July and August) did not significantly decrease infection with cauliflower mosaic virus or turnip mosaic virus or significantly increase yield, probably because there were few aphids as well as few virus infections. However, further study is justified because in November plants without symptoms yielded about a fifth more sprouts than plants infected with turnip mosaic virus.

Bacilliform particles measuring 270 × 65 nm that were found in 10% of Brussels sprouts sampled in August and in, respectively, 15 to 30% from sprayed and unsprayed plots in September, may be particles of broccoli necrotic yellows virus (Hills & Campbell, *Journal of Ultrastructure Research* (1968), **24**, 134–144). Symptoms were not noticed in infected Brussels sprouts but mechanical inoculation to *Nicotiana glutinosa* caused faint vein clearing and small necrotic lesions. The virus was transmitted by one of 30 *Brevicoryne brassicae* collected from infected field plants and often by this species reared on infected plants in the glasshouse. Similar particles were found in kale (Maris Kestrel). (Cockbain and Cook, with Etheridge, Insecticides Department)

A virus originally isolated from kale in Wales causes severe necrosis on kale and cabbage (cv Primo) in the glasshouse. The virus (KV) was propagated in Chinese cabbage (*Brassica pekinensis*) and its infectivity assayed on *Chenopodium quinoa*. Serological tests showed that KV was related to the cowpea mosaic virus group and closely related to radish mosaic virus (RMV). Antiserum with a titre of 640 against KV had a titre of 320 against RMV. KV in sap was inactivated within 10 minutes at 65°C and 10 days at 20°C. KV particles resembled those of the satellite virus of tobacco necrosis virus in aggregating in groups of 12 or more [$12n \times (n - 1)$] during purification and especially after treatment with a chloroform/butanol mixture. As with other cowpea mosaic viruses, KV has three components with sedimentation coefficients of 61 S, 103 S and 125 S. The lightest (top) component contains particles that appear empty in the electron microscope. Analytical centrifugation of the RNA of KV showed two peaks corresponding to the RNA of the middle and bottom components. The middle and bottom components of RMV, which do not aggregate, were separated in the zonal rotor attachment of the MSE Superspeed 50 centrifuge and further purified by centrifugation in sucrose gradient columns. Each component inoculated alone produced only one lesion per half leaf, whereas a mixture of both produced 32 lesions, so the two components seem complementary for infection. (Kassanis, White and Woods)

Narcissus mosaic virus. Thin sections of *Nicotiana clevelandii* cells contained no characteristic cytoplasmic inclusions but there were virus particles in the nuclei. Previously, rod-shaped virus particles have been reported only in the nuclei of cells infected with tobacco mosaic and barley stripe mosaic viruses. (Turner)

Virus-like particles in fungi. Lapierre *et al.* (*Compte rendu hebdomadaire des Séances de l'Académie des Sciences, Paris* (1970) **271**, 1833–1836) reported that virus particles were

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associated with weakly pathogenic isolates of *Ophiobolus graminis*. We have also found isometric 35 nm particles with a sedimentation constant of 148 S in shake cultured mycelium of six out of ten isolates from soils that had grown from one to ten crops susceptible to take-all. Preliminary results suggest that particles are not restricted to weakly pathogenic isolates or to soils exhibiting take-all decline (see p. 140). Similar particles occur in *O. graminis* var *avenae*. (Rawlinson and Pearson)

Isometric 30 nm diameter virus-like particles were found in shake-cultured mycelium of *Colletotrichum lindemuthianum* Race ∝ 5N2 (Bannerot, *Annales de l'Amélioration des Plantes, Paris* (1965) **15**, 201–222) but were not seen in two isolates of Race δ or in one of Race γ. Possible virus infection in Race ∝ 5N2 is interesting because the race is in many ways unique. Although an unusually weak pathogen which grows and sporulates poorly in culture, where it appeared as a suspected mutant or parasexual recombinant, it attacks a wider spectrum of differential hosts than other known races. (Rawlinson)

Scanning electron microscopy

Fossil diatoms. Diatoms long renowned as tests of skill in light microscopy can produce even finer details to test the scanning electron microscopist. Although they do not shrink in vacuum, fossil diatoms are not easy to coat with metals to prevent artefacts caused by charging at the accelerating voltages necessary to resolve the finest detail. Initially there were difficulties in mounting specimens because specimens stuck to the stub with 'Durofix' easily became charged, 'Silver Dag' proved a better conductor but rose on to the specimens obscuring detail. Our best results have followed brushing dilute suspensions of fossils in acetone on the stub, to which they adhere firmly when dry. Providing the layer is sparse, gold/palladium gave much better coating then aluminium and allowed structures only 10 nm apart to be resolved. (Turner with Ormerod, Pedology Department)

Development of *Erysiphe graminis* condia. Because so much of its growth is superficial, *E. graminis* is a rewarding subject for scanning electron microscopy, which shows many previously unrecognised details of its spore form and function. Although the spores are delicate and readily collapse during the usual heavy metal coating, this can be omitted and turgid spores photographed provided the instrument is operated quickly and the accelerating voltage is small (3 kV).

Turgid spores bear many short 'spines' but the germ tubes, appressoria and hyphae are smooth unless grown in dry air, when they become folded and ridged. When appressoria and hyphae are removed they seem to have dissolved the wax platelets from the leaf surface and a small puncture in the cuticle is often visible beneath the appressorium. The superficial hyphae first produce the characteristically bulged cell from which the conidial chain develops. As the protoplasm of spores separates internally, an annular ridge appears on the condiophore where each cross wall will develop. When several rings have formed basipetally the oldest invaginates to become a furrow and progressively separates a spore, leaving a smooth-walled blunt papillum at the distal end of each conidium and a corresponding indentation at their proximal ends. The spiny outer spore coat is probably ruptured during spore formation but spores are released only after cytoplasmic separation. In moist air, the spiny-coated mature spores may germinate in the chain, each producing several short germ tubes. (Plumb, Turner and Bainbridge)

Release mechanism of *Phytophthora infestans* sporangia. Shrinkage during drying may sometimes be important in spore discharge. This seemed likely when experiments in a micro wind tunnel showed that release mostly accompanied very rapid twisting of turgid

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sporangiophores kept in humid air until exposed momentarily to dry air. The hygroscopic twisting of flattened dry sporangiophores released few sporangia and only by entanglement of existing branches. It was considered that the walls must contain spiral structures that respond to brief small changes of humidity and that twisting occurs without dehydration, causing enough hydrostatic pressure to dislodge the sporangia.

The S.E.M. supported the hypothesis because micrographs show a helical thickening in the sporangiophore walls having a much finer pitch than that of the flat dry twisting visible under the light microscope; after discharge, the tips of sporangiophore branches are dome-shaped and the cleavage of the outer wall of the sporangial stalk seemed to be by longitudinal extension. (Stedman, Turner and Hirst)

Soil inhabiting invertebrates. Techniques that prevent shrinkage will be needed for some soft-bodied animals, such as *Isotoma* spp. (Collembola : Isotomidae) and *Schwiebia* spp. (Acarina : Astigmata) which both shrink in vacuum and need metal-coating because they are charged and damaged by 20 kV electron beams when examining minute detail. More chitinised arthropods, such as the uropodid mites and Collembola with tougher cuticles (e.g. *Sminthurinus* spp.) are strong enough to be coated with gold and examined without special methods. The mouthparts of the two British families of symphylids were compared. Both have separate first and second maxillae but they are large in the Scutigerellidae, which are mostly pests, and have a scaly surface and a slender pad at the front of the head. The Scolopendrellidae are not pests, and *Symphylella* spp. have skin covered with tiny tubercles rather than spines, weaker mouthparts but a large pad on the front of the head. (Turner with Edwards and Haines, Entomology Department)

Critical point drying. One of the best methods to prevent soft specimens shrinking is to dry them at the 'critical point' of gases such as carbon dioxide. Unfortunately, this gas is only slightly soluble in water so the specimens need to be dehydrated in organic solvents such as alcohol and amyl acetate. Sulphur dioxide has a much hotter (157°C) critical temperature than CO_2 (31°C) but solvents are unnecessary as it is soluble in water, so specimens are easier to prepare. Nematodes (*Anasakis simplex*) dried in air have wrinkled skins and distorted bodies, artefacts that were prevented by critical point drying in sulphur dioxide. (Turner with Green, Nematology Department)

Cereal diseases

Foliage diseases. In recent years mildew, rusts and *Septoria* have become increasingly noticed. Few farmers could escape having their attention drawn to mildew by intensive programmes advertising fungicides, but neither closer examination of crops, weather nor husbandry changes fully explain the upsurge in rusts and *Septoria*. Perhaps the most important single factor is the dwindling value of genetic resistance. Now that few spring barleys survive diseases for more than three years, we are familiar with the fact that introducing specific resistance one gene at a time scarcely restrains pathogens so variable and dispersible as mildew and rusts. Close inbreeding seems also to produce a proportion of varieties, otherwise excellent, that succumb catastrophically to hitherto minor pathogens; conversely, producing hybrid cereals will imply reliance on a few mechanisms of male sterility and on open-flowering (avoidance of which has for years provided an 'escape' from loose smut and ergot).

As pathogen populations become increasingly intractable to genetic resistance, pathologists are increasingly asked to explain their epidemiology, to assess their effects or to predict when to time the single application of fungicide likely to be profitable. Few of

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the basic facts are known and, even if they were, to apply them usefully would occupy several years. Besides devoting effort to these problems we need to find how to introduce non-specific resistance so that its benefits last much longer than the benefits of specific resistance have done.

Epidemiology of cereal aphids and barley yellow dwarf virus (BYDV), 1970–71

Overwintering. Although the winter was the mildest for three years with few frosts between January and April, exposed aphids did not survive well. *Rhopalosiphum padi* placed on oats and barley in November soon died but one or two *Sitobion avenae* were seen in the infested areas until early March and again early in May before flying aphids were trapped. Periodic counts were made on the same two species exposed on Powys oats in pots. A few of each species exposed in October survived until March and multiplied in milder early April weather. Aphids exposed at other times did not survive so well, because aphids suffered worst soon after exposure in cold weather and least when initially mild conditions became gradually colder.

Phenology of BYDV and its aphid vectors. Once again *R. padi* were much commoner during October 1970, than during July 1970 when the other BYDV vectors are most prevalent. Only one aphid caught in October transmitted BYDV, suggesting that autumn infection would be slight. Nevertheless, plots of oats that emerged during October had 20% of plants infected the following June, whereas those emerging four weeks later had only 5% infected.

The spring migration of *R. padi*, in late-April and early-May, was smaller and earlier than in 1970. Although cereal aphids remained scarce during June, they multiplied greatly during July so that more *R. padi* and *S. avenae* were caught than in 1970, but only one third as many *Metopolophium dirhodum*. Predators and parasites decreased aphid numbers throughout the year and parasitic fungi were particularly effective among the crowded colonies of *M. dirhodum*.

The first infective aphid trapped, 1·3 m above ground, that transmitted BYDV was again *R. padi* (19 May) and like the first of other vector species was caught ten to 14 days earlier than in 1969 or 1970 but in 1971, of 1288 aphids tested, fewer (2·2%) were infective (1% of *R. padi*, 3·5% of *S. avenae* and 2·6% of *M. dirhodum*).

Effects of BYDV and aphids. Small central areas of Zephyr spring barley plots infested during the third week of May with BYDV infective *R. padi* and *S. avenae* developed symptoms but, once again, little virus spread to the rest of the plot. Infesting with *S. avenae* produced more severe BYDV symptoms than with *R. padi* and the infected plants yielded only half as much as those infested with non-infective *S. avenae*. Virus from *R. padi* had no significant effect on yield but, surprisingly, controlling this species increased yield of infested plants by 40%, whereas controlling *S. avenae* only increased yield by 5–10%.

During the three years when *R. padi* and *S. avenae*, with or without BYDV, were introduced to plots we have learnt much of their potential effects and ability to survive. However, the spread of aphids and virus have not been sufficient or early enough greatly to affect the remainder of the plot. These experiments will be moved elsewhere and have been replaced at Rothamsted by a simpler trial testing the effect of insecticides applied on different dates on naturally occurring aphids and virus spread. In 1971, phorate granules added (4·5 kg a.i./ha) to a seed-bed for Julia spring barley just before drilling increased yield by over 5%, additional menazon (0·7 litre/ha) in mid-May added a further 2–3% but another spray in mid-June had no effect. Scattered BYDV infected plants became obvious during May and there were fewer where granular insecticide was applied but this experiment does not apportion the effects of virus and aphids. (Plumb)

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European wheat striate mosaic (EWSM). Although EWSM was unusually common in 1970 there was little in 1971 and no evidence that it decreased yield; its scarcity is fortunate because glasshouse tests showed that all commonly grown varieties of wheat, oats and barley are susceptible and are killed when infected early in growth. Cappelle winter wheat, grown in pots outside, was infested at intervals with glasshouse-bred *Javesella pellucida* carrying EWSM. Plants infected in early October developed symptoms by early December and were dead before spring. However, plants infected in late November or January showed symptoms first in April and the last infections appeared late in May. These results support the conclusion (*Rothamsted Report for 1970*, Part 1, 127) that infection probably occurs in late autumn and that the varied dates when symptoms appear do not necessarily indicate a wide range of dates of infection. (Plumb)

Powdery mildew (*Erysiphe graminis*)

Temperature responses. All phases of infection by and growth of *E. graminis* are temperature-dependent, and some were studied in Saxcil growth cabinets on leaves of wheat and barley. *E. graminis* spores were able to germinate at 5°C, the coldest obtainable; between 5 and 10°C, germination, colony growth and sporulation increased rapidly and then more slowly to optima between 15 and 20°C. At 28°C, growth slowed to equal that at 12°, and at 33°C there was very little germination or growth and no sporulation. The mildew population from wheat we used grew slightly more slowly than the one on barley, at all temperatures.

The ability of *E. graminis* to grow slowly at 5°C helps explain why it overwinters so well and increases on hosts that are themselves growing even more slowly. The wide temperature range over which it grows quickly suggests why variations in British summer temperatures seem to affect it little, whereas the much slower growth above 25°C may explain why it is less troublesome than expected in hotter climates. (Bainbridge)

Phenology of mildew. A Burkard suction spore trap and freely exposed sticky cylinders were operated in a spring barley crop at Rothamsted to compare their catches and to see how both related to the infections that developed on healthy barley seedlings exposed in the same crop or at a distance. Test seedlings were grown and, after exposure (for 24 hours on five days/week, except the earliest exposures which were longer), incubated in spore-free environments before lesions were counted on their first leaves. The first plants exposed (21–28 April) became infected, whereas in 1970 plants exposed 6–13 May were the first. More infections occurred than in 1970 (often $>$ 200 pustules/leaf/day, max 70 in 1970) and abundant infection occurred earlier (21 May, compared with *c.* 17 June 1970). Despite broad agreement between trap and plant catches, preliminary analysis shows disparities that may result from variations in trapping efficiency, viability or physiologic specialisation but still need explaining. (Jenkyn)

Between May and July, freely exposed vertical sticky cylinder traps were placed in spring barley crops growing at Rothamsted and at the National Institute of Agricultural Botany trial centres at Cambridge and in Cornwall, Hertfordshire, Hampshire, East Yorkshire and Norfolk. The trapping surface (2·5 cm $\times$ 0·5 cm dia) was adjusted at 2–3 cm above the top of the crop and changed twice weekly. Density of *E. graminis* deposits ranged from 200 to 3000 spores/cm²/day with most on traps in the North and East, but usually reflecting the amount of mildew seen locally. Catches at all centres increased to a brief peak during the first three days of June which was ended by rain and was not reached again in the north or east and not until July in the south and west. (Bainbridge and Hirst)

Records of *E. graminis* spore concentrations made since 1955 at St. Mary's Hospital, Paddington, usually showed summer maxima occurring between late May (1961 and

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1965) and late June (1962 and 1966) but usually in the first half of June. Early maxima were often followed by a second after 4–5 weeks. (Bainbridge with Dr. R. R. Davies, Wright Fleming Institute for Microbiology, London)

Overwintering and dispersal. Winter wheat (Joss Cambier) was sown at the end of September and November and in early-March; the earliest-sown plots soon became infected, and may have been damaged as seedlings, but again early infection seemed not to influence the severity of attack during the following summer. However, this does not imply that autumn infections did not influence adjacent crops. Two 37 × 23 m plots of wheat stubble were separated and flanked by similar-sized plots of Joss Cambier (sown 30 September 1970). By mid-November, all winter wheat plots contained mildew with most in the lee of the stubble plot where self-sown wheat had not been killed with paraquat. Healthy seedlings exposed centrally in the stubble with self-sown wheat, and in the winter wheat usually in the lee of it, for six days in late November became more diseased (respectively, 0·53 and 0·50 lesions/2nd leaf/24 hours) than seedlings exposed in the sprayed stubble or winter wheat in its lee (0 and 0·03 lesions/2nd leaf/24 hours). Seedlings exposed in the wheat in early-January, late-February and mid-March, after the stubbles had been ploughed, detected similar differences but by mid-April these had disappeared. (Jenkyn)

Effects of ethirimol. In spring barley variety trials, ethirimol seed dressings increased average yields by 10·5% at Rothamsted and 12·8% at Woburn where, for example, responses were greatest on Sultan 33%, Zephyr 18% and Midas 17% and least on Vada 7%, Julia 5% and Gerkra 4%. These varietal differences seemed to result both from differences in effectiveness of ethirimol and in severity of mildew attacks; e.g. Zephyr had more mildew on 2nd leaves than Sultan (52% and 39% respectively) but ethirimol decreased it, respectively by 26% and 67%. Vada had least mildew and yielded most, both with and without fungicide, at both sites. (Jenkyn, with Moffatt, Farm)

As mildew was both early and severe, the experiment testing its effect at different stages of growth was more interesting than previously. Table 2 shows that ethirimol, especially as a seed dressing, increased crop height, produced more fertile tillers and increased yield. Thus early protection was more beneficial than late protection despite the amount of mildew at Growth Stage (G.S.) 11.1 in crops protected early, but full season protection allowed the advantage of the larger plants to be more fully exploited.

TABLE 2

Effect of times and intensity of mildew attack on barley (cv. Zephyr)

Protection intended	Seedlings/m (G.S. 1)	Fertile tillers/m (G.S. 11.1)	Crop ht. (cm) (G.S. 11.2)	Mildew[1]		Yield (tonnes/ha) ± 0·029
				G.S. 5	G.S. 11.1	
None	26·8	100	92	2·0	23·9	4·59
Early[2]	28·2	113	96	0·8	19·5	4·97
Late[3]	28·6	102	94	2·0	4·1	4·70
Full season[4]	24·8	112	99	0·3	1·3	5·48

[1] % area of 2nd youngest leaf infected
[2] Seed dressed 0·28 kg 80% ethirimol w.p./ha, about 1/3 of recommended commercial rate
[3] Two sprays 1·12 kg/ha (at G.S. 10 and G.S. 11.1)
[4] Seed dressing 2·24 kg/ha and two sprays as above

Last year (p. 129) we reported effects on self-sown barley of ethirimol applied to the previous crop. To study the persistence of ethirimol in soil, the experiment was tine cultivated (October 1970) and sown to Zephyr barley in spring. On 19 May (G.S. 4–5)

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seedlings had 2·7, 3·1, 2·4 and 1·7% of their third leaves infected on treatments in the order quoted in Table 2 but by 9 July differences had disappeared. (Jenkyn)

Timing of fungicides. The effectiveness of a fungicide in controlling mildew and increasing yield depends much on the state of crop and disease when it is applied. An experiment with Zephyr barley compared different times of applying ethirimol to test recommendations from epidemiological studies (Table 3). The longest and best protection was given by the heavy seed dressing (D) but even the sprays had an effect on the development of mildew that was discernible four weeks after spraying. Of the sprays, S_2 (4 June) gave best control of mildew and coincided with the release at Rothamsted of exceptional numbers of spores, at apparently a critical period in the development of the epidemic.

TABLE 3

Percentage leaf area of Zephyr barley affected by E. graminis

		Treatment*				
Date	Leaf no.	U	D	S_1	S_2	S_3
22 June	1 (Flag)	4·3	0·4	0·5	0	0·4
	2	17·6	2·8	5·9	1·6	5·0
	3	53·0	2·8	18·2	7·1	28·8
	4	—	8·4	54·4	32·4	—
1 July	1 (Flag)	7·0	1·4	6·7	1·2	1·0
	2	39·9	6·5	18·7	9·7	13·5
	3	—	15·7	58·0	37·5	50·4
	4	—	43·6	—	—	—

— Leaf dead

* U = Untreated
D = Seed dressed ethirimol (1·8 kg/ha a.i., 1·6 lb/acre a.i.)
S_1 = Sprayed ethirimol (0·9 kg/ha a.i., 0·8 lb/acre a.i.) 12 May, Growth Stage 4–5, mildew 1% on lowest leaves
S_2 = As S_1 but 4 June, G.S. 8, mildew 10% on third leaves
S_3 = As S_1 but 15 June, G.S. 10.1

TABLE 4

Effect of systemic fungicides applied at different times on mildew and yield of spring barley (cv Sultan)

	Mildew[1]				
Treatment	20 May G.S. 4–5	9 June G.S. 8	14 July G.S. 11.1	Yield tonnes/ha	
None	1·8	4·3	64·3	3·90	± 0·128
Seed dressings	0·2	2·5	60·8	4·23	± 0·074
Early sprays (G.S. 4)	0·9	0·8	52·7	4·58	
Late sprays (G.S. 10)	1·7	4·6	26·2	4·12	

[1] % area of 3rd youngest leaf infected

Untreated plots yielded 4·69 tonnes/ha (37·4 cwt/acre); sprayed plots averaged 8·8% more, a difference not statistically significant. Plots from dressed seed yielded 19·5% more than untreated seed and were significantly better than any other. (Bainbridge)

Although triarimol ('EL 273') (a material since withdrawn by its manufacturer) and triforine ('W 524') both showed an eradicant effect on mildew only three days after they were applied, they and thiophanate methyl had equal effects on yield of Sultan spring barley when applied similarly. Table 4 shows that, on average, the fungicides increased yield more when sprayed early (17 May) than later (15 June) or when used as seed dressings. (Jenkyn and Prew)

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Root diseases. Foliage diseases are usually much easier than root diseases to identify and assess. Difficulties with root diseases are clearly illustrated by recent work with take-all (*Ophiobolus graminis*). Detailed microbiological examination is necessary to distinguish the pathogen from harmless fungi that resemble it, changes in the infectivity of soils depend not only on the number of 'infective fragments' surviving from previous crops but on how they disintegrate and how this process is affected by environment and cultivations. Reliable measurement of inoculum in soils is a prerequisite to studying take-all decline quantitatively and elucidating reasons for the disease flourishing more in some places than in others. Often differences in take-all seem to be associated with different soils, but its incidence on the sites of the two ley–arable experiments suggests that some effects of previous management may be long-lasting and that growing some crops not susceptible to the disease may also be important.

For many years we have assessed take-all by the frequency and severity of lesions visible on washed roots, usually examined under water against a white background. Although imperfect, the method proved informative and usually practical until a few years ago when we found some sites where other symptoms so confused diagnosis that experienced observers could not classify take-all confidently. We know now that the difficulties are usually worst where P is deficient or the balance of P and K is disturbed. The confusions result from several pathogens, additional to *O. graminis*, that seem to vary greatly with season, site, environmental conditions and sometimes with previous cropping. Besides studying their prevalence, we hope to assess their effect on root function by collaborating with the Letcombe Laboratory in measuring how they affect the uptake of radioactive labelled nutrients.

***Comparison of isolates of* Ophiobolus graminis *and* Phialophora radicicola.** The complex of *Phialophora radicicola* Cain is of interest because it contains a pathogen of maize roots, an avirulent fungus said to compete with *O. graminis* on cereal roots and the conidial state of *O. graminis*. The first two are said to produce microconidia that germinate to form colonies, whereas attempts to germinate microconidia of *O. graminis* isolates from this country have always failed, so it has been suggested that the latter are now functionless sex cells. The isolates studied were: three of *O. graminis* (43, a single ascospore isolate from barley; 59, an isolate from oats provided by Dr. B. C. Clifford; 76, from D. B. Slope) and three isolates of *P. radicicola* provided by Dr. P. R. Scott (77, an avirulent fungus from grass roots, see *Transactions of the British Mycological Society* (1970) **55**, 163–167; 78, *sensu* Cain, originally from the Centraalbureau voor Schimmelcultures, Baarn; 79, *sensu* Lemaire, from maize in France, thought to be the conidial state of *O. graminis*).

Three of the isolates were readily distinguishable on agar, 59 by copious microconidia, 77 by slow growth and 79 by many stromata, but the others differed only in details of colour and formation of hyphal strands or stromata. Isolates 43 and 77 did not produce micronidia, and those of isolates 59, 76 and 78 differed from each other in shape but could not be germinated. Colonies grew on agar only from thick deposits of microconidia of isolate 59, but these were not proved to be free from hyphal fragments. Only isolates that had been identified as *O. graminis* caused severe (43, 76) or moderate (59) lesions on wheat. (Hornby)

The state of* O. graminis *inoculum in soil. Since 1967 attempts to measure the amount and changes of *O. graminis* inoculum in cereal soils have shown that it is possible to enumerate the pieces of host residue that contain enough fungus to infect wheat seedlings used in the bioassay. These pieces are now called infective fragments because they vary so much in size and pathogenic capacity that it is difficult to think of them as 'units'.

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Because the proportion of small fragments that cause infections increases with increasing temperature and because the proportions of the different kinds of fragments change continually, it is not possible to recommend any one temperature that will always provide maximum estimates of infective fragments. A crude inoculum model has been used to explain the relationships between the number of infective fragments and the assay temperature for soils collected at different seasons. The predictive value of the model is enhanced by allowing for further disintegration of infective fragments during or near December, into pieces that may or may not be infective. (Hornby)

Attempts to explain the nature of 'decline' of take-all. The 'Wheat after Intensive Barley Experiment' provided fallowed soils and soils fertilised with 76 or 227 kg/ha N, that had grown one, three, five or ten consecutive cereal crops susceptible to *O. graminis*. Infection of plants sampled from these crops during May and July 1970 showed 'decline', but maximum infectivity under the third crop was not confirmed by soil samples assayed in October 1970 and March 1971. The existence of 'decline' implies a preceding peak frequency of disease incidence that usually follows a respite from crops of susceptible cereals. Possibly in this experiment the break was too brief for the cause of decline to disappear. *O. graminis* isolates from soils where many crops had grown were mostly dark in colour but there was no corresponding relationship between cropping history and pathogenicity or perithecial production.

Sterilising soils by irradiation will destroy the conditions that cause take-all decline if they depend on vital functions of soil organisms, but probably not if they depend on chemical factors. Samples of the soils were therefore γ irradiated at AERE Harwell (dosage: 2·5 megarads) and small amounts were added to agar cultures, but did not differentially affect the growth of *O. graminis*. However, in columns of moist irradiated soils the fungus grew best where ten cereal crops had grown and least after fallow; growth rate was equal after one, three and five crops. Autoclaving irradiated soils had erratic effects, increasing growth in fallowed soil but greatly decreasing it in soils that had grown three or five crops. We do not know whether the changes in growth rate were caused by differences in the release of nutrients during sterilising or some thermolabile material that affected growth and persisted in different amounts in irradiated soils with different cropping histories. When seedlings were grown in irradiated soils reinoculated with *O. graminis*, runner hyphae grew on them most in soils that were naturally most infective. Irradiation also stimulated perithecial formation on roots of seedlings infected with some isolates of *O. graminis* but water extracts of the irradiated soils did not encourage the same fungi to form perithecia on agar. (Chu Chou and Hornby)

Take-all on winter wheat after ley and arable rotations. Each year since 1967 the parts of the two Rothamsted ley–arable experiments that completed their cycles of test crops have been 'phased-out' into growing winter wheat consecutively. This provided an unusual opportunity to study the increase and, perhaps, decline of take-all in soils initially containing different amounts of inoculum as a result of different known cropping histories, including three cycles of each of the following six-year cropping sequences:

Sequence	Treatment crops	Test crops
Ah	Hay, sugar beet, oats	Wheat, potatoes, barley
Lu	Three years lucerne	
Lc	Three years grass-clover	
Ln	Three years grass with much N	

In addition, since 1948, there were plots of permanent (G) and reseeded (R) grass on the Highfield experiments and reseeded grass only on the Fosters experiment which began from arable cropping.

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The incidence of take-all on wheat given 126 kg/ha N has been assessed on all sequences each July since 1969 when, to save labour, only the Ah, Lu and Ln sequences were sampled; this proved a false economy that lost much information. The percentage of plants infected and the severity of infection were recorded, the latter for 1971 as a 'take-all rating' (the sum of, respectively, one, two, or three times the percentage of plants slightly, moderately or severely infected). Table 5 shows that the G sequence on series I and the R and G sequences on series II were out of step with other sequences because they did not grow the test crop sequence and were ploughed from grass for the first wheat crop.

TABLE 5

The effect of different crop sequences on the incidence of take-all on winter wheat, Highfield and Fosters, 1969–71

			Highfield				Fosters			
	Previous crops		% plants with take-all			Take-all rating	% plants with take-all			Take-all rating
Crop sequence	1967	1968	1969	1970	1971	1971	1969	1970	1971	1971
Series I										
		W2	W3	W4	W5		W3	W4	W5	
Ah	b	ns	49	65	62	91	6	12	23	39
Lu	b	ns	58	64	90	155	16	26	39	77
Lc	b	ns	45	67	83	163	ns	13	40	78
Ln	b	ns	ns	63	76	131	ns	8	27	46
R	b	ns	ns	50	95	190	ns	19	50	88
		W1	W2	W3	W4		—	—	—	—
G	g	ns	ns	64	98	260				
Series II										
			W2	W3	W4		W2	W3	W4	
Ah	p	b	44	58	83	149	1	10	20	33
Lu	p	b	68	61	84	149	28	37	57	87
Lc	p	b	26	60	91	188	ns	15	27	51
Ln	p	b	ns	74	97	221	ns	21	17	27
			W1	W2	W3		W1	W2	W3	
R	r	r	ns	2	71	156	ns	3	22	43
G	g	g	ns	14	95	240	—	—	—	—

Crop symbols: W, winter wheat; b, spring barley; p, potatoes; g, old pasture; r, reseeded ley. Numbers after symbols indicate successive crops susceptible to *O. graminis*

ns = not sampled

Although Highfield and Fosters were cropped similarly for over 20 years, take-all developed very differently in the two fields when consecutive wheat crops were grown. On Highfield in 1968, severe attacks were noted (but not assessed) only on W2 crops following Ah and Lu sequences on series I. Similar attacks occurred on W2 crops in series II in 1969 (Table 5), but take-all was almost equally prevalent on all sequences under W3 crops on both series. The disease also increased rapidly from little in 1970 on W2 crops on R and G sequences to much in 1971. Thus early differences were short-lived and some soils that were initially least infested became most infested, whereas on others take-all declined after severe attacks in 1968 and 1969. Surprisingly, take-all seemed to decline sooner after Ah than Lu (W5 crops, series I, 1971). By contrast, the crops on the Fosters experiment showed little take-all in 1968 and 1969, and even by 1971, the greatest 'take-all rating' on Fosters was smaller than the least on Highfield. Although comparable plots on the two fields may have had different amounts of inoculum when phased-out, this seems insufficient to explain the persistence of such large differences.

We do not know how much *O. graminis* there was in the ley–arable experiment soils when they were phased into consecutive wheat crops but parts of the experiments con-

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tinue the old treatments. In July 1969, the barley (3rd test crop) on Highfield had 8% of plants infected after the Lu sequence and only 2% after the Lc sequence. The same soils have been assayed for presence of *O. graminis* on three occasions since the leys were replanted. Wheat seedlings were grown (35 days at 15/10°C, day/night) in each of 100 cores per sequence and the numbers where infection occurred were:

Highfield	April 1970	March 1971	November 1971
Lu sequence	68	36	8
Lc sequence	6	1	2

The greater prevalence of *O. graminis* in barley after Lu than after Lc, together with the persistence of different amounts of inoculum for 26 months, may confirm the differences observed between these sequences on series I and II when cropped with wheat, respectively, in 1968 and 1969, but they do not explain how these differences developed. (Slope and Prew)

Effects of P and K fertilisers on root rots of barley. In 1965 roots of barley from Hoosfield had lesions ranging from pale brown to black. Isolations showed *O. graminis* in most black lesions, often in dark brown and seldom in pale brown ones. So it was impossible by visual examination to classify take-all lesions confidently. Confusion was greatest in crops not given P fertilisers where, in 1965, both take-all and root browning were most prevalent. In 1966 take-all was common only on crops given K fertiliser, but root browning was very prevalent on all plots except those receiving PK. Similar problems arose in 1967 when examining roots taken in July from the third successive barley crop in the Rothamsted Long-term Liming Experiment (*Rothamsted Report for 1970*, Part 2, 98–112). Diagnosis was again most difficult in plants from plots lacking P fertiliser. The difficulty of identifying causes of root lesions on plants grown where P is deficient is much more important to plant pathologists than to farmers, but farmers may be very interested if additional P fertiliser can help to maintain the yield of consecutive barley crops. This possibility was one reason for beginning the 'PK and Take-all experiment' on West Barnfield in 1968. The site was moderately deficient in P and had previously grown one winter wheat crop after three years in grass. The first years of the experiment were undramatic, for take-all increased unexpectedly little in three spring barley crops (1968–70) and, although root browning became prevalent in 1969 and 1970, especially where P was lacking, symptoms were slight and root disease probably had little effect on yield. (*Rothamsted Report for 1970*, Part 1, 46–47)

TABLE 6

The effect of P and K fertilisers on root rots of barley.[1] *P, K and Take-all experiment. West Barnfield, July 1971*

Annual K manuring (kg/ha)	P manuring (kg/ha)				
	Annually (since 1968)			In autumn 1967	
	Nil	38	150	226	904
	% plants with 'all root rot'[2]				
38	97 (83)	56 (31)	39 (21)	52 (24)	23 (10)
150	96 (80)	65 (34)	28 (10)	62 (27)	21 (7)
	% plants with take-all[2]				
38	57 (31)	33 (14)	31 (18)	19 (8)	13 (6)
150	79 (56)	54 (28)	21 (8)	39 (18)	13 (3)

[1] Data are averages for four nitrogen treatments, 38, 75, 113, 150 kg N/ha
[2] Figures in brackets are % plants moderately *and* severely affected

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TABLE 7

The effect of P, K and N fertilisers[1] on the incidence of root rot of barley, Hoosfield experiment, July 1971

N manuring (kg/ha N)	P and K manuring			
	Nil	P	K	PK
	% plants with 'all root rot'[2]			
0	69 (32)	39 (12)	64 (30)	62 (34)
48	97 (81)	54 (21)	96 (62)	34 (12)
96	99 (98)	60 (23)	97 (78)	25 (3)
144	98 (96)	63 (31)	99 (90)	40 (17)
Average	91 (77)	54 (22)	89 (65)	40 (17)
	% plants with take-all [2]			
0	25 (5)	9 (2)	40 (21)	48 (28)
48	25 (8)	6 (0)	55 (22)	22 (10)
96	52 (15)	3 (0)	76 (46)	6 (2)
144	39 (21)	4 (0)	70 (43)	4 (2)
Average	35 (12)	5 (1)	60 (33)	20 (11)

[1] Fertilisers applied (kg/ha)
P = 75 P_2O_5
K = 113 K_2O + 16 Na + 11 Mg

[2] Figures in brackets are % plants moderately *and* severely affected

During 1971 the incidence of root rots was estimated on barley after barley in the experiments mentioned above and, on barley after potatoes, on the two Residual Phosphate Experiments. Diagnosis of take-all was not confused until June when root browning became prevalent, so 'all root rots' and take-all were distinguished. The latter category approximated to black lesions but underestimated take-all because *O. graminis* also causes some dark brown lesions. Fertiliser P, with or without K, always decreased infection and residual P was as effective as fresh P on West Barnfield (Tables 6 and 7). On each site K fertiliser had less effect on 'all root rots' than P but effects of K on take-all made some results difficult to interpret. For example, on West Barnfield extra K increased take-all where applied with nil or 38 kg/ha P_2O_5, but decreased it where much K accompanied 150 kg/ha P_2O_5. On Hoosfield K alone increased take-all but when together with P, K increased take-all only where N was deficient.

Our interest in P fertilisers began from observations suggesting that generous applications might decrease take-all and other root rots and so help to maintain yields of consecutive barley crops. Results in 1971 suggest that K manuring and especially its balance with P may also affect take-all. (Slope and Broom, with Mattingly and Bolton, Chemistry Department)

Because of uncertainties in diagnosing take-all on plants during July, wheat and barley

TABLE 8

Infection indices of soils from the PK and Take-all experiment assayed for O. graminis, *September 1971*

Assay plant	K manuring (kg/ha)	P manuring (kg/ha, applied annually)		
		Nil	38	150
Wheat	38	23·2	15·5	8·2
	150	19·8	20·6	19·7
Barley	38	24·0	16·4	8·2
	150	16·5*	26·5	17·1

* The infection indices of the two replicate soils were 8·5 and 24·5

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were used to assay take-all infectivity of soils collected on 16 September using the 'Infection Index' method (*Rothamsted Report for 1968*, Part 1, 134). Table 8 shows average infection indices from ten replicate pots for each host from each of the two replicate plots in the field experiment; take-all could be identified without difficulty. With 38 kg/ha K_2O increasing P decreased infection but not with 150 kg/ha K_2O and, with the one exception noted, wheat and barley gave similar results. We do not yet understand why the assay indicated different effects of K fertiliser on surviving inoculum from those it had on take-all development in the crop. (Slope and Broom)

Plants from experiments mentioned above often had pale brown (PB), dark brown (DB), or black (BL) lesions on different roots so causes had to be studied on individual roots. In June 1 cm lengths of barley root with lesions of each category were taken from each experiment, washed (90 minutes), incubated on water agar discs (11d at 22°C) and examined microscopically; other lesion-bearing root pieces were plated on potato dextrose agar and later examined for colonies of *O. graminis*. Table 9 suggests that *Helminthosporium sativum* was limited to Hoosfield and did not occur in black lesions, where *O. graminis* was most likely at all sites. *Pythium* spp. occurred in each experiment and each lesion type, except pale brown lesions on plants from Hoosfield, where *H. sativum* was abundant. On fields where *Fusarium* was found, it occurred mostly on dark brown or black lesions. *Aureobasidium bolleyi* was common on all lesions and on all experiments, but although we have often isolated it from surface-sterilised roots, its importance as a pathogen is not known.

TABLE 9

Frequency of fungi on roots with different root-rot symptoms; June 1971

Experiment	Hoosfield			PK and take-all			Long-term liming			Residual phosphate		
	Type of symptom											
	PB	DB	BL	PB	DB	BL	PB	DB	BL	PB	DB	BL
(a) On water agar												
No. of root pieces	15	12	13	9	14	13	4	17	9	10	18	0
% pieces with												
H. sativum	93	42	0	0	0	0	0	0	0	0	0	—
Pythium spp.	0	42	31	89	43	8	75	47	22	50	50	—
A. bolleyi	40	50	69	89	86	62	75	35	33	90	89	—
Fusarium spp.	0	0	0	0	14	38	0	18	56	0	17	—
(b) On potato dextrose agar												
No. of root pieces	15	13	13	8	14	15	0	18	10	8	15	3
% pieces with												
O. graminis	0	8	54	0	7	33	—	0	30	0	13	33

TABLE 10

Frequency of fungi on roots with different root-rot symptoms; July 1971

Colour of lesion	Pale brown → Black			
Symptom classified as	Definitely not take-all	Probably not take-all	Probably take-all	Definitely take-all
No. of root pieces	31	36	36	36
% pieces with				
Runner hyphae	3	17	47	97
Oospores of *Pythium* spp.	48	44	25	8
Cysts of *Endogone* sp.	68	81	81	56

A representative selection of root lesions from West Barnfield, cleared in potassium hydroxide and stained in trypan blue for microscopic examination (Phillips and Hayman, *Transactions of the British Mycological Society* (1970), **55**, 158–161), showed (Table 10)

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that runner hyphae indistinguishable from those of *O. graminis* were commonest on black lesions and *Pythium* oospores were commonest in roots with pale lesions, although their occurrence overlapped considerably; *Endogone* spp. showed no large differences. Similar examination of roots selected at random from some plots on West Barnfield showed *Pythium* oospores in 24% of barley root pieces grown without added P and little K, but only 5% where there was much P and much K. (Broom)

Pythium root rot. In July, Pythium root rot lesions were commoner than in 1970 on spring barley (Julia) on Hoosfield, with 28% of plants infected (13% in 1970); and again most (39%) were on plants not given phosphate (19% in 1970). By contrast, Cappelle winter wheat from Pennel's Piece had less, 23% in plots of continuous wheat and 17% in wheat after oats, beans (33% and 29% in 1970).

Most infected roots contained oospores, of which 60% of isolates from barley were *Pythium arrhenomanes* but only 25% from wheat. Isolates from cereals commonly included *P. vexans* and *P. sylvaticum*; but when inoculated to wheat (Cappelle) and barley (Julia) seedlings grown in tubes containing sand and 2% of colonised bran inoculum, these caused less damping-off, root rot and stunting of roots and shoots than did *P. arrhenomanes*. In pots *P. arrhenomanes* decreased the height and weight of six-week old seedlings by about 10%. Root stunting was more often associated with oospores in roots than with the soft brown root rot, which seems to indicate the presence of secondary invaders. Most *Pythium* isolates failed to produce zoospores, but the oospores germinated directly to infect roots.

The prevalence and effects of *Pythium* spp. are difficult to estimate because they colonise much fine root which is difficult to recover from soil. Soil cores, from various depths, were soaked overnight and then the suspension washed through a 2 mm sieve was passed up a sedimentation column at 4·5 cm/second. Most organic matter, silt and clay was carried up the column and the root fragments were retained at the top on a 0·3 mm mesh. From this fine root material, fragments cut to 5 mm length were cleared, examined microscopically, plated on agar and used in bioassay tests on seedlings. Samples from cereal plots in July and August showed that about 20% of sampled root fragments were infected with *Pythium* spp. (Waller)

Infection of winter wheat by chytrid and other pathogens. Roots of Cappelle winter wheat sampled monthly from Broadbalk (plots 2, 3 and 8 in sections following fallow beans and wheat) showed (Table 11) that infection by *Pythium* spp. and *Endogone* spp. increased steadily, whereas *Olipidium* spp. decreased. Runner hyphae of *Ophiobolus graminis*, *Phialophora radicicola* and *Aureobasidium bolleyi* infected a smaller proportion of roots during spring than winter or summer, when roots were probably being formed

TABLE 11

Per cent of winter wheat roots[1] *on Broadbalk infected by fungi*

	Date sampled					Manures		
	19 Jan	2 Feb	8 Mar	18 May	26 June	Plot 2 FYM	3 Nil	8 Inorganic
Runner hyphae	23	20	2	9	12	10	12	17
Pythium spp.	3	4	6	22	25	16	6	12
Endogone spp.	5	18	14	31	38	20	29	11
Olpidium spp.	25	26	20	18	17	27	17	19
Unknown resting spores	14	16	6	15	9	15	11	11
Total roots examined (1978)	414	411	420	394	339	641	692	645

[1] See *Rothamsted Report for* 1970, Part 1, 135

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faster than they were infected. *Endogone* was commonest from plot 3 (no manure) but *Olpidium* and *Pythium* infected more roots from plot 2 (FYM) than plot 3. Previous cropping seemed not to affect the incidence of *Olipidium* or *Pythium* but *Endogone* and runner hyphae infected more roots of wheat after wheat than after fallow or beans.

In June on the nearby Pennels Piece, *Polymyxa graminis* infected 39% of roots from two plots of winter wheat after spring oats, but was not found in two plots in a continuous sequence of winter wheat crops. *Lagena* spp. were not found in an experiment at Saxmundham where in 1970 they infected 15% of roots, but in February on Summerdells (Rothamsted) they infected 15% of roots from plots fumigated with dazomet and 8% from unfumigated plots.

The survey suggests that *Olpidium*, *Pythium* and *Endogone* are widespread on wheat whereas *Polymyxa* and *Lagena* may be common locally. *Olpidium*, *Pythium* and *Endogone* often infected field beans but only *Pythium* was found in potato roots. (Salt)

Take-all and pyrolysis—gas–liquid chromatography. An attempt to use this technique to measure amounts of disease on roots failed to distinguish between healthy and diseased roots or between different isolates of *O. graminis*. (Hornby with Dr. A. Myers, Botany Department, Southampton University)

Preservation of* O. graminis *cultures. Isolates of *O. graminis* sometimes alter or fail to grow when frequently subcultured on agar medium. Mycelium of two isolates minced in skimmed milk and vacuum-dried, grew normally when reconstituted with water but we do not know for how long they can be preserved. (Hornby)

Fungicides and foot and root rots of cereals. Winter wheat (Cappelle, moderately resistant to *Cercosporella herpotrichoides* and Gaines, a susceptible dwarf variety) was grown on land where eyespot was expected. Plots sown (180 kg/ha on 14 October 1970) with (M) or without (Nil) an organo-mercury seed dressing were compared with plots in which benomyl was used on the seed (D = 280 g/ha a.i.), as a spray (S = 1·12 kg/ha a.i.) or both seed dressing and spray (DS). Table 12 shows that benomyl sprays greatly decreased eyespot but, in agreement with 1970 results, seed dressings did not. Possibly seed dressings failed because too little persisted until spring when most infections occurred, rather later than usual (average April infection 3·6% of plants). Although eyespot was controlled by spraying, the increase in yield was not statistically significantly increased and would not have been profitable. (Prew with McIntosh, Insecticides Department)

TABLE 12

Effect of benomyl on eyespot, and the yield of winter wheat

Variety	Cappelle					Gaines				
Fungicide treatments	Nil	M	D	S	DS	Nil	M	D	S	DS
% straws infected with eyespot (June)	25	21	28	0	2	38	50	42	2	2
Grain yield tonnes/ha	6·18	6·46	5·91	6·19	6·71	5·06	5·07	4·94	5·45	5·36

Table 13 shows the result of applying to winter wheat (Cama) seed dressings and sprays (at G.S. 5 and G.S. 10) of the systemic fungicides we tested on spring cereals in 1970. On wheat the main purpose was to test activity against foot and root diseases although ethirimol and thiophanate methyl both greatly decreased mildew. All seed dressings, except organo-mercury, apparently decreased eyespot before sprays were

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TABLE 13

Effect of fungicides on diseases and yield of winter wheat

Treatment	Mildew[1]	Brown rust[2]	Eyespot[3]	Eyespot[4]	Sharp eyespot[4]	Take-all[5]	Shoots/ plant[6]	Yield (tonnes/ha) ± 0·208
none	1·7	2·0	7·1	42	39	64	1·6	6·10
organo-mercury	2·4	1·4	8·9	50	43	65	1·6	6·08
benomyl	0·7	1·7	4·8	1	58	72	1·9	6·31
ethirimol	0·2	1·2	5·0	37	42	76	1·7	6·01
fuberidazole	1·0	2·9	3·4	18	57	74	1·4	5·82
triarimol ('EL 273')	1·9	1·2	0	20	42	70	1·0	5·51
thiophanate methyl	0·3	1·1	4·1	5	62	66	1·7	6·30
triforine ('W 524')	0·8	1·1	4·9	38	45	76	1·6	5·61

[1] % area of 2nd youngest leaf infected at G.S. 10.5.4
[2] % area of youngest leaf (flag) infected at G.S. 11.2
[3] % shoots infected at G.S. 2–3
[4] % straws infected at G.S. 10.5.4
[5] % plants infected at G.S. 10.5.4
[6] at G.S. 2–3

applied; triarimol (a material since withdrawn by its manufacturer) had the greatest effect but when used as a seed dressing it damaged seedlings and the delay it caused in tillering may have increased escape from eyespot infection. By harvest, only benomyl and thiophanate methyl, which are active through the same breakdown product, still controlled eyespot well. No chemical was active against take-all.

Six seed dressings and a liquid fungicide ('Fun 52.133') applied to soil as a high volume spray) were tested against diseases of Sultan spring barley in comparison with seed untreated and treated with organo-mercury or organo-mercury + carboxin. Differences in seedling populations (Table 14) between treatments may partly be attributed to different flow rates of treated seed, but 'BAS 3191 F' and 'BAS 3260 F', which share a common active ingredient (Proposed common name: furcarbanil) delayed emergence in the field and in pots. Mercarbinzid ('BAS 3200 F') and 'NF 48' increased yield significantly perhaps by early control of mildew; both decreased loose smut but less than the materials containing carboxin, 'BAS 3191 F' and 'BAS 3260 F'. Some materials seemed to decrease take-all but the disease was too scarce for the results to be reliable. (Jenkyn and Prew)

TABLE 14

Effect of fungicides on diseases and yield of spring barley

Treatment	Seedling emergence[1]	Frit fly[2]	Mildew[3]	Mildew[4]	Loose-smut[5]	Yield (tonnes/ha) ± 0·165
none	19·6	37	1·2	45·7	791	3·69
organo-mercury	21·6	48	2·0	36·3	584	3·95
organo-mercury + carboxin	22·0	38	1·7	36·8	4	4·11
'BAS 3191 F' (BASF)	12·0	53	1·1	33·3	13	3·66
'BAS 3260 F' (BASF)	11·8	64	0·9	32·3	1	3·09
'BAS 3200 F' (BASF) (mercarbinzid)	14·4	47	0·3	38·3	123	4·38
'MC 833' (Murphy)	26·0	38	1·9	42·9	745	4·01
carboxin + thiram	20·0	47	1·8	45·0	1	3·63
'NF 48' (Nippon)	19·0	43	0·1	34·2	46	4·83
'Fun 52.133' (Sandoz)	24·8	34	1·8	37·3	764	3·72

[1] Seedlings/m of row (G.S. 1)
[2] % plants attacked (G.S. 7–8)
[3] % area of 3rd youngest leaf infected at G.S. 4–5
[4] % area of 2nd youngest leaf infected at G.S. 11.1
[5] No. of smutted heads/200 m of row

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The time to apply formalin. Winter wheat (Cappelle) and spring wheat (Kolibri) yielded much more at Rothamsted than at Woburn where take-all was more severe and cereal cyst nematode severely damaged spring wheat. Although treating soil with formalin or applying up to 226 kg/ha N increased yields at Woburn, the best was only half the average yield from the experiment at Rothamsted.

TABLE 15

Effect of formalin on yield of winter and spring wheat and on the incidence of take-all and cereal cyst nematode damage

Site	Rothamsted				Woburn			
Crop	Winter wheat		Spring wheat		Winter wheat		Spring wheat	
Time of sowing	Autumn	Spring	Spring	Spring	Autumn	Spring	Spring	Spring
Time of formalin	Autumn	Autumn	Autumn	Spring	Autumn	Autumn	Autumn	Spring
Yield tonnes/ha								
Nil	5·90	4·86	4·72	4·53	2·33	1·55	2·19	2·18
Formalin	6·25	4·17	4·81	4·93	2·66	2·03	2·31	2·38
	± 0·244 (V)*		±0·205 (HI)*		±0·126 (V)		±0·093 (HI)	
% take-all (straws in July)								
Nil	31	38	37	37	41	45	34	21
Formalin	20	34	22	24	28	31	30	24
% severe take-all								
Nil	2	4	1	5	25	18	13	14
Formalin	1	3	0	1	14	14	16	8
% plants with roots deformed by cereal cyst nematodes in May								
Nil	0	0	0	0	6	41	35	79
Formalin	0	0	0	0	11	38	46	23

* V for vertical comparison
HI for horizontal comparisons and interactions

Take-all was equally common in autumn and spring wheat but only spring wheat was severely damaged by cereal cyst nematodes. Formalin decreased nematode damage only where applied during spring, suggesting that it may be more effective the nearer the date it is applied is to the date when eggs hatch. Although formalin applied during autumn or spring decreased take-all at both sites, it increased yields significantly only at Woburn. Formalin applied at Woburn before the previous wheat crop increased the proportion of straws with severe take-all from 16 to 38% in winter wheat and from 9 to 26% in spring wheat but did not affect nematode damage or yield. At Rothamsted, formalin applied before the previous crop had no residual effect. (Salt)

Field Beans (*Vicia faba* L.)

As a crop that fits well with cereal growing but is not susceptible to the major root diseases of cereals, field beans were attractive to many farmers, especially between 1968 and 1970 when they received an acreage subsidy. However, few crops can ever have lost popularity so fast as beans in the last two years. This is not entirely because the subsidy ended or because of the unusual dependence of beans on favourable weather or to damage from their traditional enemies, *Aphis fabae* (black fly) and *Botrytis fabae* (chocolate spot) (although the latter was unusually severe locally on winter beans in 1971), but to other factors that decrease yields. Work in several departments shows that aphids, weevils and nematodes are often important together with several viruses and fungi some of which are newly recognised as common in the crop.

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Virus diseases. Until this year broad bean stain virus (BBSV) and Echtes Ackerbohnemosaik-Virus (EAMV) (syn, broad bean true mosaic virus) were not distinguished in reports of virus diseases occurring at Rothamsted. The two viruses have similar-sized isometric particles, often cause indistinguishable mottles or mosaics in field beans and can only be distinguished reliably by serology.

Transmission of BBSV and EAMV. Besides being transmissible by mechanical inoculation, both viruses can be transmitted in infected seed and by weevils. Of 400 Maris Bead seedlings from seed grown at Rothamsted in 1970, nine were infected with BBSV and four with EAMV. Although the proportion of seeds infected is usually small, there are ample to provide sources from which adult weevils can spread both viruses through crops. Weevils collected from a crop at Rothamsted in June 1971 suggest that vectors can be plentiful, for when caged for three days on healthy bean seedlings, 8% of *Apion vorax* transmitted BBSV and 10% EAMV; *Sitona lineatus* was less efficient, although more numerous, and only 1% transmitted EAMV and none BBSV. In another test, EAMV was transmitted by 53% of *A. vorax* but not by *A. aestivum*, *A. aethiops*, *A. apricans*, *A. assimile* and *A. pisi*, when caged for five days on infected beans and then three days on healthy bean seedlings.

Virus incidence. There were fewer *A. vorax* at Rothamsted than in 1970 and fewer plants showed BBSV/EAMV symptoms. From 5 to 30% of Maris Bead plants were infected in different crops by July. The aphid-transmitted viruses, bean leaf roll virus (BLRV) and pea enation mosaic virus (PEMV), ranged respectively from 17 to 40% and 3 to 14%. Elsewhere, BBSV/EAMV ranged from 2% at Broom's Barn Experimental Station, Suffolk to 90% at Bridget's Experimental Husbandry Farm, Hants. Serological tests on plants with obvious symptoms suggested that about one-third were infected with BBSV and two-thirds with EAMV.

Table 16 shows the yield and incidence of viruses in ten varieties drilled in March. Dinoseb sprayed early in May unaccountably killed some weevils, scorched many plants and probably affected yields. All varieties proved susceptible to both BBSV and EAMV, and in mid-July these viruses had infected 20–30% of plants of stocks that contained infected seed. Incidence of BLRV (9–70%) and PEMV (5–15%) varied widely. Chocolate

TABLE 16

Virus incidence and yields of different varieties of field beans

Variety	% plants with symptoms of			Yields (tonnes/ha)
	BBSV/EAMV	BLRV	PEMV	
Blue Rock	10	25	15	1·87
Franck's Ackerperle*	23	31	11	1·82
F_1 hybrid 6 × S45*	20	55	9	2·04
Herz Freya	8	70	9	1·86
Maris Bead (1)*	29	23	10	1·94
Maris Bead (2)*	22	17	7	2·07
Maris Bead (3)*	21	28	13	2·00
Maris Bead (4)*	19	26	8	2·05
Maxime	9	19	7	2·06
Minor	6	16	6	2·13
Ostlers	9	32	10	2·01
Tarvin	10	9	14	1·97
Throws MS*	20	48	5	1·90
S.E.	±3·0	±4·8	±3·0	±0·094

* Stock contained seed infected with BBSV/EAMV

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spot (*Botrytis fabae*), which was common in several varieties and severe in Franck's Ackerperle, may have decreased yields but in this experiment no variety yielded significantly more than Stock 3 of Maris Bead, which was grown at Rothamsted in 1970.

Effects of BBSV and EAMV on yield. Pods were not set by any of 255 Maris Bead plants that grew from seed infected with BBSV or EAMV. In the same crop, healthy seedlings that developed mild symptoms (mainly BBSV) before flowering yielded 68% less than plants without symptoms, and plants that developed severe mottle (mainly EAMV) yielded 76% less. In the glasshouse the proportion of seeds infected rose from 4% on beans inoculated with EAMV two weeks after they emerged to a maximum of 26% with inoculation four weeks from emergence and then decreased to 10% on plants inoculated ten weeks after emergence.

Heat therapy of BBSV/EAMV-infected seed. The main source of BBSV and EAMV seems to be infected seed, so attempts were made to free batches of seed from the viruses by immersing them in hot water (45°C for 60 minutes or 50°C for five minutes) or keeping them in air at 47°C. The hot-air treatment was the more effective and, in glasshouse and field tests with a seed stock known to contain 2–3% BBSV/EAMV-infected seeds, all seedlings that emerged from seed kept for eight days at 46–48°C were without symptoms (Table 17). Whether this was because the infected seeds were freed from the viruses or failed to germinate is not known.

TABLE 17

Effects of keeping field bean seed for different times at 46–48°C on germination, emergence and infection

Days at 46–48°C	% germination in glasshouse[1]	No. seedlings emerged in field[2]	% infected with BBSV/EAMV in field
0	93·0	872	2·44
1	89·5	892	1·09
2	80·5	972	0·34
4	82·5	774	0·17
8	83·5	485	0

[1] 200 seeds per treatment
[2] Per 27 m row, mean of three replicates

TABLE 18

Effects of insecticides on virus incidence and yield of field beans

Treatment[1]	% plants with symptoms of BBSV/EAMV	BLRV	PEMV	Yield (tonnes/ha)
untreated	17	37	10	2·84
BHC spray (0·56 kg/ha a.i.)	9	29	6	2·96
malathion spray (1·12 kg/ha a.i.)	16	22	11	3·14
menazon spray (0·28 kg/ha a.i.)	9	9	3	3·12
aldicarb in soil (1·12 kg/ha a.i.)	13	27	5	3·04
aldicarb in soil (11·2 kg/ha a.i.)	5	7	2	3·30
S.E.	±2·2	±3·2	±3·5	±0·116

[1] Soil applications were broadcast and rotavated in before drilling in early March, sprays were applied three times between late-April and late-June

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Heat treatment of a seed stock known to contain 7–10% infected seeds gave less promising results, for although no EAMV-infected seedlings emerged from three out of five batches of seed kept for eight days at 46·5–47·5°C, many BBSV-infected seedlings emerged. Heat treatment merits further investigation, but is not yet a sure way to prevent emergence of infected seedlings.

Control of virus spread by insecticides. BLRV became the commonest virus in unsprayed plots of Maris Bead although PEMV appeared earlier. Aphids were commonest during July when *Acyrthosiphon pisum* infested 36% of plants and *Aphis fabae* 13%. BBSV and EAMV showed in emerging seedlings during April, when *Sitona* spp. (mostly *S. lineatus*) were present. *A. vorax* was not found until mid-May and became commonest in early June (2/100 shoot tips compared with 6/100 during 1970).

Table 18 shows that aldicarb (11·2 kg) and menazon checked virus spread most but only aldicarb increased yield (by 16%, $P = 0{\cdot}02$). Plot yields were negatively correlated with the incidence of BBSV/EAMV ($P = 0{\cdot}05$) and with BLRV ($P = 0{\cdot}01$). (Cockbain, Cook and Vorra-urai)

Fungal diseases

Root rot. In the part of Barnfield where beans have been grown each year since 1967, *Phytophthora megasperma* Drechsl. was again associated with root rot and wilting. However, Table 19 shows that the crop was afflicted by many other pathogens including viruses, nematodes and fungi (especially *Pythium* spp.). In an attempt to apportion the damage they caused, small plots were treated with chemicals reputedly active against different groups of organisms. Formalin was used as a general biocide (soil drench in November with 3000 litres/ha of 38% solution). In February, before sowing, three chemicals were broadcast and rotavated in; a fungicide 'Dexon' reputedly especially active against members of the *Pythiaceae* (78 kg/ha a.i.): a nematicide, aldicarb (11 kg/ha a.i.) and an insecticide BHC (4·5 kg/ha a.i.).

TABLE 19

Effect of chemicals on yield and pests and diseases of field beans

Treatment	Virus infected plants (%)[1]	*Ditylenchus dipsaci* (% plants infested)	Disease rating %[2]	Per cent roots infected by		Yield T/ha
				P. megasperma	*Pythium* spp.	
nil	20	73	74	27	20	1·08
'Dexon'	12	69	57	0	37	1·96
aldicarb	6	25	47	17	3	2·42
BHC	13	68	59	20	20	1·51
formalin	11	69	66	20	20	1·23
aldicarb + formalin	8	23	49		—	1·88 ±0·109

[1] Mainly BLRV but also PEMV, BB V and EAMV
[2] A weighted assessment, '0' indicating that all roots were healthy and '100' that all roots were black and most laterals had rotted and broken off. For details of method see research paper number 7.38, p. 346

Aldicarb had the greatest effect on the health of roots and yield, not only giving fewer plants with *Ditylenchus dipsaci* but also fewer infected with viruses and *Phythium* spp. (Table 19). 'Dexon' increased yield and eliminated *P. megasperma* but, unexpectedly, almost doubled the incidence of *Pythium*. BHC increased yield but apparently not by controlling infections with any of the pathogens listed. Although the best yield was more than double that from untreated plots, none of the treatments produced healthy roots or convincingly apportioned damage between various possible causes. (Salt and Hornby)

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Potato diseases

Development and infection of tuber lenticels. The skin of potato tubers at first bears stomata, which later change into lenticels, a process that is usually complete on the third internode behind the tuber apex. Varieties susceptible to common scab (*Streptomyces scabies*) can be infected through stomata but not through lenticels, although the exact anatomical stage at which lenticels become resistant is not known. However, it is improbable that varietal resistance depends on the speed lenticels form because they form slower on Pentland Crown than on the more susceptible Majestic tubers.

In wet soil lenticels proliferate parenchymatous cells, especially on immature tubers, and become very permeable to dye solutions. In dry soil, older tubers deposit suberin in the walls of cells packing the lenticel and may form cork barriers underneath, two processes that impede penetration. Tests in the laboratory showed that *Erwinia carotovora* var. *atroseptica* readily infects proliferated lenticels but not those of mature dry tubers. Lenticel-structure seems to be the most important factor determining tuber susceptibility and differences in the readiness with which lenticels proliferate during growth may explain varietal differences in susceptibility to invasion by bacteria and by *Phytophthora infestans*. (Adams)

Bacterial soft rots. Experiments testing the invasion of stems and tubers by varieties of *Erwinia carotovora* were repeated (*Rothamsted Report for 1970*, Part 1, 137). Rots caused by stab-inoculating seed tubers with *E.c.* var. *carotovora* soon stopped growing and did not cause rotting faster than in stabbed but uninoculated controls. Stab-inoculating with *E.c.* var. *atroseptica* hastened rotting, so that much occurred between late-May and late-June, whereas few dipped tubers rotted until after rain in mid-June, although most had by mid-July. Majestic tubers rotted sooner than Pentland Crown.

In 1970 few tubers whether or not they were inoculated with *E.c.* var. *carotovora*, rotted before late-August, but this year some tubers had rotted by 29 June and by early-August most of them had shown a rapidly spreading watery brown rot, from which *Phytophthora erythroseptica* was easily isolated. After 98 mm of rain fell the rots developed fast during a subsequent warm dry spell early in August, when 75% of plants showed symptoms similar to the wilt associated with pink rot. In September all plants had some stems wilted and about a quarter had some tubers with pink rot, but the proportion of tubers affected was only about 2% on Majestic and 5% on Pentland Crown.

During the heavy June rain *E.c.* var. *atroseptica* obviously spread widely for it was easily cultured from rain-water standing in the furrows and must have reached many of the forming tubers. However, only nine Majestic and 20 Pentland Crown tubers (each out of 120) harvested at mid-September could be induced to rot and only two and three yielded *E.c.* var. *atroseptica*. Although this bacterium may not have infected many progeny tubers, the plots planted with inoculated seed tubers yielded only 7 tons/acre compared to 14 tons/acre from seed uninoculated or inoculated with *E.c.* var. *carotovora*. In another experiment, stab-inoculating the rose end of seed tubers with *E.c.* var. *atroseptica* at planting confirmed that this caused black leg symptoms to appear sooner than by inoculating the middle or heel end of tubers, and that symptoms developed sooner in Majestic than Pentland Crown. A partial explanation for fewer Pentland Crown than Majestic plants showing symptoms may be that the bacterium in Majestic is limited to visibly affected tissues whereas in Pentland Crown it can occur several centimetres beyond the limit of vascular browning. (Lapwood and Whitehead)

Irrigation practice for scab control. When soils are dry at the time potato tubers are being initiated, irrigation can prevent common scab (*Streptomyces scabies*) and it can

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also increase yield of maincrop varieties when soil is dry later in the season. The last in a series of experiments to test the effects of irrigation at different times on scab and yield was made with four maincrop varieties at Gleadthorpe Experimental Husbandry Farm, near Mansfield, Nottinghamshire. Table 20 shows the yield and scab infection of potatoes from plots that were unirrigated (Regime F), irrigated only to increase yield (E) or to do this and decrease scab (ABCD).

TABLE 20

Effects of irrigation on scab and yield of potatoes; Gleadthorpe E.H.F., 1971

Irrigation regimes[1]		A	B	C	D	E	F
Irrigations (number)		5	4	3	3	2	0
		Mean % tuber surface scabbed					
Variety							
King Edward		2·0	3·3	4·5	6·6	5·7	31·4
Majestic		3·5	5·8	5·4	8·5	10·4	29·9
Record		0·6	0·4	1·0	2·3	1·0	5·7
Pentland Crown		0·05	0·06	0·06	0·1	0·2	1·4
		Ware yields (1½ to 3¼ in.) tons/acre and % 'clean'[2] tubers ( )					
King Edward	wt	21·9	20·8	22·6	20·8	22·0	19·4
	%	(83)	(69)	(53)	(43)	(49)	(3)
Majestic	wt	22·1	23·0	21·1	22·2	19·9	20·3
	%	(56)	(42)	(38)	(27)	(19)	(4)
Record	wt	23·4	22·9	22·6	22·6	23·2	20·9
	%	(98)	(95)	(90)	(78)	(92)	(57)
Pentland Crown	wt	25·3	27·6	25·4	25·9	25·4	24·9
	%	(100)	(100)	(100)	(98)	(99)	(86)
S.E. between irrigation regimes		(a) scab ± 1·41			(b) yield ± 0·75		
S.E. between varieties		(a) scab ± 1·16			(b) yield ± 0·74		

[1] A 0·6 in. (15 mm) soil moisture deficit before irrigation allowed for six weeks after tuber initiation of KE and then 1·5 in. (38 mm) deficit
B 0·6 in. (15 mm) deficit for four weeks and then 1·5 in. deficit
C 0·9 in. (23 mm) deficit for four weeks and then 1·5 in. deficit
D 1·2 in. (30 mm) deficit for four weeks and then 1·5 in. deficit
E Irrigation when 1·5 in. (38 mm) deficit
F No irrigation to supplement rain

[2] 'Clean' includes tubers without scab and with, at most, one or two lesions, figures in brackets.

Irrigation began on 4 June when stolons on King Edward plants began swelling to form tubers but rain made further irrigation unnecessary until 25 June. By 21 July soil moisture deficit (SMD) had reached 3·6 in. (91 mm) in unirrigated plots but soon afterwards rain made further irrigation unnecessary. All irrigations decreased scab, and the largest effects were on the susceptible varieties Majestic and King Edward. Differences between the mean per cent tuber surface scabbed with irrigation regimes A to E were smaller than previously because June was wet, but the proportion of tubers sufficiently free from scab to pass the Potato Marketing Board standard for prepacks (Table Grade) differed greatly (bracketed figures in Table 20). For example, 83% (18·2 tons/acre) of King Edward ware tubers from regime A were acceptable but only 49% from regime E and 3% from F. Tolerances for even the PMB 'Standard Grade' would have led to the rejection of tubers from regime E (with 28% of tubers having > 10% area scabbed) and F (91%).

Results from the three experiments show that common scab can be prevented by carefully timed irrigation even on very susceptible varieties in unusually dry summers and on the 'sandlands' at Gleadthorpe. Farmers irrigating potatoes merely to increase yield aim to prevent soil moisture deficits exceeding 1·0–1·5 in. (25–38 mm) after the tubers reach 'marble' size (approximately 13 mm dia). To prevent scab infection, soil

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moisture deficits must be kept smaller than 0·5–0·75 in. (13–19 mm) for at least four weeks after tubers begin to form. In exceptionally dry weather this might mean irrigating five times at five-day intervals, but with susceptible varieties the reward in yield and quality can be large and with some rain, commercially acceptable standards of tubers are obtained with from one to three early irrigations. The results gave no evidence to support the view that irrigating early increases significantly the number of tubers formed by King Edward plants. (Lapwood with Mr. L. W. Wellings, Experimental Husbandry Farm, Gleadthorpe)

Maintaining health of seed tubers. Producing healthy tubers for elite seed stocks from rooted stem cuttings needs to be followed by other treatments to maintain health while the stock is being multiplied. At Dunning, Perthshire, tubers in the second and third years of multiplication remained healthy when treated after lifting with organo-mercury fungicides, as also did fourth and fifth year stocks treated with benomyl (0·09 kg a.i./tonne of tubers). Plants in small areas of crops in their fourth and fifth year of multiplication, from seed tubers untreated for one or two years, became severely infected with *Oospora* and *Helminthosporium*, showing that fungicide treatment is needed regularly especially when stocks become large and are handled mechanically. (Hide and Hirst)

At High Mowthorpe Experimental Husbandry Farm, benomyl (0·23 kg/tonne of tubers) was applied to seed tubers grown from English and Scottish seed that was either treated with fungicide or untreated in 1970, to see whether repeated annual treatment can keep seed healthy. Tuber infections were many fewer with the fungicide, which increased total yield by 0·5 ton/acre and seed ($1\frac{1}{4}$–$2\frac{1}{4}$ in.) yield by 1·5 tons/acre (Table 21). The largest benefit from using fungicide was with Majestic (total yield increased by 1·4 tons/acre, seed by 2·2 tons/acre), probably because seed untreated for two years had much *Oospora* infection and much of the produce was ware-sized. Healthy plants tend to produce more small tubers than infected ones, which is particularly beneficial to seed producers. (Hide, Hirst, Bell and Mr. B. Evans, High Mowthorpe E.H.F.)

Effects of health and disease on yield. Since 1969 field experiments at Rothamsted and Woburn have compared the yields and diseases of produce from 'commercial' seed tuber

TABLE 21

Effect of benomyl on yield and disease incidence: High Mowthorpe, 1971

		Majestic		Pentland Crown		Record		
		Untreated	benomyl	Untreated	benomyl	Untreated	benomyl	S.E.
Total yield (tons/acre)	E*	14·60	15·18	18·07	18·75	16·16	16·27	±0·750
	S	15·68	17·94	18·00	18·14	15·93	16·21	
Seed yield ($1\frac{1}{4}$-$2\frac{1}{4}$ in.) (tons/acre)	E	7·97	9·43	11·77	12·71	11·77	13·13	±0·590
	S	7·51	10·47	13·63	14·11	12·41	13·34	
Tuber infection (% eyes)								
Oospora	E	49·5	4·5	11·9	0·8	30·1	0·9	±2·13
	S	13·7	1·5	7·5	1·6	7·9	1·3	
Rhizoctonia	E	19·8	13·9	7·7	0·7	16·9	0·4	±4·25
	S	20·6	2·4	17·5	1·4	4·0	6·9	
Helminthosporium	E	32·9	0·3	58·0	0·3	64·3	1·7	±5·55
	S	35·4	0·3	47·5	0·3	37·8	0·3	

* E = English seed
S = Scottish seed, recently multiplied from stem-cuttings

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stocks (usually once-grown at Rothamsted from high grade certified seed) and 'healthier' seed, recently multiplied in Perthshire from the produce of rooted stem-cuttings. Table 22 shows yields of tubers (over $1\frac{3}{4}$ in.) from such experiments done this year, it also includes additional treatments that were intended to measure the effects of dusting tubers with benomyl (0·23 kg a.i./tonne of tubers); of inoculating 'healthier' tubers with *Oospora pustulans*, *Rhizoctonia solani*, or both, and the effects of chitting. Chitted and unchitted seed tubers were compared, not only because both types are still planted but also to try to apportion the benefits of chitting between effects on the physiology and the pathology of tubers.

In these and other experiments chitting consistently increased yield more than any other treatment, but the reason for the benefits often being larger at Woburn than at Rothamsted is unknown, for the seed stocks were similar and stored together. Chitting also usually increased the yield of 'healthier' seed (often by more than 20%) more than that of 'commercial' seed (approx. 15% increase). This may indicate that diseases do contribute to the effects of chitting although perhaps not as might have been expected. Unfortunately our storage facilities and the delay in delivering seed from Scotland, prevented our early-season inoculations from reproducing the damage to buds and sprouts caused by natural infections. Inoculated tubers therefore usually experienced only post-planting effects such as making tubers fewer by infecting stolons. This rarely decreased yields of ware-sized tubers ($>1\frac{3}{4}$ in.) and often increased it slightly. Otherwise untreated 'healthier' tubers produced an average of 6% more ware tubers than similarly chitted 'commercial' seed tubers. Benomyl usually had little effect on yields, especially from unchitted tubers but it consistently decreased incidence of *O. pustulans* and *Helminthosporium solani*.

TABLE 22

Comparison of yield of saleable tubers (tons/acre, $>1\frac{3}{4}$ inch) from commercial and 'healthier' seed; Rothamsted and Woburn, 1971

	Rothamsted					Woburn			
	K.E.[1] (±0·58)	Mj. (±0·58)	P.C. (±0·58)	Rec. (±0·58)	Mean (±0·32)	Mj. (±0·98)	P.C. (±0·98)	Rec. (±0·98)	Mean (±0·57)
Commercial seed									
Unchitted	13·8	16·6	15·9	10·6	14·2	14·3	13·6	7·1	11·7
Unchitted + benomyl[2]	11·3	16·0	14·5	10·8	13·2	11·8	13·0	9·3	11·4
Chitted	17·0	17·9	17·8	12·3	16·2	16·6	13·9	9·3	13·3
Chitted + benomyl	16·0	20·0	18·1	13·3	16·9	15·9	18·1	8·9	14·3
Healthier seed									
Unchitted	14·5	17·4	13·5	13·1	14·6	12·7	10·9	7·0	10·2
Chitted	17·8	18·9	18·5	13·8	17·3	18·2	17·3	10·2	15·2
Chitted + benomyl	17·3	21·1	18·3	14·3	17·8	18·0	17·7	10·8	15·5
Chitted + Oospora E[3]	17·2	19·7	18·3	14·7	17·5	17·1	14·9	10·0	14·0
Chitted + Oospora L	17·8	19·6	19·3	14·0	17·6	18·3	15·3	10·4	14·7
Chitted + Rhizoctonia L	17·8	19·3	19·3	14·3	17·7	17·0	12·2	10·2	13·1
Chitted + Oospora L and Rhizoctonia L	18·5	20·6	17·8	13·9	17·7	16·5	11·9	9·2	12·5
Mean	16·4	19·0 ±0·16	17·5	13·3		16·2	14·7 ±0·51	9·4	

Varieties:
[1] K.E. King Edward, Mj. Majestic, P.C. Pentland Crown, Rec. Record
[2] benomyl diluted in Kaolin and dusted on tubers at 0·5 lb a.i./ton
[3] Oospora E = early inoculation with spore suspension in January
Oospora L and Rhizoctonia L = late inoculation, *O. pustulans* or *R. solani* grown on vermiculite and sprinkled along furrow at planting

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Effects on *Phoma exigua* var. *foveata* and *R. solani* were erratic but those on *Rhizoctonia* seemed to agree with the supposition that the fungicide prevents infection from fungus on seed tubers but not from that surviving in soil, which is thought to be commoner at Woburn than Rothamsted. Such differences do not explain why inoculating seed tubers in furrows at planting often slightly increased yield at Rothamsted but usually decreased it at Woburn, where *R. solani* often became commoner than at Rothamsted.

Table 22 shows that the largest differences in yield were with the variety Pentland Crown, which usually produces few tubers and so may suffer severely from damage to stems or stolons. King Edward produces many more tubers, especially when healthy, so although the modal riddle grade changes from $2\frac{1}{4}$–$2\frac{3}{4}$ in. to $1\frac{3}{4}$–$2\frac{1}{4}$ in., tubers of this and other varieties have a more uniform tuber size distribution. Although increases in yield attributable to health were seldom large, they are expected to be followed by less loss in store, an aspect now being investigated. (Hide, Hirst, Bell, Griffith and Stedman)

The agronomic effects of healthier seed potatoes. Healthy plants produce more small tubers than plants infected with some tuber-borne fungi, but this seldom decreases ware yield because total yield is increased. However, it is undesirable to increase harvested chats or the number of tubers that are not harvested and may become ground keepers. Hence, last year we started to see how tuber size of the harvested crop would be affected by planting seed of different size at different spacings; large seed at conventional spacing (16 in. apart in 28 in. rows) produced most ware tubers. This year we compared large (average 3·8 oz) and small (average 2·1 oz) seed tubers of King Edward dusted with benomyl (0·5 lb a.i./ton) planted with 12 or 20 cwt/acre of compound fertiliser (13 : 13 : 20) at the spacings shown in Table 23. Total yields were increased by 20 cwt of fertiliser

TABLE 23

Effects of seed size, spacing and fertiliser on saleable yield (tons/acre > $1\frac{3}{4}$ inch) and stem populations

	Large seed Row width		Small seed Row width		
	28 inch	36 inch	28 inch	36 inch	mean (±0·316)
12 cwt fertiliser					
12 in.	13·33	13·00	12·06	13·15	12·88
16 in.	13·21	14·18	13·45	13·53	13·59
20 in.	14·30	13·82	12·93	13·50	13·64
24 in.	13·61	14·44	15·32	14·57	14·98
				mean (13·77)	
20 cwt fertiliser					
12 in.	14·36	15·48	14·65	14·02	14·63
16 in.	15·36	15·10	13·92	13·92	14·57
20 in.	16·05	15·08	15·34	13·90	15·09
24 in.	17·71	16·23	14·61	15·00	15·89
				mean (15·05)	
mean (±0·458)	14·99	14·67	14·04	13·95	
mean (±0·324)	14·83		13·99		

Stem populations (mean of fertiliser treatments). ('000/acre)

					mean
12 in.	101·6	79·2	88·1	67·7	84·2
16 in.	81·8	63·0	71·3	50·9	66·7
20 in.	66·7	51·9	58·0	42·3	54·7
24 in.	53·8	42·7	49·3	34·7	45·1

Theoretical plant populations ('000/acre)

Spacing with rows (in.)	12	16	20	24
28 in. rows	18·6	14·0	11·2	9·5
36 in. rows	14·5	10·9	8·7	7·4

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and large seed and decreased by wide spacing within and between rows. By contrast, saleable yields (> 1¾ in., Table 23) were increased by wider spacing along rows but not between them. Large seed 24 in. apart in 28 in. rows with 20 cwt/acre of fertiliser gave the greatest saleable yield. Yield of chats was not influenced by seed size or fertiliser, but was decreased by wider spacings, at which yield from fungicide-treated seed was not always positively correlated with stem-number. Total yields from 36 in. rows were consistently smaller (mean 19·1 tons/acre) than from 28 in. rows (mean 21·0 tons/acre); however, with fewer than 14 000 plants or 70 000 stems/acre saleable yields were similar from both row widths, so for convenience and cheapness of farming operations the wider rows might well be preferable.

In another experiment, benomyl decreased total yield when applied to chitted seed planted on plots that were irrigated (when S.M.D. reached 1 in. in July) but not on non-irrigated plots. By contrast, benomyl increased the yield from unchitted seed, especially when irrigated. Both the fungicide and 20 cwt/acre fertiliser delayed the formation of tubers but eventually increased the total and the number of ware-size. Irrigation did not affect tuber numbers. (Hide, Hirst and Bell with Widdowson, Chemistry Department and Moffatt, farm)

Relationships between diseases of seed, plants and stored tubers. Until recently diseases of the growing potato crop and of the tubers during storage were studied by different research organisations. This division 'at the farm gate' hindered recognition that diseases perennate very differently on different seed stocks and meant that conditions within stores received much more attention than the health of potatoes used to fill the stores. After preliminary work during 1971, we expanded studies on the seed tubers, growing plants and crops destined to fill stores at the Potato Marketing Board Experimental Station at Sutton Bridge, Lincs. We hoped to relate disease in store to earlier assessments, so that crops likely to be troublesome could be identified and their use managed to lessen losses. Disease incidence may often change as crops mature or the weather changes, so we would wish to make some tests as late as possible but they would then need to produce results very quickly to be of value in deciding how to handle the lifted crop. Incomplete results from the first season show some correlations between diseases in crops and on tubers going into store and they also suggest improvements to the timing of disease counts and of the tests made to assess the potential of tubers to rot. Observations during storage should also help evaluate the benefit from keeping crops free from tuber-borne fungi. (Hide, Griffith, Lapwood and Whitehead).

Control of potato cyst nematode and *Verticillium* wilt. Experiments were continued on Broadmead field, Woburn (Table 24) where chemicals were applied to plots in 1969, 1970 and 1971. On plots treated in 1969, benefits from methyl bromide and aldicarb

TABLE 24

Effects of pesticides on potato yields, 1971 (tons/acre)

	Site 1		Site 2	Site 3
Treatment year	1969	1971	1970	1971
untreated	2·37	—	1·39	8·57
benomyl	—	—	7·32	13·97
aldicarb	3·50	—	4·11	13·45
benomyl and aldicarb	—	—	—	14·34
dazomet	—	—	—	14·45
methyl bromide	2·47	15·19	6·07	17·49
	±0·593		±0·600	±0·616

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had disappeared, but reapplying methyl bromide again gave acceptable yields. On an adjoining area treated in 1970, all materials increased yield in 1971, benomyl more than it did in 1970. On a third area that last grew potatoes in 1965, benomyl and aldicarb were applied separately or together and compared with methyl bromide and dazomet. Foliage symptoms were least where benomyl and aldicarb were applied together, but yields were no different from applying either separately, suggesting that the combined materials restricted yield. Plots treated with methyl bromide yielded most. (Hide with Corbett, Nematology Department)

Survey of diseases of seed tubers. Blight was scarce (0·75% of King Edward tubers blighted, Table 25) and fewer tubers had gangrene than in recent years. Powdery scab was unusually common with more than a quarter of King Edward tubers affected, but the most noteworthy change was in Pentland Crown (8% infected compared to 0·8 and 2·5% in the two previous years). This increase confirms reports from advisers and growers that a proportion of Pentland Crown stocks suffered much with unusually severe canker type infection. The survey included two such stocks with 25% P.C. tubers severely attacked. (Hide, Griffith and Bell)

TABLE 25

Survey of fungal diseases of seed tubers 1970–71 (% tubers infected / % stocks with infected tubers)

Examined	Disease	King Edward	Majestic	Pentland Crown
R	Skinspot (*Oospora pustulans*)	37/90	34/91	28/86
P	Gangrene (*Phoma* spp.)	6/53	4/64	11/72
P	Dry rot (*Fusarium caeruleum*)	1/24	5/59	5/59
R	Blight (*Phytophthora infestans*)	1/20	<1/9	<1/7
R	Black scurf (*Rhizoctonia solani*)	23/94	22/97	29/100
R	Powdery scab (*Spongospora subterranea*)	26/94	20/93	8/69
R	Common scab (*Streptomyces scabies*)	22/96	44/98	17/93
Number of stocks examined		49	44	29

R = at recept; P = at planting

Fungi on potato roots in the Woburn Ley–Arable experiment. Since 1967 our reports have mentioned small yields of potatoes on the continuous arable series of the Woburn Ley–Arable experiment, the great increases sometimes obtained by treating the soil with chloropicrin or aldicarb, and difficulties in explaining the increases.

Populations of potato cyst nematode had previously dwindled after changes in the crop rotation and planting with the resistant variety Maris Piper and differences in yield could not be attributed to effects of chemicals on root fungi. Elsewhere in this report (p. 175) the Nematology Department show that chemicals or their residues were associated with large differences in numbers of migratory ectoparasitic nematodes and *Longidorus* spp. below plough depth. In assessing these effects it is important to know the incidence of root fungi.

In July, *O. pustulans* macroscopically infected an average of 60% of underground parts of Maris Piper plants, *R. solani* 16% and *Colletotrichum coccodes* only 1% and no differences were attributable to chloropicrin or aldicarb. Although *Verticillium dahliae* is common and damaging on other fields at Woburn it was not found in haulm or underground stem bases in July and only occasionally in dead haulm in September. On fine roots, microscopic infections of *C. coccodes* were little affected by the chemicals but fragments infected by *R. solani* were increased from 13 to 25%. Cropping sequences had larger effects than chemicals, thus after a three-year ley (L) *C. coccodes* occurred on

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5% and *R. solani* on 60% of root pieces but after continuous arable cropping, respectively on the A and Ah series, *C. coccodes* occurred on 40% and 56% and *R. solani* on only 9 and 6% root pieces. Species of *Pythium* and *Fusarium* occurred infrequently and in cleared and stained roots *Endogone* spp. were rare and chytrids absent, in striking contrast to their frequence on cereal roots. (Salt)

Incidence of virus diseases at Rothamsted. The potato experiments planted with home grown seed contained few plants with leaf roll (0–0·1%) or potato virus Y (0·1–0·3%) when examined at the end of June. Although only a few *Myzus persicae* and other potato aphids were caught in the 40 ft suction trap at Rothamsted tower, potato virus Y spread during the season and, by the end of July, the King Edward on Whittlocks contained 2·5% plants showing leaf drop streak (current year infection with potato virus Y). The King Edward crop on Drapers, grown to provide seed for the 1972 experiments had only 0·03%. This crop had been free from potato virus Y when inspected at the end of June and good isolation had prevented much infection being brought in by aphids coming from outside the crop. (Govier)

Spore dispersal

Deposition on wheat ears. When fluorescein-labelled dry Lycopodium spores were liberated level with the ears of mature wheat, the ears caught more than equal areas of leaf or stem. This might be because spores were more concentrated at ear level or because the complex structure of ears made them trap spores more efficiently. Deposition of polyethylene spheres (15–40μm dia) on the 'wide' or 'narrow' faces of ears held in a wind tunnel, perpendicular to winds ranging from 1·0 to 6·0 m/s was compared to deposition on wooden slats of similar dimensions, while 'area dose' was measured with a Cascade Impactor. Deposited particles were removed by washing in 1% salt solution and counted with a Coulter Counter. The two faces of wheat ears did not differ but both consistently caught more particles than the wooden replicas. On all surfaces, efficiency was greatest between 2 and 4 m/s, less at 1 m/s, perhaps because of less impaction, and least at 6 m/s, perhaps because some particles were blown off. Although the complex surfaces of ears caught spores more efficiently than simple surfaces, the differences we found in crops probably depended more on variations in spore concentration with height than in efficiency. (Stedman and Hirst).

Measurement of rainfall patterns in crops. Methods to measure rainfall within crops were tested for use in later studies of spore dispersal by rain. The catch of gutters (4 cm wide and 81 cm long) of various cross sections was compared to that of a recording rain gauge having the same catchment area. In open situations gutters caught up to a fifth more water than the rain guage when parallel to the wind direction but differed little when oriented across wind. Steep-sided gutters (base angle 20°) caught up to 8% more water than gutters of semicircular or right angle cross section perhaps because they lost less through splash and drain more effectively to the recorder. However at *c.* 12 cm, approx. $\frac{1}{8}$ crop height, in mature wheat there was no difference between gutter shapes, although all caught only about a third of the rain falling on the crop. (Waller)

Biodeterioration

Deterioration of stored crops by fungi and actinomycetes can have many undesirable effects; loss of nutritive value; the production of metabolites toxic to people or stock or production of spores that when inhaled may cause allergies or infections.

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Feeding experiments with mouldy hay. Sheep that had been fed hay made at different water contents (*Rothamsted Report for 1970*, Part 1, 143) grazed pasture during the summer and their content of antibodies decreased. During winter they were again fed comparable batches of hay but no important changes were detected in body temperature, blood enzymes, total white blood cells or differential white cell counts. No symptoms attributable to mouldy hay developed during the second feeding period, except loss of weight resulting from its poor nutritive value. Antibodies to *Micropolyspora faeni* and *Aspergillus fumigatus* again increased. Post-mortem samples contained up to 2500 *Thermoactinomyces vulgaris* propagules/g of fresh lung tissue and there were lesions in the lungs of some sheep although their cause is not yet determined. (Lacey, with Mr. G. A. Embleton, A.R.C. Institute of Animal Physiology, Babraham, and Professor J. Pepys and Miss V. Holford-Strevens, Institute of Diseases of the Chest, London, S.W.3)

Dust hazards during harvesting. Farm workers are often exposed to much dust while baling hay and combining grain. Table 26 shows spore concentration in dust clouds close downwind of machines (measured with the cascade impactor) and experienced by the driver (measured with a Casella Personal Sampler). During baling, yeasts accounted for 43% of 'spores', actinomycetes and bacteria for 29% and *Cladosporium* spp. for 24%. The yeasts were seen mainly as groups of vegetative cells, and *Sporobolomyces* spp. were the most abundant type of colony on Andersen sampler plates. This contrasts with the usual release of ballistospores of *Sporobolomyces* spp. at night and during wet weather. When combining grain, *Cladosporium* spp. were most abundant (53% of the total) with *Alternaria* spp. (19%), actinomycetes and bacteria (16%) and rust uredospores and *Ustilago* spp. (2% each). Many of these spores are known to be allergenic but we do not know the results of sensitivity tests on farm workers.

TABLE 26

Spore concentration (10^6 *spores*/m^3) *during combining and baling*

	Cascade impactor carried behind machine		Personal sampler on driver	
	Range	Mean	Range	Mean
Baling hay	6·4–89·7	31·4	0·1–14·8	3·5
Combining grain	12·6–110·5	57·2	0·6–34·0	18·7

Table 26 also suggests that tractor drivers towing pickup balers were exposed to only one-ninth of the spore concentration close to the machine, whereas combine-harvester drivers are exposed to a sixth of the larger concentration emitted from their machines. The combine-harvester driver is seated between two sources of dust, whereas the tractor driver is well in front of the baler and affected only when driving downwind. (Lacey and Bell with Dr. C. S. Darke, Sheffield Royal Infirmary)

Staff and visiting workers

A. J. Cockbain transferred from the Entomology Department. The following were appointed: A. Bainbridge, Mari James, Vivienne Pearson, C. J. Rawlinson, M. J. Tisdale, R. F. White and Philippa R. Whitehead. Those who left were Myra C. Chou, A. J. Gibbs, D. A. Vince and J. M. Waller.

Visiting workers included Mr. S. Chareonridhi (Thailand), Dr. D. Frey (Sydney, N.S.W.), Dr. S. Nilsson (Stockholm University), Dr. A. Rao (Madras, India), and Mr. S. Vorra-urai (Thailand); J. M. Bell and R. A. Irwin each spent six months in the

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department as part of 'sandwich courses'. M. J. Adams continued his Potato Marketing Board scholarship and P. H. Gregory continued working at the invitation of the Lawes Trust Committee.

During April J. M. Hirst visited Indian universities of agricultural science on behalf of UNESCO and in late-summer, together with D. Hornby and D. H. Lapwood, took part in an Advanced Study Institute on Epidemiology of Plant Diseases at Wageningen, The Netherlands. J. Lacey who attended the 2nd International Biodeterioration Symposium in The Netherlands and the 4th Davos Medical Symposium on Aspergillosis and Farmer's Lung also visited laboratories in Zurich, Giessen, Marburg and Baarn. At the request of the Overseas Development Administration, J. M. Waller visited Brazil to advise on control of coffee rust. B. Kassanis and R. H. Kenten attended the Second International Congress for Virology in Budapest.

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