ROTHAMSTED RESEARCH

Report for 1973 - Part1

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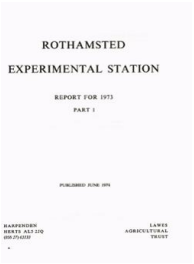

Plant Pathology Department

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PLANT PATHOLOGY DEPARTMENT

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Summary

Record or near-record yields, coupled with high prices, brought satisfaction to many arable farmers. To plant pathologists 1973 was much less a 'vintage' year for their diseases. The wet spells that studded a predominantly dry summer were insufficient to encourage the most moisture-dependent pathogens, but the early lodging of many crops encouraged the production of some mycotoxins (p. 121) as well as limiting some yields.

Within the laboratories we appreciated the convenient and efficient new quarters for the electron microscopes and related equipment, and the better facilities for examining samples from potato experiments. However, it will obviously be some time before the associated potato stores, the new wind tunnel and the vacated rooms are completed or effective.

Viruses and virus diseases. Mycologists would not find it easy to match the success achieved in controlling several of the major virus diseases of arable crops during the last 30 years. Thus, wartime scourges such as sugar-beet yellows and the aphid-transmitted potato viruses (p. 148) are no longer causes of serious loss. Epidemiologists may claim that this is because lack of direct means of controlling viruses enforced reliance on sound, and successful, programmes for eliminating or avoiding either the infection reservoirs or the vectors that make them active. As a result we are able to turn increasing attention to virus diseases of other crops or countries (p. 118). Two seed- and weevil-transmitted viruses of field beans (*Vicia faba* L.) are important recent examples (p. 139). The distribution and efficacy of their vectors is being revealed, as is the importance of infection at or before flowering both to seed infection and decreased yields. Even when weevils were as common as during 1973, the amount of seed infection determined the amount of crop infection, suggesting that the vectors were either too sedentary or still too few (p. 139) to spread much virus far. Because heat therapy, roguing and insecticide treatment seem impractical or difficult, this may be another crop for which we may need to seek areas without vectors where seed crops can be grown. Such attractively simple solutions may not be feasible for other crops and diseases. For example, cereal crops probably receive barley yellow dwarf virus (p. 124) not only from infected volunteer cereals or earlier sowings but also from a reservoir of infected grasses. Fortunately, unless sown imprudently early in autumn (p. 125) cereals are at serious risk only from spring infection, so insecticide treatment against vectors is often valuable. A different strategy may be required to control virus diseases of grasses and herbage legumes which are ubiquitous and mostly perennial; so methods used to avoid infection sources and spread of viruses of arable crops are unlikely to be effective.

Furthermore, pastures are so frequently grazed by dairy herds that it will be difficult to use sufficiently persistent chemicals to control vectors without endangering milk supplies with potentially toxic residues (p. 138). Methods better suited to such situations will only be developed by learning about the viruses (p. 136), their characteristics, vectors (p. 136) and effects (p. 136). In a plastic film house ventilated with filtered air, we succeeded in excluding the mite vectors of ryegrass mosaic virus and so hope to measure

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differences in the yield of healthy and diseased plots over several years, and the extent to which grass-cutting machines transmit the virus mechanically (p. 136).

Damaging pathogens do not always spread among crops; we need to know why, lest changes in agriculture remove the present limitations. In the glasshouse the seed-transmitted bean viruses are very damaging to peas but have not yet been recorded among pea crops. Perhaps, the feeding preferences or scarcity of vectors may explain this and perhaps the scarcity of two other diseases of uncertain cause, oat sterile dwarf (p. 137) and European wheat striate mosaic, or a virus recently recognised in meadow fescue that seriously damages oats (p. 137). Quite opposite difficulties confront the work on viruses of fungi (p. 118), many of which, although prevalent, have not been transmitted other than by hyphal anastomosis and which usually seem harmless to their hosts. Indeed the difficulty of recognising, isolating and culturing any lethal virus from an organ so inconspicuous as a moribund fungal hypha must make their detection improbable with current methods.

Successful control of virus diseases by limiting their spread and sources of infection does not remove the need to find ways to counteract viruses directly. Any properties that might be employed must therefore be investigated carefully; two remote possibilities were suggested by features of viruses studied during 1973. The first is the possibility of artificially simulating the resistance mechanism whereby one virus may protect a host plant against infection by a second (p. 117). The second arises from the discovery that aphid transmission of potato virus Y group viruses depends on a virus-coded component of plant sap (p. 117). Should either promise development of a prophylactic treatment we may be able to test it more quickly and quantitatively by our developing skill in infecting naked plant protoplasts with viruses (p. 116).

Fungus and other diseases. Mycological plant pathologists have a superfluity of problems, much more complicated by difficulties of the soil, plant nutrition, changing weather or competing micro-organisms than those the virologists are currently studying. Furthermore, fungal diseases especially those of foliage have progressed much further among the doubtful blessings of technology, into problems of specialised races and fungicide tolerance. Difficulties of eradicating these pathogens imply the need to show how to live with them by adapting farming systems.

Although we began studying the pathological consequences of direct drilling more than ten years ago, difficulties with machinery and herbicides then limited the success of the experiments and the interest of farmers. However, the area of crops sown without ploughing has increased greatly in recent years and research institutes are combining their special skills on a new series of experiments (p. 135) that become ever more topical as the possible consequences of energy shortages are more widely recognised. Less cultivation implies less soil mixing and changed distributions of plant nutrients with depth in the soil. Shortage or excess of nutrients influences root diseases and our ability to diagnose their symptoms (p. 131, and 134) so we have begun to study how much inoculum is formed at different depths and redistributed by various cultivations. However, we expect trash-borne diseases to be affected more quickly by reduced cultivations than either root diseases or, if herbicides are effective, obligate pathogens of foliage (p. 135). Different crop sequences (p. 131) and cultivations will add still other factors to the complexities of take-all and other root diseases (p. 135).

Two kinds of partial inhibition of take-all have been transferred, one with large fragments of plant debris (p. 129) and another temporary inhibition (p. 130) associated more with material that passes a 150 μm sieve. Difficulties have arisen in interpreting experiments aimed to accelerate the development of take-all decline by growing sequences of cereal crops (p. 129).

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Few tasks in plant pathology are more necessary or more difficult than attempting to measure the effects of pathogens. The search for better understanding and methods is one which will occupy an increasing amount of our effort in almost all phases of our field work (p. 122). The special methods being tested with ryegrass mosaic virus (p. 136) will be extended to other virus and fungal disease pathogens. Studies of effects of root pathogens on nutrient uptake and translocation continue in collaboration with Letcombe Laboratory (p. 123) and will be matched by work just begun on foliage and root diseases of cereals. Tests of the gains from fungicide applications continue to be important in potatoes (p. 143), grasses (p. 138) and cereals. Powdery mildew of barley serves as an example of an air-dispersed organism causing interactions between plots in field experiments and its dispersal gradients (p. 125) are being studied in the hope of suggesting better experimental designs (p. 127). In common with most plant protective chemicals (p. 141), fungicides used on cereals seldom have effects restricted to one disease. Thus on cereals they may affect not only foliage pathogens (p. 126) but also populations of moulds that may cause problems in storage (p. 120). Although methods are still imperfect it is plain that the widespread lodging of crops encouraged colonisation of grain by organisms that produced the mycotoxin zearelenone (p. 121) and could have contributed to the development of organisms previously not implicated in the immunological reactions of sera from the drivers of combine harvesters (p. 121).

Experiments on many potato diseases continue to be hampered by the lack of summers wet enough to allow adequate testing of the spread of bacterial and other tuber rots (p. 142). However, we continue to improve the health of the potato seed tubers that are used on experiments at Rothamsted. For some years the Plant Pathology Department has been able to grow the healthiest seed crops at Rothamsted for its own experiments; in 1973 the roles were reversed and for 1974 experiments the Farm will provide the best, while the pathologists have had to grow small quantities of commercial stocks to ensure diseases. Comparisons show that the healthiest again out-yielded the average of commercial stocks by more than 10% (p. 145), even more with irrigation (p. 146), and that incidence of several diseases was approximately halved (p. 144). However, there is still no effective bactericide (p. 143) and although fungicides are essential to maintain healthy stocks (p. 145) available materials are inadequate for controlling established inoculum (p. 147) or symptomless infection which remains a troublesome problem in controlling gangrene (p. 144).

Properties of viruses and virus diseases

Simplified preparation of tobacco protoplasts for virus infection. The usefulness of naked protoplasts, for studying virus infection and multiplication, depends much on simple and reliable methods of preparing protoplasts that are easily infected. Initially it seemed that close standardisation of the conditions of leaf growth might be necessary. However, we now find the methods of separation and the constitution of the medium during virus multiplication are more crucial. The lower epidermis of tobacco leaves is peeled away and small (2–3 cm^2) pieces of them are placed, peeled side down, in Petri dishes containing 0·3% Macerozyme, 0·6% cellulase and 13·2% D-mannitol. The protoplasts are released during overnight incubation at 25°C and then handled and infected as described by Takebe and Otsuki (*Proceedings of the National Academy of Science*, (1969), **64**, 843–848). Using mixed enzymes in this way it is not necessary to shake the preparation and this results in consistently large yields of protoplasts of which many can be infected by tobacco mosaic virus (TMV). From leaves produced in various conditions we obtained yields of virus (2×10^6 TMV particles/protoplast) equal to those from the 'two-step' method. We found it unnecessary to add the polyanionic substance, potassium

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dextran sulphate, but $CaCl_2$ (10 m*M*) must be present in the medium for multiplication of the virus. This is true even when potassium citrate, which chelates calcium, is omitted from the infection medium. (Kassanis and White)

Resistance of tobacco plants to virus induced by polyacrylic acid. Tobacco leaves (cv. Xanthi) become completely resistant to infection by TMV about two days after injecting their intercellular spaces with polyacrylic acid preparations varying in mol. wt. from 3500 to 320 000. Even injection just before virus inoculation slightly decreased lesion number and made them much smaller than lesions on control half-leaves injected with water. Resistance was not induced by injecting polyacrylamide of similar molecular weight, so it seems that the distribution of the polyanionic charges within the polymer molecule is the important feature. After leaves become resistant, three extra proteins occur in half-leaves injected with polyacrylic acid but are lacking in half-leaves injected with water. When injected plants are kept for two days at 32°C both the extra proteins and resistance disappear. The induced resistance is complete against TMV and tobacco necrosis virus both of which cause hypersensitive reactions but only partial against potato virus X which infects tobacco (cv. Xanthi) systemically. (Gianinazzi and Kassanis)

Like polyacrylic acid, the RNAs of viruses have polyanionic charges. Therefore, a similar resistance might be expected in leaves systemically infected by viruses and the effect should not be specific. Tobacco plants (cv. Xanthi) were systemically infected with potato virus Y, potato virus X, potato aucuba mosaic virus, cucumber mosaic virus and alfalfa mosaic virus. When leaves, inoculated or infected systemically, were reinoculated with TMV they developed only 0–60% of the number of lesions on comparable plants not systemically infected. Furthermore they contained the same three extra proteins as found in leaves injected with polyacrylic acid and both the proteins and the resistance decreased in plants kept at 32°C.

Thus, plants seem to have a resistance mechanism comparable to that in animals where the protein interferon is produced as a response to virus infection or the injection of polyanionic substances. (Kassanis, Gianinazzi and White)

A transmission component for potato virus Y (PVY). Last year (*Rothamsted Report for 1972*, Part 1, 123) we described a method of preparing PVY extracts that enabled aphids to transmit virus acquired by probing through artificial membranes. Transmission efficiency was increased when virus preparations were concentrated by precipitation with ammonium sulphate or polyethylene glycol. In further experiments, virus purified by two cycles of differential centrifugation was not transmitted. However, the ability to transmit was restored by mixing the purified virus with supernatant obtained by ultracentrifuging a fresh extract. The supernatants alone were practically non-infective and aphids never transmitted virus from them. When aphids probed into supernatant and then into purified PVY, they transmitted almost as well as if the two were mixed but aphids did not transmit if they probed virus before supernatant.

Transmission by aphids that probed supernatant before purified virus was only slightly decreased when antiserum to PVY was added to supernatant but completely prevented when it was added to the virus.

Aphids also acquired potato aucuba mosaic, severe etch and henbane mosaic viruses through membranes if the virus was first mixed with supernatant from a PVY extract, but potato virus X and tobacco mosaic virus were not transmitted. These results suggest that sap of plants infected with PVY contains some component, other than the virus or its structural protein, that is necessary for the transmission of PVY and enables aphids to transmit other viruses of the PVY group. (Govier and Kassanis)

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Virus diseases of tropical crops

The purification and particles of maize streak and related viruses. In collaboration with the East African Agricultural and Forestry Research Organisation maize streak virus was purified by homogenising infected leaf tissue in 0·01*M* phosphate buffer, pH 3·9, and clarifying the extract with butan-1-ol (7 ml/100 ml extract). Purified preparations contained particles 20 nm in diameter, some single, but most paired characteristically to form structures 30 nm long and 20 nm across. The sedimentation coefficients of single and paired particles were respectively 54 and 74*S*. Preparations made at pH 3·9 gave a single light scattering zone when centrifuged in sucrose density gradients and this contained paired particles. One or two additional zones were formed from preparations made at pH 5·9 or 7·9 and contained single particles or fragmented material.

Serologically related viruses with similar particles and sedimentation coefficients were isolated from streak-diseased sugar cane and guinea grass. (Woods, with Dr. K. R. Bock and Dr. E. J. Guthrie, EAAFRO, Kenya)

***Viruses infecting taro* (Colocasia esculenta).** Three possible vectors of the viruses causing Alomae and Bobone diseases (Kenten & Woods, *PANS* (1973), **19**, 38–41) are now established at Rothamsted; the planthopper *Tarophagus proserpina*, the aphid *Aphis gossypii* and the mealy bug *Planococcus citri*. Transmission experiments in the British Solomon Islands, confirmed by electron microscopy at Rothamsted, have suggested that *T. prosperina* transmits both Alomae and Bobone. Tests at Rothamsted have confirmed the planthopper transmits Bobone but, so far, not Alomae. (Plumb, with Mr. D. Gollifer, British Solomon Islands Protectorate)

Plants with symptoms similar to Bobone, collected in Papua New Guinea, contained particles similar to those from Bobone plants from the Solomon Islands. Thus this virus seems more widespread in the S.W. Pacific than previously recorded. No Alomae has been recorded in Papua New Guinea. (Plumb, with Dr. Dorothy Shaw, Department of Agriculture, Fisheries and Stock, Papua, New Guinea)

Virus-like particles (VLP) in fungi

***Incidence of VLP in* Gaeumannomyces graminis.** A culture of the variety *G. graminis graminis* (cause of brown sheath rot of rice) from Dr. J. Walker, Department of Agriculture, New South Wales contained no VLP.

Isolates of *G. graminis tritici* from Little Knott field grew faster and produced more perithecia when they came from a twelfth consecutive susceptible cereal crop than when they came from the third but the difference was unrelated to the occurrence of VLP. (Rawlinson and Muthyalu)

***Purification of VLP from* G. graminis.** It is more difficult to use differential centrifugation to purify fungal viruses than those from flowering plants, because some components of fungi centrifuge similarly to virus particles, and are not denatured and coagulated by repeated centrifuging. Analytical electrophoresis suggests that electrophoresis in sucrose density gradients might be useful for separating VLP from fungal material. Using borate or tris-chloride buffers at pH 8·8, VLP moved towards the anode while the unwanted material remained close to the origin. During 24 hours some VLP migrated 6 cm, enabling clean preparations to be recovered. However, the yield was small because other particles remained closer to the origin, probably complexed with fungal material. To improve the separation it will be necessary to find how to disrupt these complexes. (Carpenter)

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***Properties of nucleic acid from VLP in* G. graminis.** Nucleic acid extracted from purified preparations of VLP by a single phase phenol method gave a positive orcinol test for RNA and weak Dische reaction for DNA. The u.v. spectrum showed that the extract also contained some protein, but this was not important in the experiments described. The nucleic acid extract gave positive double-stranded RNA reactions with acridine orange and reacted in gel diffusion plates with antisera prepared against a complex of methylated bovine serum albumin and double stranded polyinosinic–polycytidylic acid; which is said to be specific for ds RNA (Moffitt & Lister, *Virology* (1973), **52**, 301–304). These reactions were also obtained with nucleic acid extracted directly from cultures of *G. graminis* with VLP.

On polyacrylamide gels the nucleic acid showed two main bands which migrated close together. The electrophoretic mobility of this doublet depended much less on gel concentration than did the mobility of ribosomal RNA. It moved faster than rRNA on gels with above 4% acrylamide, but slower on weaker gels; behaviour characteristic of double-stranded molecules. Identical results in gels were obtained when nucleic acid was released by incubating VLP for 5–10 minutes with 1% SDS at 55°C; thus the protracted phenol extraction procedure did not change the nucleic acid detectably. Release was not improved by longer incubation or adding urea up to 8*M*. Nucleic acid from purified preparations was not broken down by pancreatic ribonuclease and deoxyribonuclease; this is consistent with the nucleic acid being double stranded. Attempts to separate the strands have not yielded intact single-stranded molecules so we are unable to estimate their size. However, when the nucleic acid was spread on protein monolayers, electron microscopy showed many threads about 1 μm long and from this we estimate the duplex molecules to be about 2×10^6 daltons. The genome probably consists of two such segments of doubled-stranded RNA, but we do not know whether the two pieces of RNA are within the same or different particles. (Carpenter and Rawlinson)

Attempts to transmit fungal VLP. Studying the effects of VLP is hampered by the lack of simple ways of transmitting them without possibilities of genetic change in the host. We found no difficulty in producing protoplasts from *G. graminis tritici* isolates containing VLP (using 'HPJ special' enzyme preparation from Micro-Bio Laboratories Ltd.). However, uninfected isolates produced few protoplasts from which we were unable to make any regenerate mycelium.

Mycophagous nematodes (*Aphelenchoides blastophthorus*, *Aphelenchus avenae* and *Ditylenchus destructor*) were fed for up to one month on isolates of *G. g. tritici* that contained VLP and then transferred, quickly and aseptically, to uninfected isolates. Extracts from these cultures did not contain detectable particles during any of the first six weeks of growth with potentially infective nematodes.

Properties of fungi with VLP. Virus-like particles occur commonly in fungi, but seldom has their presence been associated with evident damage. Among other possible effects, we investigated whether fungicide tolerance might be related to the altered metabolism of isolates containing VLP. No such relationship was established between tolerance to benomyl and the presence of VLP in species of *Aspergillus*, *Botrytis*, *Colletotrichum*, *Gaeumannomyces* and *Penicillium*. (Rawlinson and Muthyalu)

Biodeterioration

Spoilage of plant produce by fungi and actinomycetes is important both because feeding value is lost and moulds can produce toxic metabolites in the substrate while their spores may cause allergy or infection when inhaled.

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Incidence of moulds and toxins

In barley grain. The surface microflora of maturing barley grain comprised only about 5% of the number of micro-organisms found on senescing leaves. During the four weeks before harvest, the grain microflora increased by about 60%, mostly after the grain was mature. At harvest the microflora was dominated by bacteria, yeasts (especially *Sporobolomyces*), *Aureobasidium*, *Hyalodendron*, *Cladosporium*, *Alternaria* and *Epicoccum*. Species of *Fusarium*, *Aspergillus* and *Penicillium* were also present in many samples. Fungicides used against foliage pathogens of barley modified the surface microflora of the grain. Fewer micro-organisms occurred and grain germinated slightly better after spraying with captafol than without fungicide or with tridemorph, benomyl and 'BAS3170F' (for which the common name benodanil is being adopted) (Table 1). Many cereal crops were lodged early by storms and three to five times as much wheat or barley grain from lodged plants yielded *Fusarium* colonies as that from plants standing nearby.

TABLE 1

The effect of fungicide treatment on germination and microflora of barley grain at harvest

Treatment	Control	tridemorph	benomyl	'BAS3170F'	captafol
Grain germinated (%)	93·2	93·6	92·6	92·8	96·5
Organisms/g dry wt. ($\times 10^3$)	606	229	196	82	76

Barley grain was stored in sealed or unsealed containers with initial water contents ranging from 15 to 40%. During storage, the water content, heating and aeration of the grain controlled the amount and type of moulding. Table 2 shows the organisms that became dominant and the maximum temperatures attained. Grain in sealed containers did not heat, but unsealed grain with more than 25% of water heated to 58°C. Although rewetted grain (30–40% water content) eventually reached the same temperature and grew the same micro-organisms as grain of the same water content straight from the field, it took two or three times as long to do so and produced fewer spores. (R. A. Hill and Lacey)

TABLE 2

Dominant organisms and maximum temperatures in barley grain stored with different water contents in sealed and unsealed containers

Initial water content (%)	15	22	30	40
Unsealed containers	Little growth	*Aspergillus glaucus*	*Penicillium piceum*	Thermophilic fungi and actinomycetes
	(22°C)	(24°C)	(55°C)	(58°C)
Sealed containers	—	*Penicillium hordei* (25°C)	*Penicillium roqueforti* (27°C)	*Penicillium roqueforti* (25°C)

In feeding stuffs. Toxins in feeding stuffs have usually been attributed to fungi growing in them during storage, but occasionally they occur in apparently clean grain. The source of these toxins may often be *Fusarium* spp., which are usually commoner in fields than grain stores. Experiments were therefore started to detect how often toxins are produced in feeding stuffs before harvest.

The moisture content of freshly mown hay was modified by watering or covering swaths with polyethylene tents and sampling periodically to determine the microflora and presence of substances toxic to chick embryos. Most plots that had been watered or covered eventually developed populations of *Fusarium* spp., and extracts decreased the hatch of fertile eggs from 70% to between 22 and 48%.

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Plots of barley, wheat and oats were also covered during parts of the ripening period. Hot weather prevented humid conditions or detectable changes of microflora. However, grain samples taken from lodged but untreated barley contained 10–15 ppm of the oestrogenic toxin zearalenone. Extracts from samples of oats that contained lodged grain decreased the hatch of fertile eggs from 70% to between 0 and 16%. The toxic factor and its distribution between treatments has not yet been defined. (Lacey with Mr. A. Hacking, Agricultural Development and Advisory Service, Shardlow)

Actinomycetes from stored products. Previous work on the microflora of heated sugar cane bagasse (*Rothamsted Report for 1969*, Part 1, 172) revealed actinomycetes that resembled *Nocardia* spp. These have been compared with species of *Nocardia*, *Actinomadura* and *Micropolyspora* by numerical taxonomy based on physiological and morphological characters. The isolates from bagasse formed a distinct and homogeneous group with spore chains that are bead-like, of indeterminate length, with hairy sheaths and with vegetative mycelium that fragments. They were not acid-fast, had type IV cell walls, but lacked nocardomycolic acids; they utilised most of the carbon sources tested, hydrolysed most of the test substrates including elastin, a character associated with pathogenicity to mammals, and are resistant to many antibiotics. They most resemble *Actinomadura dassonvillei* but differ from it in spore characters and type of cell wall, the last a character so important that they may need to be placed in a new genus. (Lacey, with Dr. M. Goodfellow, Newcastle University)

Consequences of mould growth

Feeding mouldy hay. Sheep fed mouldy hay develop precipitins to the thermophilic actinomycetes that cause farmer's lung. Experiments were continued to test the effect of intermittent heavy exposure to airborne spores on clinical, immunological and pathological changes. Sheep fed hay that had been baled damp to encourage the growth of thermophilic actinomycetes were exposed, usually for three days, in pairs in polyethylene tents to dense concentrations of airborne hay dust released by shaking. Others were exposed by feeding alone. Before and after exposure, blood samples were taken for precipitin tests and skin tests were made for allergic responses. Sheep were killed immediately after exposure and at intervals up to three weeks later for microscopical examination of the lungs and culture of their contents. After exposure to dense concentrations of airborne dust, the lungs contained $2{\cdot}5 \times 10^4$ propagules/g of *Thermoactinomyces vulgaris* and $4{\cdot}7 \times 10^4$ propagules/g of *Micropolyspora faeni*. Fungi were much less numerous. After 13 days feeding on unheated hay these organisms were still present, although numbers had decreased to one-tenth or less, and organisms characteristic of the new hay were found. Clinical changes were few, although lungs contained some lesions that still have to be investigated. Skin test reactions were inflammatory with many neutrophils but few eosinophils. (Lacey, with Mr. G. A. Embleton, ARC Institute of Animal Physiology, Babraham, and Miss J. Mitchell, Cardiothoracic Institute, Brompton, London)

Dust hazards during harvesting. Extracts of 20 fungi and actinomycetes representing the most common genera present in combine harvester dust, the actinomycetes causing farmer's lung and *Aspergillus fumigatus* were tested in gel diffusion plates against sera from 26 farm workers exposed to this dust. Most extracts gave no reaction but precipitins were detected in 13 sera, 12 to *Aphanocladium album*, 11 to *Paecilomyces farinosus* and 10 to *Verticillium lecanii*. All had spores previously classified as '*Cephalosporium* type' (*Rothamsted Report for 1972*, Part 1, 128). Partial immunological cross reactions were

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found between *A. album* and *V. lecanii*, but the precipitins were not identical and there was no cross-reaction with *P. farinosus*. Positive skin test reactions were obtained using extracts of these three organisms and of other common species. The significance of these precipitins and positive skin tests in respiratory complaints by combine harvester drivers will be examined. (Lacey, with Dr. C. S. Darke and Dr. M. Ward, Sheffield Royal Infirmary)

Suberosis. Following the discovery of precipitins to extracts of *Pencillium frequentans* in sera from workers in a cork factory who suffer from suberosis (*Rothamsted Report for 1972*, Part 1, 129), it has been shown that sensitised people who inhale aerosols of extracts of *P. frequentans* develop respiratory symptoms typical of the disease. However, granulomata in the lung characteristically contain cork particles, so the role of cork dust in the suberosis syndrome remains uncertain. (Lacey, with Dr. R. Avila, Faculdade de Medecina de Lisboa)

Prevention of moulding in damp hay. On analysis, samples from a 1972 experiment showed that hay baled at 41% water content lost more than half its soluble carbohydrate, presumably through moulding. Losses were decreased as initial water content was decreased (to 28 and 26%) or as more propionic acid was applied (up to 3%). Losses of dry matter, indicated by increasing ash content of samples, were much greater from untreated hay than was indicated by weighing whole bales and determining the dry weight before and after storage, but the response to applying propionic acid was similar by both methods. (Lacey, with Festenstein, Biochemistry Department)

The difficulty of applying propionic acid uniformly during hay-baling is a major factor limiting commercial application. Testing experimental distributions has been difficult, but should be simplified by a new technique based on gas chromatography, using a 'poropak Q' column and flame ionisation detector. Hay baled at 28% water content, with 3% propionic acid applied during baling, contained on average 1·5% propionic acid after storage. However, the distribution of the material was erratic within bales and even along individual grass stems. Mould-free stems contained slightly more propionic acid than others but individual 1 cm segments often contained less than 10% of the average for a whole stem. Fungal growth was usually greatest on segments of stem containing little propionic acid, but occurred on adjacent segments containing more; perhaps because the fungi colonised untreated parts and later grew beyond them. This emphasises both the slow redistribution of the propionic acid vapour and the need to improve the distribution of acid during baling. (Lacey, with King, Pedology Department, K. A. Lord, Insecticides and Fungicides Department and Mr. R. Charlick, National Institute of Agricultural Engineering, Silsoe).

Measuring effects of pathogens

Diseases affect agriculture both directly, through the quality and quantity of crop yield and indirectly through crop rotation or the cost and reliability of crops influencing farming systems. Measuring the consequences of diseases is one of the most necessary but most difficult tasks in plant pathology, and one where success has been limited. To decide research priorities within plant pathology and of the subject relative to others, sound estimates are necessary. Diseases are much affected by weather, so measurements must be continued over several years; disappointingly often they are then invalidated by changes in cultural practice or of crop varieties, now perhaps the major variable in the incidence of many diseases.

Methods differ greatly between countries, but in Britain most effort has been given

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to using surveys of incidence to extend the application of results from experiments involving chemical control. Often scant understanding enforces reliance on empirical relationships. Late in 1973 we began investigating how foliage and root pathogens of cereals affect plant activity and if possible to find improved methods for measuring this. These studies will be linked with our collaborative work on root diseases with the Letcombe Laboratory (see below) and others described elsewhere in this Report.

Nutrient and water uptake by healthy and diseased wheat. During 1972 we inoculated microplots on a sandy loam at Woburn, using wheat seedlings infected by *Gaeumannomyces graminis* but not enough take-all developed in spring wheat to produce detectable differences from healthy crops in the extraction of soil moisture or of injected ^{32}P (*Rothamsted Report for 1972*, Part 1, 127). In autumn, the same plots with others that had been fallow, were sown with Cappelle-Desprez wheat to give plots growing healthy wheat and others with two different severities of disease (Table 3).

TABLE 3

Incidence of take-all and yield of Cappelle wheat: Woburn 1973

Cropping in 1972	Spring wheat, inoculated	Spring wheat, not inoculated	Fallow
% plants infected			
20 February	15	4	0
9 May	45	24	0
16 July	72	84	20
Yield			
Grain, t/ha	1·64	2·95	4·84
Straw, t/ha	2·90	4·23	5·96

Soil moisture content was estimated weekly with a neutron probe, at intervals between 10 and 100 cm deep. Table 4 shows large differences in the amount and depth distribution of water extracted by the different crops. Unfortunately, not all the differences can be attributed to the differing incidence of take-all. For example, wheat after fallow was the strongest growing, even before roots on any plot were infected with take-all, and despite the addition of extra N fertiliser to wheat after wheat to compensate for N released into fallow soil. Wheat after fallow also suffered least winter killing and

TABLE 4

Water extracted from soil by Cappelle wheat: Woburn 1973

Cropping in 1972	Sp wheat inoculated		Sp wheat not inoculated		Fallow	
Dates: From	31 May	25 June	31 May	25 June	31 May	25 June
To	25 June	30 July	25 June	30 July	25 June	30 July
	Change in soil moisture—arbitrary units					
Depth (cm)						
10	−8·66	−2·07	−7·49	−2·82	−10·66	−2·76
20	−7·07	−0·26	−7·69	−1·00	−9·69	−3·70
30	−6·99	+1·38	−7·41	+0·59	−9·29	−1·84
40	−5·62	+0·92	−7·27	+0·36	−10·28	−0·51
50	−3·01	−0·44	−5·19	+0·08	−9·46	−0·94
60	−3·07	−0·49	−4·11	−1·21	−7·97	−2·12
80	−1·74	−0·34	−1·63	−1·80	−4·86	−3·53
100	−1·76	−0·78	−1·74	−0·63	−2·26	−3·00
Total: 0–100 cm	−55·18	−5·43	−57·75	−11·60	−84·25	−21·69

Rainfall—31 May–25 June: 36 mm on 3 days
25 June–30 July: 73 mm on 15 days

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grazing, had larger wheat populations and consequently less competition from mayweed and annual grasses. These differences may account for much of the difference in total water extracted between 31 May and 25 June. However, the effects of take-all seem more likely to explain why diseased crops extracted so much less between 25 June and 30 July and always took a greater proportion from the top half of the soil profile. The uptake of ^{32}P into leaves was measured seven weeks after it was injected early in May at depths of 20, 30 and 40 cm. Differences in uptake resembled those for water extraction but were less spectacular, presumably because no ^{32}P was injected below 40 cm and uptake was measured over the period 8 May–26 June, before take-all had much effect on water extraction. Of the total ^{32}P extracted from the three depths respectively, infected wheat took 38, 32 and 40% and healthy wheat 28, 25 and 47%. (Salt, with Dr. F. Ellis and Mr. K. R. Howse, Letcombe Laboratory, Wantage)

Damage by zoosporic fungi

Olpidium *infection and iron deficiency in cabbage*. When *Olpidium brassicae* infects cabbage roots, it disturbs some transport processes, especially the movement of iron. Chemical analyses showed that infection did not affect uptake of iron but considerably diminished translocation to the shoot. Thus, in plants grown in solutions containing 2, 0·4, 0·08 or 0·016 ppm iron the proportions of total iron in the shoots were respectively 19, 48, 52 and 64% in uninfected plants and 11, 24, 38 and 40% in infected plants. Infection scarcely changed uptake and distribution of potassium, magnesium and phosphorus but increased amounts of calcium in shoots and roots and the proportion of the total in shoots. (Macfarlane)

Tests, using uninfected and infected plants grown in solutions containing 0·5 or 0·05 ppm iron and then transferred to solutions containing 0·5 ppm iron labelled with ^{59}Fe, showed greater uptake and proportion translocated in plants initially grown with less iron. Infecting with *O. brassicae* did not affect uptake but greatly diminished translocation to shoots, from 56% in uninfected plants to only 16% in infected plants. Microautoradiographs (using ^{55}Fe) confirmed that iron was retained in infected roots especially in their outer layers although we do not yet know whether it was concentrated on the surface, in the fungus or the infected host cells. Infection had no effect on uptake and translocation of phosphorus (^{32}P) but, in contrast to the previous experiment, it decreased uptake and translocation of ^{85}Sr an isotope often used to simulate the movement of calcium. (Macfarlane, with Dr. D. T. Clarkson and Mr. J. Sanderson, Letcombe Laboratory, Wantage)

***Damage to sugar beet by* Polymyxa betae.** In Italy this fungus is associated with 'rhizomania', an excess production of fibrous root at the expense of the storage root. The fungus occurs in England but has not been associated with root deformation or other symptoms. Beet plants were therefore grown in sand culture and inoculated with zoospores of an East Anglian isolate of *P. betae*. Infection decreased yield of storage roots by 50% in one experiment and 20% in another but formation of fine roots seemed normal. The results need confirming with cultural methods better suited both to the growth of beet and an essentially aquatic fungus. (Macfarlane)

Cereal diseases

Barley yellow dwarf virus (BYDV)

Phenology of BYDV and its aphid vectors. Slightly more *Rhopalosiphum padi* were caught in the Entomology Department suction trap at Rothamsted than in 1972 but *Sitobion avenae* and *Metopolophium dirhodum* were much less numerous, and the total

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catch was the smallest for five years. Infective alate *R. padi* and *S. avenae* were first trapped on 30 May and 21 June respectively, one and two weeks later than in 1972. No infective alate *M. dirhodum* were found. In autumn *R. padi* were a little commoner than in 1972 and many more carried BYDV; of those trapped to the middle of October, 17% carried virus, often of severe isolates. Early sown winter crops may therefore have been at considerable risk.

Effects of BYDV and aphids. Recent concern about cereal aphids has stressed direct feeding damage, especially to ears by *S. avenae*, in eastern regions; whereas in the south and west their role as vectors is thought more important. Consequently much of our work is now based at Rosemaund Experimental Husbandry Farm (Hereford) and, in conjunction with the National Institute of Agricultural Botany, at Seale Hayne Agricultural College (Devon).

During 1973 there were few aphids and little virus on spring barley (Julia) in Devon, Hereford or Hertfordshire, so insecticides had little effect on yield. Experiments testing the effect of insecticides and sowing date on BYDV infection and yield of winter oats (*Rothamsted Report for 1972*, Part 1, 131) were more successful. At Rothamsted (Table 5) plots without insecticide yielded most when not sown until November. However, the best yield was obtained by sowing in September, after applying phorate granules and followed by a menazon spray in May. Grain size was greatest from September sowings but insecticides only increased it significantly where both phorate and menazon were applied. During June 1973, untreated plots sown the previous September had ten times as many plants with BYDV as plots sown in October or November. Phorate treatment of September plots decreased virus infection and aphid number by 75%.

TABLE 5

Effects of insecticides and their times of application on yield of winter oats (cv. Peniarth) sown on different dates (Rothamsted 1972–73)

Date of sowing (D)	25 September	26 October	23 November
		t/ha	
Treatment			
Nil	4·90	4·57	5·23
phorate (P)	5·25	5·03	5·04
menazon (M)	5·21	5·01	4·99
P + M	5·46	5·18	5·08

SED	D	P	M	DP	DM	PM	DPM
	0·131	0·107		0·185		0·151	0·262

These results support our previous suggestion that very early sowing in autumn may encourage much virus infection and suggest that it may be economic to use insecticides to prevent this. However, the treatment would not always succeed because, in a comparable but simpler experiment at Rosemaund, there was no significant difference in yield although plots sown in October developed less BYDV than those sown in September. (Plumb)

Powdery mildew (*Erysiphe graminis*) of cereals

Mildew on winter barley and its role as a source of infection of spring barley. There is little doubt that mildew developing early on winter barley often provides the inoculum that infects spring crops. There is therefore much interest in the infection of newly sown crops in autumn, in the gradients of infection from them in spring and the extent to which their menace can be decreased by adjusting sowing date or chemical control.

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Winter barley (Maris Otter) was sown in September, October, November and February in one series of contiguous plots and in another where plots were isolated from earlier sowings. The isolated September plot was rejected because of severe grazing but its equivalent in the contiguous series had more mildew in early February than the October sowing (1·8 and 0·7% respectively, of the second youngest leaves). By mid-May all contiguous plots had much more mildew than isolated plots but plots sown in October and November had as much or more disease than those sown in September. Later comparisons became difficult, because mildew seemed then to be affected more by differences in growth stage resulting from different dates of sowing. These and previous observations show that sowing early in autumn increases the risk of severe infection soon after emergence and that mildew can develop and spread considerably before spring. However, it has not proved possible to predict infection in spring or the risk to other crops from the date of sowing or infection in autumn.

Two large plots of barley stubble were separated and flanked by equal areas of winter barley (Maris Otter); the stubbles were ploughed and sown to spring barley (Zephyr). One stubble plot was sprayed and cultivated to eliminate volunteers, which were permitted on the other plot. In early February there was most mildew in the winter barley to the east of the untreated stubble, but differences were much less by late March. However, Table 6 shows there were steep gradients of infections in the spring barley on 16 May which had become more gradual by 6 June; presumably the earliest infections had by then become active sources. By contrast, the gradient of leaf blotch remained steep, presumably because it is caused by a fungus (*Rhynchosporium secalis*) which is predominantly dispersed by rain splash rather than air dispersal. (Jenkyn)

TABLE 6

Average disease gradients in spring barley to East and West[1] of winter barley

Mean distance from winter barley (m)	1·0	1·4	2·3	4·3	8·3	16·9
	(% area affected on 3rd youngest leaf)					
Mildew, 16 May	11·6	9·8	4·5	4·0	1·8	1·2
Mildew, 6 June	16·3	14·4	9·6	13·0	11·5	10·4
Leaf blotch, 6 June	2·4	1·1	0·7	0·3	0·1	0·1

[1] Gradients to the west were slightly steeper than those to the east

In another experiment, winter barley (Senta) was grown from seed dressed with ethirimol or untreated until it was sprayed with tridemorph on 19 March (Growth Stage 3), 18 May (Growth Stage 8) or 31 May (Growth Stage 10·5). Little mildew developed throughout the winter on untreated plots, on 19 March <1% of the third youngest leaf was affected, and 0·1% where seed was dressed with ethirimol. By early May, it had increased to 10 and 4% on these leaves and then spread quickly. Table 7 shows that, within this latin square design experiment, neither seed dressing nor early spraying prevented infection in early June, although both decreased it, ethirimol seed dressing the more effectively. (Since then, the manufacturers ceased recommending the dressing of winter barley seed with ethirimol in the hope of decreasing the establishment of ethirimol-tolerant strains of *Erysiphe graminis*). The greatest yield was given by the plots sprayed on 18 May and this also may have been the treatment that would have decreased infection of spring barley most, because information given below suggests much infection occurred between mid-May and early June when this treatment decreased mildew more than any other. (Bainbridge)

Phenology of mildew and timing of fungicides on spring barley. At Rothamsted the catches of mildew spores on sticky vertical cylinders exposed above barley crops and on a

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TABLE 7

Control of mildew and yield of winter barley (Senta)

Treatment	Nil	Seed[1] dressing	Spray,[2] 19 March	Spray,[2] 18 May	Spray,[2] 31 May	SED
			(% area mildewed)			
2nd youngest leaf						
7 June	15·1	7·9	10·2	1·0	8·2	2·0
14 June	33·6	22·3	29·8	8·6	10·7	2·6
22 June	33·2	28·5	38·8	23·9	13·2	5·5
3rd youngest leaf						
31 May	25·0	9·1	18·3	0·1	20·7	2·3
7 June	46·7	30·4	34·3	3·4	32·3	3·7
			Yield (t/ha)			
	5·56	5·94	5·65	6·06	5·84	0·15

[1] ethirimol, 0·54 kg/ha
[2] tridemorph, 0·7 litre in 290 litres/ha

laboratory roof showed that, as in 1972, mildew conidia became increasingly common in late May and, especially above crops, increased greatly at the beginning of June to reach a maximum by mid-June. Traps were also exposed above grass, where the pattern of catches resembled that on the roof more than above barley because the increase in May and June was slow. Unlike other traps where the catches decreased greatly in July and August, as cereals ripened and were harvested, those above grass caught most during August. (Jenkyn and Geary)

Traps exposed above seven other barley crops (Lofa Abed) in Hertfordshire indicated similar mildew development. In two of these crops (one adjacent to winter barley), spray experiments measured the response to single fungicide applications on different dates, both showed greatest benefit from the first spray applied, late May on the crop next to winter barley where the big increases in spore catch came earlier, and, early June in the other. There seems to be good evidence that catches from a few spore traps sited in susceptible crops can now be interpreted to indicate both disease development and the optimum timing of a single mildew fungicide spray over wide areas. (Bainbridge, with Mr. D. Yarham, Agricultural Development and Advisory Service, Cambridge)

Fungicides also increased the yield of spring barley (Zephyr) at Rothamsted from 4·34 t/ha (untreated) to 4·88 t/ha (ethirimol seed dressing). Sprays on 1, 11 and 25 June gave yields of 5·23, 4·83 and 4·50 t/ha respectively with tridemorph and 4·91, —, and 4·45 with ethirimol. Combinations of seed dressing and spray or two sprays did not give greater yield than the most effective single spray of tridemorph. However, yield was increased to 5·55 t/ha where tridemorph and captafol sprays were applied three times suggesting that organisms besides *E. graminis* were limiting yield. (Jenkyn)

The design of field experiments involving air-dispersed pathogens. Last year we described experiments designed to measure the effect of distance from infected crops on the mildew infection and yield of spring barley (*Rothamsted Report for 1972*, Part 1, 133). During 1973 we compared the effects of no spray and single tridemorph sprays applied on 1, 11 or 25 June in two latin squares, identical in arrangement but differing greatly in inter-plot separations. In a compact layout, plots (4·3 × 9·1 m) of susceptible Zephyr barley were separated only by 4·3 m of unsprayed Zephyr whereas in an 'exploded' layout plots were separated by 22·9 m of mildew resistant Mazurka barley, seed-treated with ethirimol as an additional precaution to prevent it becoming a source of mildew. Sprays on 1 June increased yield most, spraying on 25 June had no effect on yield. Plots sprayed on 1 June had equal amounts of mildew in the two experiments until 22 June,

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but on and after 29 June there was more mildew on plants from the compact layout. However, this difference was not reflected in yield. (Bainbridge and Jenkyn)

The above differences were smaller than might have been expected from the results of last year's experiments and improved designs may require much more information on the contribution of infective spores from local and distant (background) sources. Observations on spore dispersal and deposition gradient just above and within uninfected Mazurka barley downwind of an untreated plot of Zephyr illustrate the differences in June when sporulation was profuse. Catches on sticky cylinders and rotorod traps centred 12·5 cm above the crop at 0, 5 and 15 m from the infected crop were, respectively ten times, five times and equal to the background for the field. Later when the infected plot was producing fewer spores, differences (two to four times) were discernible only at 1 and 2 m and counts of spores deposited on flag leaves of Mazurka showed similarly small differences. (Bainbridge and Cross)

Effects of host nutrition on barley mildew. Zephyr spring barley was grown in pots with different amounts of N and infected with mildew at growth stage (G.S)7. Spore germination was examined microscopically at intervals up to 144 hours, by embedding the spores in cellulose acetate films which were then removed from the leaf surfaces. Nitrogen rate did not influence germination or appressorial formation but applications of 200 and 400 mg N/kg soil theoretically representing respectively 224 and 448 kg N/ha to a depth of 75 mm, increased the proportion of spores that produced colonies by three and five times more than those given 100 or 50 mg N/kg soil (112 and 56 kg N/ha). Plants given 50 mg N/kg showed nitrogen deficiency in the later growth stages. Hyphal growth and spore production also increased with amount of nitrogen. (Bainbridge)

On Hoosfield, spring barley (Julia) dressed with ethirimol developed more mildew on plot 22, which receives only P fertiliser, than on other plots of the same series. In the Arable Reference Plots, Deba Abed barley was sprayed with tridemorph but mildew was most severe on plots that receive no fertiliser, nitrogen only or nitrogen with phosphorus. Shortage of potassium has been claimed to increase susceptibility to mildew, but there is a need to investigate whether it also decreases the effectiveness of fungicides. (Jenkyn and Broom)

The means by which nitrogen can increase mildew attacks is not known, but as most of it enters cereals through the roots as nitrate we tested a simple analytical method to indicate the amount of nitrate in the stem base of glasshouse grown barley. (See *Rothamsted Report for 1969*, Part 1, 51–52, and Williams, *Chemistry & Industry* (1969) 1735–1736). Nitrate accumulated in the stem bases of plants with mildew but not in plants where the disease had been controlled by ethirimol seed-dressings. Perhaps mildew decreased the ability of plants to use all the nitrogen their roots absorb. Before judging the agricultural significance it will be necessary to repeat the observations on a field crop where soluble nitrogen is less generously applied than in the glasshouse, and to study changes in other components of plant nitrogen. (Jenkyn, with Williams, Chemistry Department)

Take-all and other root rots

Pot experiments aimed to accelerate the development of take-all decline. The extent to which the pathogen, the host or their interaction (disease) account for the inhibition of take-all in long sequences of susceptible cereal crops is still unknown. Two attempts were made to induce it quickly by frequent cropping in the presence of added or natural inoculum.

A field soil, thought free from natural inoculum of *G. graminis*, was newly cropped with susceptible wheat or non-susceptible oat seedlings during each of five consecutive months.

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Every crop of each host was grown with the addition of *G. graminis* growing on kibbled maize, with similar but killed inoculum or with uncolonised kibbled maize. After each oat crop a wheat seedling assay was made on a sub-sample of each soil using equal weights of added inoculum, to measure inhibition of take-all. Increasing inhibition occurred during the first four crops of oats in soils with only kibbled maize added but after the fifth crop inhibition had decreased and soils to which live or dead inoculum was added never became increasingly inhibitory. Unfortunately natural inoculum in the field soil invalidated the treatments to which living inoculum was not added but inhibition increased during the first three crops of inoculated wheat seedlings before reverting to the original amount in the fourth and fifth.

Gerlagh (*Laboratorium voor Fytopathologie, Wageningen, Mededelingen* 241, 1968) produced a persistent inhibition of take-all in similar experiments in which he introduced inoculum on wheat grains and chopped straw and also fertilised the soil from the second crop onwards. The accumulation of kibbled maize or depletion of nutrients could have explained our different results. We detected large changes in pH, total N in soil and forms of N in seedling rhizospheres during the experiment. (Pope, Hornby and Dr. V. Pearson)

To overcome the problems of adding nutrients with inoculum and to counter the large changes that occur without fertiliser, we tested the following procedure. Take-all infested soil from plots on Little Knott I that had grown sequences of 2, 3, 6 and 13 susceptible cereals was cropped with wheat seedlings during each of 11 successive months in pots in a glasshouse and given 7–10 mg N/kg soil, as KNO_3, for each crop. Initially the severity of disease increased to maxima occurring in the four soils in, respectively, the fourth, third, second and third seedling crops and thereafter decreased suggesting the establishment of take-all decline. Disease was negatively correlated with rhizoplane and rhizosphere bacterial populations confirming usual field experience. However, the soils that had carried 6 and 13 susceptible crops already exhibited take-all decline and were not expected to respond to frequent seedling crops with a further maximum and decline of disease. Others who have used such experiments to examine the cause of take-all decline have assumed that the inhibition established in pots is identical with that which occurs in field crops. However, these results and the lack of a long period of survival on straw are reasons to question the assumption. (Pope and Hornby, with M. E. Brown, Soil Microbiology Department)

Two kinds of transmissible inhibition of take-all. Vojinovic (*OEPP/EPPO Bull.* (1973) 9, 91–101) suggested that the intensified development and activity of antagonistic organisms in plant residues, particularly those infested by *G. graminis*, were responsible for take-all decline. If true this would imply that antagonism could be transferred in extracted debris and perhaps intensified by frequent cropping in pots provided that seedlings roots are equivalent to the residues of a mature crop. Debris (>150 μm length) extracted in April from 1 kg samples of Little Knott I soils that had carried 1, 3, 6, 13 consecutive susceptible cereals was mixed, with 20 g 'Mag Amp', slow-release fertiliser containing granulated ammonium potassium sulphate, supplied by W. R. Grace and Co., Baltimore, Maryland, USA, into 1 kg samples of soil from Barnfield, long free from cereals. Initial wheat seedling infection assays showed that the relative infectivity of the mixtures simulated the changes in disease severity in Little Knott. Monthly seedling crops increased disease to maxima in the fifth and sixth months when, respectively, the residues from first and third field crops were used; disease remained constant when residues of the sixth crop were used but decreased to a minimum in the fifth month with residues of the thirteenth crop. The results support the claim that factors inhibitory to take-all are associated with infested plant debris. We found no evidence of soluble

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inhibitory substances but bacteria associated with debris (especially that collected later from third cereal crops in May and sixth and thirteenth cereal plots in August) inhibited growth of *G. graminis*. (Pope and Hornby, with M. E. Brown, Soil Microbiology Department)

Another, more ephemeral, form of inhibition was established in soils where take-all developed unimpeded, by adding as little as 0·1% of unsieved soils where take-all was impeded (take-all decline soils). Mixtures were tested from suitable cropping sequences within and between experiments on sandy loam and a clay loam with flints. The method of adding the minor (impeded soil) component seemed important; top dressing was better than mixing and both were better than placing it beneath the wheat grain. The most successful additions decreased infection of test seedlings by as much as 50%, whereas adding equal amounts of Barnfield soil (long free from cereals) had no effect. However, in 1 m² boxes in the open air the difference, in disease severity on seedlings in 'unimpeded' soil with and without added 'impeded' soil, decreased progressively until after 6 weeks it became undetectable. Soil fractions retained by sieves >150 μm failed to transfer this ephemeral inhibition. Other experiments implicated microorganisms capable of surviving 30 min at 60° but not at 70°C. (Pope and Hornby)

The effect of cropping on the survival and re-establishment of take-all. Take-all developed differently on winter wheat crops following various ley crops of the Ley–Arable Experiment on Highfield (*Rothamsted Report for 1971*, Part 1, 141–143). To examine the causes, an experiment was started late in 1970 in which for one, two or three years, plots carried lucerne (Lu), grass–clover ley (Lc) or were fallowed (F) before a sequence of winter wheat crops. Initially the area had little take-all inoculum (2% of soil cores infective) so sub-plots were infested with the stubble and roots from a similar area of severely infected wheat crop. Under the treatment crops (leys and fallow) the survival of *G. graminis* infectivity was assayed by seedling infection tests on soil samples taken in June, before the leys were ploughed. Similar assays and crop samples were used to measure disease development in the succeeding wheat crops (Table 8). The infectivity of added inoculum decreased faster under Lu and F than Lc but by the third year was

TABLE 8

The survival of G. graminis *under ley treatments and subsequent development on winter wheat (inoculated sub-plots only)*

		Treatment		1st Wheat			2nd Wheat		
Samples Date Infection (%)	Crops	Soil June Pots[1]	Soil June Roots/ inf. pot	Crop July Plants[2]	Soil October Pots[3]	Soil October Roots/ inf. pot	Crop July Plants[2]	Soil October Pots[3]	Soil October Roots/ inf. pot
One year	LC	54	1·7	1 (0)	40	6	29 (8)	75	10
	LU	42	1·5	2 (1)	79	14	86 (46)	97	20
	F	38	1·9	Tr (0)	82	19	91 (72)	97	14
Two years	LC	18	2·0	5 (0)	18	11	—	—	—
	LU	2	1·0	2 (0)	67	18	—	—	—
	F	2	1·0	1 (0)	92	24	—	—	—
Three years	LC	2	1·0	—	—	—	—	—	—
	LU	2	1·0	—	—	—	—	—	—
	F	2	1·0	—	—	—	—	—	—

[1] Soil sampled before leys ploughed, soil mixed and 5 wheat seedlings/pot grown for six weeks
[2] Total % plants infected, figures in brackets % moderately *and* severely infected
[3] Soil sampled after ploughing stubble, each core kept separate and 10 wheat seedlings/pot grown for five weeks

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no different and no greater than on uninoculated sub-plots. In first wheat crops no differences were detectable in July and take-all was slight. However, soil samples taken in October were most infective after F and least after Lc, differences reflected in take-all incidence on second wheat crops the following July but that did not persist to the October soil assays.

During 1973, assay seedlings were also examined for *Phialophora radicicola*, which proved very prevalent after three years Lc (or first wheat after Lc), common after Lu but scarce after F (Table 9). Perhaps its frequency after Lc may explain the smaller incidence there of *G. graminis*, because Balis (*Annals of Applied Biology* (1970) **66**, 59–73) showed that prior inoculation with *P. radicicola* decreased take-all. Under second winter wheat crops *P. radicicola* became less and *G. graminis* more prevalent, even following Lc. This suggests that grass–clover leys may delay but not prevent the establishment of epidemic take-all on this soil; a hypothesis the experiment will continue to test. (Prew)

TABLE 9

The effect of different crop sequences on the incidence of P. radicicola

	% pots infested		
	after 3 years[1] treatment cropping	after 2 years treatment[2] and 1 year test cropping	after 2 years treatment[2] and 2 years test cropping
Lc	100	100	27
Lu	55	67	7
F	8	13	10

[1] Five wheat seedlings/pot, grown for six weeks in soil mixed after taking cores
[2] Ten wheat seedlings/pot, grown for five weeks in a single soil core

Effects of P and K fertilisers on root rots of barley. Collaboration between chemists and plant pathologists has revealed interactions between host nutrition and root diseases in several experiments that will help explain the results and, we hope, improve the advice that we can give. On barley roots from well nourished soils there was usually little difficulty in diagnosing take-all during May. However, summer samples (June–July), especially from plots that received no P often showed symptoms of several diseases that graded imperceptibly into one another. As previously in these circumstances (*Rothamsted Report for 1971*, Part 1, 143–146) we have reported categories of 'all root rots' and discernible 'take-all'.

The identity and role of some of the pathogens present is still uncertain. In addition to *G. graminis*, the following seemed common. In soils deficient in P, barley roots were often attacked by *Pythium* spp. From these soils *Aureobasidium bolleyi* was isolated from many surface sterilised roots, including some without obvious lesions. Although not usually regarded as an important pathogen, this fungus caused brown lesions, similar to some on barley roots from our experiments, when inoculated to seedlings grown in sterile sand. The unique history of Hoosfield may account for the occurrence there, but rarely elsewhere, of an unidentified fungus that locally stained roots of inoculated seedlings a bright magenta, and of *Helminthosporium sativum* which occurred most on plots without K and causes brown lesions on the crown and roots of affected plants.

Of the three experiments from which results are mentioned below the Hoosfield Permanent Barley Experiment offered the greatest contrasts of plant nutrients in soil. This experiment is unique in testing the effects of P and K fertilisers on spring barley grown continually since 1852, except for four fallow years. So long without fertiliser or with much each year has created soils atypical of modern farming but valuable to plant

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pathologists because they demonstrate effects of extreme deficiency and enrichment on root diseases. Table 10 shows that root rots were much less prevalent on crops with P than without; K alone increased take-all, but K and P increased take-all only where N was deficient. Presumably the fertilisers increase yield much more by nourishing the barley than by suppressing its root diseases but it is noteworthy that even after 120 years of almost continuous spring barley the fully fertilised plots suffered little damage and yielded over 5·5 t/ha. (Slope and Broom)

TABLE 10

The effect of P, K and N fertilisers on root rots and yield of barley: Hoosfield experiment, 3-year averages 1971–73

N manuring, kg/ha	P and K manuring[1]			
	Nil	P	K	PK
	% plants with 'all root rots', summer[2]			
0	65 (26)	43 (13)	73 (29)	65 (25)
48	92 (71)	35 (10)	92 (52)	37 (8)
96	99 (94)	36 (12)	96 (63)	28 (5)
144	99 (94)	42 (16)	98 (79)	52 (18)
	% plants with take-all, summer[2]			
0	32 (8)	14 (2)	53 (20)	53 (20)
48	30 (7)	6 (0)	58 (19)	26 (6)
96	48 (17)	2 (0)	65 (25)	4 (1)
144	44 (15)	2 (0)	73 (37)	3 (1)
	Grain yield, t/ha			
0	1·59	1·89	1·47	1·94
48	2·03	2·93	2·74	3·78
96	2·21	3·00	2·67	5·62
144	2·36	2·32	3·04	5·79

[1] Fertilisers applied annually, kg/ha, P = 73 P_2O_5
K = 110 K_2O + 16 Na + 11 Mg

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

In the PK and Take-all Experiment on West Barnfield, where six successive crops of spring barley followed one of winter wheat, there was little take-all until the fourth and later barleys. Barley given no P had most take-all in May and summer (Table 11), extra K increased take-all at most levels of P but N fertiliser had little effect. When the experiment began in 1968 the soil contained 6 ppm $NaHCO_3$–soluble P and the area was lightly infested by *Agrostis gigantea*, a grass weed and host of the take-all fungus. Ground cover by *A. gigantea* increased more where little P was applied (in autumn 1973 on P0 to P24 respectively, 16, 5, 2, 3 and 1%) so its prevalence may partly account for the relationship between P fertiliser and take-all. As expected, yields from crops without P were small, and responses to 38 kg P_2O_5/ha were large but we cannot say how much these were affected by root rots. Unexpectedly, yields were not increased by more than 38 kg N/ha. (Slope and Broom, with Mattingly, Chemistry Department)

On the Long-term Liming experiment, beans were followed by spring barley in 1965, 1966 and 1967. The average response in barley grain to P fertiliser increased each year, not because yields increased but because they decreased more without P than with it; unfortunately root diseases were not assessed (*Rothamsted Report for 1970*, Part 2, 98–112). Four more barley crops have been grown (1970–73), following potatoes (1968) and fallow (1969). Table 12 shows that the yield response to P again increased each year and that root diseases were commoner on crops without P. Take-all was never severe and

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TABLE 11

The effect of P and K fertilisers on root rots and yield of barley:[1] PK and Take-all experiment, West Barnfield, 3-year averages 1971–73

K manuring (kg K_2O/ha) Annual	P manuring (kg P_2O_5/ha)				
	Annually, since 1968			In autumn 1967	
	Nil P0	38 P1	150 P4	226 P6	904 P24
	% plants with take-all, May				
38	13	9	8	6	4
150	18	14	8	13	8
	% plants with 'all root rot', summer[2]				
38	97 (75)	71 (30)	49 (13)	68 (24)	40 (9)
150	97 (68)	76 (27)	48 (13)	76 (27)	45 (11)
	% plants with take-all, summer[2]				
38	68 (26)	39 (11)	27 (7)	28 (6)	16 (4)
150	80 (38)	55 (18)	24 (5)	51 (16)	26 (5)
	Grain yield, t/ha				
38	3·09	4·41	4·90	3·87	4·69
150	3·45	4·48	4·96	4·25	4·90

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

TABLE 12

Effects of liming and P fertiliser on root rots of barley: Rothamsted Long-term Liming experiment

		Limestone, t/ha in 1962		
		5	10	20
pH (water) in October	1973	5·2	6·1	7·2
		Grain, t/ha		
Response to P (63 kg P_2O_5 annually)	1970	0·70	0·54	0·32
	1971	1·34	0·90	0·76
	1972	1·91	1·27	1·33
	1973	2·13	2·04	2·02
		% plants with 'all root rot', summer[1]		
Without P	1971	83 (31)	65 (23)	51 (16)
	1972	92 (34)	85 (20)	79 (18)
	1973	96 (51)	95 (36)	97 (41)
With P	1971	31 (13)	18 (2)	21 (6)
	1972	57 (12)	58 (11)	71 (16)
	1973	52 (13)	56 (6)	55 (6)
		% plants with take-all, summer[1]		
Without P	1971	12 (2)	26 (10)	14 (4)
	1972	5 (0)	15 (4)	11 (0)
	1973	17 (1)	46 (7)	40 (2)
With P	1971	1 (0)	8 (2)	9 (2)
	1972	4 (2)	10 (1)	9 (1)
	1973	10 (1)	34 (3)	23 (3)

[1] Figures in brackets are % plants moderately *and* severely attacked

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the relation between root diseases and yield response to P was not close enough to be considered causal. (Slope and Broom, with Bolton, Chemistry Department)

These experiments with P and K fertilisers show that adequate P manuring is necessary for growing barley with healthy roots. They do not suggest that barley grown continuously on our soils needs much more fertiliser than the Agricultural Development and Advisory Service currently recommend. Furthermore, satisfactory yields of barley can be obtained for many years on this soil, with little damage from root diseases provided manuring is adequate and grass weeds are controlled. If farmers suspect their barley crops are seriously damaged by root rots they should check their manuring, especially that they are supplying enough P. (Slope and Broom)

Chytrids and other fungi on roots of winter wheat. On Broadbalk and Pennels Piece roots of Cappelle-Desprez winter wheat were again frequently infected with species of *Olpidium*, *Endogone*, *Pythium* and with brown runner hyphae but unlike previous years, *Polymyxa graminis* and *Lagenocystis* spp. were rare. Table 13 shows that on Broadbalk *Olpidium* infected 24% of 1-cm root segments in December, very few by March (spring was unusually dry) but more again later. Most other fungi became prevalent only in spring. Previously *Pythium* spp. have behaved in this way even in wet springs and have been found more on crown than seminal roots. Infestation of the cortex of wheat roots by nematodes, probably *Pratylenchus* spp., was much commoner in winter than spring and in wheat after wheat (25%) or field beans (30%) than after fallow (10%).

TABLE 13

Seasonal occurrence of fungi in segments[1] of winter wheat on Broadbalk[2]

	Date sampled						
	12 December	23 January	5 March	12 April	29 May	26 June	1 August
	(% segments infected)						
Brown runner hyphae	0	1	5	4	3	12	20
Pythium spp.	1	4	1	1	21	20	23
Olpidium spp.	24	9	2	18	26	21	22
Endogone spp.	8	9	7	29	31	24	34
Unidentified mycelium	4	14	10	5	7	6	18
Nematodes	22	19	12	3	2	1	1

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

[2] A total of 360 root segments (1 cm long) examined on each date December–March, and 480 April–August

Previous cropping had little effect on *Pythium* or *Olpidium* (Table 14) but *Endogone* was again more numerous on unmanured plots. Brown runner hyphae were commonest late in growth and where wheat followed wheat. Those on three-quarters of the segments were ascribed to *G. graminis*, a proportion that agreed with lesion counts and isolations on culture media. The remainder resembled *Phialophora radicicola* (Cain) in the positions of septa and the presence of brown swollen hyphal cells each with a circular pore, but did not occur on more than 4% of segments from wheat following wheat and 1% after beans. Although *Aureobasidium bolleyi* occurred commonly in diseased or senescent roots, its brown hyphae were recognised by their small delicate appearance, the position of their septa and the presence of dark sclerotial cells.

Not all fungi can easily be distinguished from *G. graminis*. One isolated from barley was similar and produced lunate phialospores but had more aerial mycelium, grew faster, produced dark brown or black sclerotial clumps but no perithecia. On wheat roots this isolate caused a pale brown to grey discoloration of the root cortex which

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did not decrease dry weight at ear emergence; whereas in the same test pathogenic *G. graminis* isolates from wheat and rye both halved it.

TABLE 14

Effects of manuring and previous crops on fungi in segments of winter wheat on Broadbalk (means for samples April–August)

	Manures			
	FYM + N (Plot 21)	FYM (Plot 22)	Nil (Plot 3)	NPK (Plot 8)
	% segments infected			
Brown runner hyphae	5	16	9	9
Pythium spp.	16	15	15	19
Olpidium spp.	24	25	16	22
Endogone spp.	12	33	53	20

	Previous crops			
In 1971	W	F	W	P
1972	W	W	F	Be
	% segments infected			
Brown runner hyphae	19	11	5	3
Pythium spp.	12	17	21	15
Olpidium spp.	19	21	25	23
Endogone spp.	33	30	19	37

A correction. On page 140 of *Rothamsted Report for 1972*, Part 1, it was incorrectly stated that runner hyphae were commoner on wheat after beans than wheat after wheat. The reverse was true, wheat after wheat, 17% and wheat after beans, 3%. (Salt)

Reduced cultivation systems and plant diseases. Drastic changes in crop husbandry may alter disease incidence, but often not greatly for some years, until pathogen populations have changed. Cereal crop residues are often collected or burnt and volunteers sprayed with herbicide, treatments that decrease the carry-over of many obligate parasites and viruses such as BYDV or, if the herbicides act fungicidally, should decrease trash-borne pathogens that can survive there saprophytically. Although root diseases may be affected less quickly than those above ground they could be altered greatly by decreased soil inversion and mixing, changed soil environments or distributions of nutrients down the soil profile. Present concerns over straw disposal and energy conservation promise to affect the incidence and control of diseases of cereals and other crops.

The Cultivations for Cereals Experiment begun at Rothamsted in 1971 in conjunction with Mr. D. E. Patterson of the National Institute for Agricultural Engineering, Silsoe, provided an opportunity to continue our studies of these problems. The treatments compare various primary cultivations (plough, chisel plough, rotary digger) combined with different secondary cultivations. The experiment could only be sited on a field previously cropped several times with spring barley and known to be predisposed to take-all (and yellow rust) that attacked the Joss Cambier winter wheat so severely during 1972 that it yielded only 3·39 t/ha. Cappelle-Desprez winter wheat in 1973 again had take-all but less severely, so that yields averaged 5·43 t/ha. Cultivation method did not modify take-all in either year, but in both eyespot (*Cercosporella herpotrichoides*) was less prevalent in wheat after ploughing to 20 cm (average three treatments 21 and 32% straws infected in 1972 and 1973 respectively) than in wheat after chisel ploughing or rotary digging (averages for six treatments: 46, 52%). Unexpectedly, sharp eyespot

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(*Rhizoctonia solani*) was more prevalent on wheat after ploughing to 20 cm (24 and 38% straws infected in 1972 and 1973) than on wheat after chisel ploughing or rotary digging (6, 18%). Also, during 1973 wheat had more sharp eyespot after deep (20 cm) than shallow (10 cm) chisel ploughing or rotary digging. (Slope and Gutteridge)

Diseases of grass and forage crops

Ryegrass mosaic virus (RMV)

The effect of RMV on grass yield and the importance of mechanical transmission. Work at the Grassland Research Institute showed that it is difficult to test the effect of ryegrass mosaic on the yield of established ryegrass because plants in uninoculated plots quickly become infected, presumably by infective wind-borne mites. Uncontrolled spread of RMV by vectors also made it impossible to measure how much the virus was spread by grass-cutting machinery. Consequently plots (1·5 m^2) were sown (16 May) to S22 Italian ryegrass within a house (35 m × 5 m and 2·5 m high) covered with clear polyethylene film. Plots were irrigated from an overhead sprayline and mites were excluded by filtering incoming air and by limiting access to a minimum of people, who always changed to uncontaminated footwear. It was accepted that the small reciprocating knife grass-cutter and the environment within the house were unrepresentative of conditions outside.

Each month from July to October, 25 tillers were examined. No mites were found within the house, although during August 396 mites were found on 12 tillers from a similar plot outside. Crown rust (*Puccinia coronata*) was common on ryegrass outside but was not found within the house, although it is not known whether it was excluded by the filters or was unable to infect plants inside. During July, different proportions of plants in plots within the house were mechanically inoculated with RMV, and by September treatments averaged 0, 25, 33 and 40% of tillers showing symptoms. These proportions had changed little by 23 October although plots had been rolled and cut in sequences designed to give maximum and minimum chances of mechanical transmission. Among these newly-sown plots those with most RMV infection yielded 5% less dry matter than uninfected plots but the difference was not significant. (Gibson and Plumb)

***The importance and ecology of the mite vector* (Abacarus hystrix).** RMV symptoms developed on about one-quarter of S22 Italian ryegrass plants to which groups of ten adults of this eriophyid mite were transferred after being reared on plants infected with RMV. Further confirmation that *A. hystrix* is a vector came by blowing mites in an air-stream from infected plants to healthy ones which later developed symptoms. Wind-borne mites probably account for most distant spread of RMV.

Evidence is accumulating that *A. hystrix* is commonest during late summer and early autumn. Uninfested ryegrass plants were exposed 0·75 and 1·25 m above a ryegrass sward for sequential 14-day periods from February to November but were colonised only between June and October. Plants, similarly exposed on a roof 8 m high, were also colonised but only during August and September. No *A. hystrix* were found before late June 1973 on ryegrass sown in October 1972. Grass management, especially the frequency of cutting, affects the increase of mite populations. However, by October there were more than 100 mites/tiller on ryegrass cut two and three times. (Gibson)

Other viruses of ryegrass

Ryegrass bacilliform virus. This virus is proving difficult to study, because it causes no symptoms we can recognise, we have not found any vector and the concentration of

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virus particles is usually small. However, thin sections showed there are large aggregations of particles in a few cells. The virus previously found only in the hybrid ryegrass (*Lolium multiflorum* and *L. perenne*) cv Grasslands Manawa from Kent and Warwickshire, has now been recorded in the perennial cultivar S23 from other sites in Kent, Somerset, N. Wales and at Rothamsted. (Plumb)

Ryegrass spherical virus RSV. The fact that this virus is so commonly seed-borne creates difficulties in experiments to measure its effects or to identify its vectors. We could find no evidence of transmission in tests with beetles, *Oulema* spp. (Coleoptera : Chrysomelidae); planthoppers, *Javesella pellucida* (Homoptera : Delphacidae) and six species of aphid, *Myzus persicae*, *Rhopalosiphum padi*, *Metopolophium dirhodum*, *M. festucae*, *Sitobion avenae* and *S. fragariae*. Virus-free seedlings of S22 Italian ryegrass grown in soil from areas where ryegrass carried RSV developed no symptoms although the soil contained several nematodes, especially *Longidorus macrosoma*, from genera known to transmit other spherical viruses.

In pots, plants of S22 manually inoculated with RMV plus RSV showed much chlorosis followed by death of leaves. When harvested 10 and 16 weeks after inoculation the yield of doubly infected plants was, respectively, 50 and 25% that from uninoculated plants. This difference is thought to be greater than attributable to RMV alone although this is difficult to measure because a proportion of seedlings often contain RSV. (Plumb and Misari)

Oat sterile dwarf (OSD) in ryegrass. Planthoppers (*Javesella pellucida*) swept from established grass swards at Rothamsted were placed singly on S22 ryegrass. Symptoms similar to those of OSD developed on 87% of plants where nymphs fed and 37% where adults fed. Chlorotic flecks followed by enations appeared on the adaxial leaf surface, the plants stopped growing then became dark green and produced many stunted tillers. Similar symptoms appeared on S22 plants to which *J. pellucida* reared in the glasshouse were transferred after feeding on plants showing OSD. No plants infected at the 2–3 leaf stage produced fertile tillers, several died and the remainder were barely 10 cm tall six months after sowing. Previously the disease has only once been reported in Britain at the Welsh Plant Breeding Station. Whether the pathogen is a virus or a mycoplasma remains uncertain. (Plumb, Misari and Lennon)

A virus from meadow fescue that infects oats. Mottling was noticed on leaves of about 20% of tillers in a crop of S215 *Festuca pratensis* during June 1973. Electron microscopy revealed isometric particles 26–28 nm in diameter. The virus was readily transmitted to healthy S215 *F. pratensis* by mechanical inoculation with sap and symptoms appeared three weeks later. By contrast, S53 *F. pratensis* developed no symptoms although the presence of virus particles showed it had been infected. In particle size and being aphid transmitted, this virus resembles cocksfoot mild mosaic which is widespread in Germany but, because it has a different host range, the virus from fescue is tentatively named festuca mottle virus.

Oats (Blenda, Powys, Peniarth, Manod and Astor) were all infected by sap inoculation or via the aphid *Metapolophium festucae*. In oats necrotic streaks developed two to three weeks later and increased in size and number until whole leaves withered and died. Four or five months after infection oat plants were moribund or dead. We know of no record of such symptoms among oat crops. Mechanical inoculation to other crop plants failed to produce symptoms in maize, wheat (Cappelle), barley (Zephyr), S22 Italian or S24 perennial ryegrass, timothy or cocksfoot; although back-inoculation experiments suggested that timothy may be a symptomless host. Similarly, among dicotyledonous

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test plants, we could not infect *Brassica pekinensis*, *B. rapa*, *Phaseolus vulgaris*, *Vicia faba*, *Cucumis sativus*, *Nicotiana tabacum* cv Xanthi, *N. clevelandii*, *Lycopersicon esculentum*, *Chenopodium quinoa*, *C. amaranticolor* or *Datura stramonium*. (Gibson and Boyes)

Incidence of fungal pathogens of ryegrass foliage. Italian and perennial ryegrass varieties in an observation trial were all infected with crown rust (*Puccinia coronata*) by late-August, the perennial variety Glasnevin Leafy most severely. Mildew (*Erysiphe graminis*) was most severe on Asso, RvP and Grasslands Manawa but none was seen on S22 or on the perennial varieties Glasnevin Leafy, Reveille, Endura and S24. *Helminthosporium* spp., were most severe on Reveille. (Jenkyn and Plumb)

Chemical control of ryegrass diseases. In a previous experiment fungicides had not appreciably altered the yield from old pasture. One possible explanation was that the pathogens were too firmly established to be controlled by chemicals; certainly this would be true of virus diseases where only the vectors can usually be controlled. Therefore plots in a newly-sown perennial ryegrass (Gremie) experiment were intensively and differentially treated with aphicide, acaricide and fungicides to test whether they could prevent the establishment of BYDV, RMV, leaf and root disease fungi or increase yield.

Dazomet was applied to soil in autumn 1972 but sprays of menazon, endosulfan, benomyl and 'BAS 3170F' (for which the common name benodanil is being adopted) and drenches of captafol were applied to the seedlings and after each of two cuts. Dazomet increased the yield of both cuts and by more than was likely to be attributable to the nitrogen it released or contributed. Few plants were infected with RMV but vector numbers were decreased by endosulfan. Crown rust was nowhere severe but in late-August there was most on plots that received little N fertiliser (37·5 kg/ha/cut); it was decreased only by 'BAS 3170F'. Mildew was worst with most N (150 kg/ha/cut) and was decreased by benomyl. Samples showed that some roots were black and often contained *Fusarium* spp., and many were brown, but neither symptom seemed much affected by treatments. (Broom, Jenkyn and Plumb)

As a simple test of the difficulties of measuring the effects of diseases in mixed plant communities, Italian ryegrass (RvP), broad red clover (Hungaropoly) and a mixture of the two were sown. Ryegrass plots where aldicarb was applied before drilling did not become infested by *Abacarus hystrix* and RMV did not spread from manually inoculated plants. However, aldicarb increased mildew (*Erysiphe polygoni*) on clover. Aldicarb increased the yield of mixed swards at each of two cuts (10%, $P = 0{\cdot}01$), ryegrass swards only at the second cut (30%, $P = 0{\cdot}002$) but not the yield of clover alone. (Plumb and Cockbain)

***Sclerotinia* rot of clover.** Red clover (S123) was sown in spring 1972 to test the effect on clover rot of benomyl sprays. Although there was little evidence of rotting, five sprays one each month from September to January increased the first cut yield by 32% (Table 15). Of the dates tested the best months during which to apply two sprays were October, November and December, when the yields of both the first and second cuts were increased. On untreated plots apothecia were common in late-October 1973 but estimates made on two 0·5 × 4·3 m transects per plot showed there were many fewer after spraying in November and December. The treatments were not intended to be economic but the results do suggest that the use of fungicides to decrease losses from clover rot might merit further study. (Jenkyn)

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TABLE 15

The effect of benomyl sprays on yield of red clover and apothecia of S. trifoliorum

benomyl sprays 1972–73	Dry matter yield (t/ha) 25 June 1973	Dry matter yield (t/ha) 3 September 1973	Approximate number of apothecia/m² 25 October 1973
None	5·58	4·23	13·9
September and October	5·57	4·56	4·0
October and November	6·59	4·82	8·3
November and December	6·23	4·86	0·4
September to January (5 sprays)	7·37	4·53	0·2

Diseases of field beans (*Vicia faba* L.)

Virus diseases

Incidence in 1973. In July the weevil transmitted viruses, broad bean stain (BBSV) and Echtes Ackerbohnemosaik (EAMV) (syn. broad bean true mosaic) infected less than 1% of plants in most crops grown from virus-free seed at Rothamsted, but 15–90% in the few crops grown from stocks that contained 0·02–0·7% of infected seeds. Serological tests showed that BBSV was commoner than EAMV in infected seedlings but vectors spread EAMV much more, particularly during and after flowering. The most important vector of both viruses (*Apion vorax*) was less common during May than it was in 1970, when there was much spread of BBSV. However, populations increased to 18 $\times$ 10³/ha in June compared to 19, 4 and 1·5 ($\times$10³/ha) respectively, in June of 1970, 1971 and 1972.

The most prevalent aphid transmitted viruses were the complex of bean yellow mosaic and pea mosaic (BYMV/PMV) but although up to 30% of plants were infected, the viruses were spread late and caused little damage. Bean leaf roll virus (BLRV) infected up to 15% of plants.

Table 16 shows the virus infection in July and yield of four varieties drilled in March. Of the Maris Bead seed 0·7% were infected with BBSV/EAMV but seed of the other varieties was uninfected. Before flowering in June, less than 3% of Maris Bead and 1% of other varieties showed symptoms of BBSV/EAMV, so subsequent spread was both rapid and extensive. Maris Bead and Minor yielded, respectively, 23 and 13% less than Minden (P = 0·01 and 0·05) and Maris Bead 13% less than Herz Freya (P = 0·05). However, the Maris Bead in this variety trial yielded 33% less than the same variety in an adjacent experiment where only 0·02% of infected seeds resulted in only 20% of plants infected with BBSV/EAMV in mid-July.

Extreme variations between crops resulting from different seed infection and activity of vectors seems to have been common during 1973. Thus BBSV/EAMV ranged from 0–70% in three other Hertfordshire crops (examined for an Agricultural Development and Advisory Service survey) and, between varieties in National Institute of Agricultural Botany trials, from 0·1–0·8% in Norfolk, 0·4–3·6% in Cambridge and 6–23% (with

TABLE 16

Virus incidence and yields of different field bean cultivars

Variety	% plants infected in July BBSV/EAMV	% plants infected in July BLRV	Yield (t/ha)
Herz Freya	40	25	3·58
Maris Bead	87	7	3·10
Minden	49	20	4·05
Minor	85	5	3·51
S.E. of difference			±0·205

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much *Apion* damage) in Hampshire. Over the same sites BLRV ranged from 1–19%, and BYMV/PMV 0–23%.

Catches of airborne weevil vectors. The catches (at 12·2 m a.g.l.) from suction traps (see p. 193) were again examined for *Apion* and *Sitona* spp. *Apion vorax* was rarely caught; one each in traps in Essex, Derbyshire and Berkshire and four between the three traps at Rothamsted. As populations reached 18 000/ha in bean crops at Rothamsted during June, this method plainly cannot be used to indicate infestation of crops.

Transmission of BBSV and EAMV by weevils. Glasshouse tests confirmed that *A. vorax* transmits EAMV more readily than BBSV. EAMV was transmitted by 10, 50, 70 and 60% of weevils caged on infected plants for, respectively, 1, 8, 24 and 48 hours and then on healthy seedlings for three days; corresponding results for BBSV were 0, 0, 10 and 30%.

Seed transmission of BBSV and EAMV. In the glasshouse BBSV was transmitted through 4–16%, and EAMV through 2–5% of seeds from Frank's Ackerperle, Herz Freya, Maris Bead, Minor and Tarvin plants that were infected before flowering. We do not know if pollen transmission occurs among crops but 2 of 382 seeds were infected when uninfected emasculated plants were pollinated from BBSV-infected plants. No seeds were infected from plants comparably treated with pollen from EAMV-infected plants.

Heat treatment of infected seed stocks. Continued efforts to rid infected seeds of virus or to prevent emergence of infected seedlings were unsuccessful in field experiments that followed promising laboratory tests. Only two-thirds of a Throws MS stock (treated four days at 55–60°C, initial water content 14%) produced seedlings. Although the treatment decreased the proportion infected with EAMV, the proportion with BBSV was unchanged. In another experiment there was no germination from similarly treated Maris Bead (12% water content). Although it now seems very unlikely that heat treatment can be practical, a further field test will be made of seed treated 1 hour at 80°C.

The value of roguing to decrease seed infection. Last year (*Rothamsted Report for 1972*, Part 1, 143) we commented on the success of roguing in a year when *A. vorax* was scarce. During 1973 we confirmed our expectation that it would be difficult when vectors were common. Plots grown from a seed stock containing only 0·02% BBSV/EAMV-infected seeds were rogued three times between early May and early June, but roguing was abandoned in late June when 18% of plants were infected and 11% in plots rogued and sprayed with insecticide. Much of this infection may have spread from adjacent unrogued plots, and from a badly infected crop grown about 100 m away.

Glasshouse tests on samples of 800 seeds/treatment suggest that insecticide plus roguing was useful in limiting seed infection. However, much larger samples would be required to test accurately for amounts of infection like that in the parent stock. (Cockbain, Davies and Vorra-urai)

Effects of pesticides on viruses and vectors. Aldicarb (5 kg a.i./ha) applied to soil before drilling decreased the incidence of BBSV/EAMV in plots sown with infected seed (0·1–0·3%), but not in adjacent plots sown with healthy seed. It decreased adult populations of *S. lineatus* but not of *A. vorax* (see p. 246). Elsewhere at Rothamsted aldicarb failed to check the spread of BBSV/EAMV in plots sown with 0·7% infected seed. (Cockbain)

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Applying insecticides to foliage had more effect on weevils. Two days after spraying in late May, populations of *A. vorax* were decreased by 89–97% and *S. lineatus* by 94–95% by fenitrothion (0·85 kg a.i./ha), malathion and methomyl (both 1·0 kg a.i./ha). Spraying with gamma-BHC (0·5 kg a.i./ha) decreased *A. vorax* by 94% but *S. lineatus* by only 65%. However, reinfestation of the plots was rapid, so that after eight days sprayed plots had as many *A. vorax* as unsprayed plots. Reinfestation by *S. lineatus* was slower, especially after treatment with methomyl. Second sprays in late June had similar effects on weevils and all, but especially fenitrothion, decreased *Aphis fabae* and *Acyrthosiphon pisum*.

Phorate (1·0 kg a.i./ha as granules) was less effective than sprays against *A. vorax* but among the most effective against *S. lineatus* and aphids. All insecticides significantly increased yield, malathion least (24%) and fenitrothion most (38%). Little BBSV/EAMV spread because the seed was healthy, and BYMV/PMV spread too late to be damaging. (Cockbain, with Etheridge, Insecticide and Fungicide Department)

Other pests and diseases. Wilt was not serious in the seventh consecutive crop of spring beans on part of Barnfield. Table 17 shows that formaldehyde, aldicarb and 'Dexon' applied before sowing again increased crop height and yield. Formaldehyde decreased wilting but failed to control stem eelworm (*Ditylenchus dipsaci*), *Rhizoctonia*, *Pythium* or root rotting. Aldicarb and 'Dexon' decreased *Pythium*, wilt and root rot equally but only aldicarb decreased stem eelworm. Aldicarb had decreased *Pythium* in 1970 but although it usually decreases wilting we have not shown that it made *Phytophthora megasperma* less common. The greatest yield and healthiest roots occurred where all three chemicals were applied; formaldehyde gave most benefit alone and aldicarb and 'Dexon' were equal; while BHC had least effect. Unlike 1972 when formaldehyde and 'Dexon' decreased the prevalence of mycorrhizal infection by *Endogone* spp., none of the chemicals affected it in 1973 and 62% of segments were infected in July.

TABLE 17

Effect of chemicals on yield, pests and diseases of field beans, Barnfield 1973

Treatment[1]	Yield, t/ha	Height, cm	Plants wilted 30 July, %	Plants infected with *D. dipsaci*, %	Root[2] disease rating in July, %	Root segments (1 cm) with: *Pythium* %	Root segments (1 cm) with: *Rhizoctonia*, %
Nil	2·71	105	12·0	94	56	45	8
'Dexon' (F)	3·80	110	8·4	96	32	10	12
aldicarb (N)	3·83	115	8·7	3	27	10	50
BHC (I)	3·22	108	8·8	88	41	48	40
formaldehyde (B)	4·00	116	8·7	93	47	30	52
F + N + B	4·16	131	2·9	4	18	15	25
SED	±0·347						

[1] Rates (active ingredient/ha):
'Dexon', 78·5 kg
aldicarb (granules), 11·2 kg
BHC (emulsion), 4·48 kg
formaldehyde 3000 litres of 38% solution

[2] Weighted assessment: '0' healthy to '100' completely diseased, for details see *Proceedings of 6th British Insecticide and Fungicide Conference 1971*, **1**, 251–257

On Barnfield we have encouraged root diseases by growing beans annually. Only there had we found *P. megasperma* causing wilt until it occurred in 1973 on beans in rotation on the heavier parts of Warrenfield and Broad Mead at Woburn, where waterlogging had occurred in May. Bean crops in rotation at Rothamsted showed considerable infection by *Endogone*, little by *Pythium* or *Rhizoctonia* and none by *Phytophthora megasperma*.

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Neither aldicarb nor 'Dexon' increased yield significantly (see p. 207). (Salt and Hornby)

Potato diseases

During the next few years more and more ware crops will be planted with seed produced from rooted stem cuttings (*Journal of the Royal Agricultural Society of England* (1970) **131**, 87–106) through the VTSC (virus tested stem cutting) Grade. This procedure aims to increase yield and to improve the health of seed tubers and ware crops. Present problems include maintaining the health of these stocks and testing their benefits to agriculture (*Rothamsted Report for 1972*, Part 1, 147). '*Healthier*' seed in later paragraphs signifies that tubers originated from the produce of rooted stem cuttings (but often before official VTSC certification began) and implies the best health that we have so far achieved in Scotland or at Rothamsted, rather than complete freedom from diseases.

Since 1969 we have had an exceptional sequence of dry summers. Potato growers have welcomed the relief from severe attacks of potato blight (*Phytophthora infestans*) and bacterial diseases. Fortunately little research on blight has been attempted but 1973 was the fifth successive season when our weather inhibited spread of *Erwinia* spp. and another season when pink rot (*Phytophthora erythroseptica*) failed to develop where we intended, although it considerably modified the yield of harvestable tubers on some plots on the wetter parts of Barnfield. This unusual weather has led to some experiments being prolonged in the hope of testing wetter conditions and continues to restrict the conclusions that we can draw about the average development and effect of most tuber pathogens.

Bacterial soft rots

Activity in soil. Dry soils and temperatures at tuber depth often exceeding 16°C, probably explain why symptoms of blackleg (*Erwinia carotovora* var. *atroseptica*) were seldom seen except following artificial inoculation and why we learnt so little of what we hoped from most of our experiments designed to measure bacterial spread and infection. Evidence of these effects came from vertical tubes filled with soil infested with *Erwinia* spp. buried in soil to a depth of 15 cm. After six weeks burial from 12 June, 24 July, 4 September and 23 October initial populations had decreased from 10^8 cells/g soil, respectively, to approximately 10^2, 10^2, 10^5 and 10^6 cells/g soil. Survival obviously increased as moisture increased and temperature decreased and rather more survived in sterile than unsterile soil but *E. c.* var. *atroseptica* differed little from *E. c.* var. *carotovora*.

Nevertheless we hope that the dry seasons have allowed us to improve methods of ensuring meaningful results should unfavourable conditions recur. In some tests of spread by machinery this will involve irrigation or waterlogging plants grown in a following season from sample tubers. During 1973 we also seemed to have been more successful in labelling sources by inoculation with, and later recovering, a strain of *E. c.* var. *atroseptica* (supplied by Mr. Elis Jones, Agricultural Development and Advisory Service, Cambridge), which is identifiable by an unusual pattern of bacteriophage specificity.

Assessing bacterial contamination of tubers. We have been developing a method (the 'bucket test') in which 40 tubers are held for seven days at 15 or 20°C in damp air-tight polyethylene buckets from which all but 2–4% of the oxygen has been replaced by carbon dioxide or nitrogen. Tuber respiration exhausts most of the remaining oxygen giving anaerobic conditions that encourage growth of several tuber-rotting genera of bacteria. At present, therefore, the test reliably reflects how well potato tuber stocks will tolerate anaerobic conditions but is not selective enough to discriminate the potential rotting by *Erwinia* spp. from that caused in the test by bacteria such as *Pseudomonas marginalis* and *Bacillus polymyxa*, species that are less pathogenic in aerobic stores. Table 18

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shows rotting potential estimated by several methods on King Edward stocks shown to have large and small bacterial populations and risks of rotting in store. The bucket test seems comparable to the polythene bag test suggested by Pérombelon (*Annals of Applied Biology* (1972) **71**, 111–117) but allows more tubers to be tested for the same effort and less mess.

TABLE 18

The contrasting bacterial contamination of two potato stocks assessed by different methods

Stock		Large risk	Small risk
No. of *Erwinia* spp./lenticel		1200	7
Test (No. of tubers tested)		% tubers rotting	
Bucket (60)			
15°C	CO_2	32	0
	N_2	75	13
20°C	CO_2	82	22
	N_2	75	2
Polythene bag (20)			
15°C	Air	75	0
20°C	Air	80	30

Where potato crops have to be harvested, washed and packed before maturity, bacterial soft rots are often serious. Using King Edward tubers lifted prematurely from stocks differently contaminated with *E. c. atroseptica*, we tried to decrease rotting, as measured by the bucket test, by dipping for 5 minutes in different chemicals or curing for seven days at 20°C. 'Bronopol' (Boots Ltd., Nottingham) was the most effective chemical especially at 2% a.i. but was also phytotoxic at more than 1%. Curing was usually as good as any of the chemical treatments. (Lapwood and Legg)

The infection of tuber lenticels. The actinomycete *Streptomyces scabies* that causes common scab does not infect tuber lenticels in wet soil although it infects young lenticels when the soil is dry (*Rothamsted Report for 1972*, Part 1, 146). Some evidence suggests that fluctuations in bacterial populations may be partly responsible. Drops of *S. scabies* spore suspension were dried on clean glass slides and used for germination tests. No germination occurred in saturated air at 25°C unless the surface was wetted with water, or better, with dilute solutions of sugars or potato extract. Wetting with a dense suspension of *Bacillus subtilis* prevented germination or mycelial growth from germinated spores. Bacterial suspensions and their culture filtrates (supernatants) decreased germination of *S. scabies* proportionally to their concentration. Cultures of other bacteria isolated from tuber surfaces also decreased germination, thus supporting the hypothesis that it is an increase in the bacterial populations of tuber lenticels, or antibiotics they produce, that inhibits infection by *S. scabies* more than the soil moisture itself. (Adams)

Gangrene (*Phoma exigua* var. *foveata*)

Effect of storage temperature before wounding. There is much evidence from experiments and farms that riddling or wounding after cold storage increases gangrene. Tubers stored at 2° and 5°C before wounding developed (at 5°C) more gangrene than tubers previously stored at 15° or 20°C but the lesions were not so large. Another experiment showed that size of lesions increased with between 0 and 18 days pre-wounding storage at 20°C but no more when stored for 18–28 days. Larger lesions developed on tubers stored (four weeks) at 10°C or warmer than at 5°C before wounding, inoculating with *P. exigua* var. *foveata* and then storing for six weeks at 5°C.

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Effect of tuber maturity on incidence of gangrene. Tubers lifted early, wounded and stored at 5°C usually develop fewer lesions than tubers lifted later. However, these tests do not differentiate changes in susceptibility to the establishment and spread of *P. exigua* in tissues from changes in density of inoculum. The infectivity of soil to slices of old Arran Banner tubers did increase similarly, indicating increased infectivity. The number of lesions that developed on King Edward and Majestic tubers, wounded and inoculated uniformly, decreased with later lifting between August and October but tubers sampled from store between October and February developed increasing numbers of lesions.

Tuber-borne inoculum. During 1972, soil and tubers were periodically sampled from plots planted with Pentland Crown tubers from the same stock but with or without gangrene lesions. On six dates progeny tubers were lifted, wounded and stored at 5°C and adherent soil was inoculated to test slices of Arran Banner tubers. On samples taken in September, plots planted with seed bearing lesions produced tubers with most lesions and most infective soil but the produce of seed without lesions produced more gangrene from October samples and in storage.

In September the side of some ridges was carefully removed to allow soil sampling adjacent to seed tubers and at 5 cm intervals between them. Tests on Arran Banner tuber slices showed soil adjacent to seed tubers with lesions was less infective than that around seed tubers without lesions. Infective soil samples were erratically scattered between lesion-bearing seed tubers whereas they were much more densely clustered around lesion-free seed from this heavily infected seed stock. (Griffith)

Relationship between diseases of seed, plants and stored tubers. This investigation, in collaboration with the Potato Marketing Board Experimental Station at Sutton Bridge, Lincolnshire, aims to test whether the crops that are likely to be troublesome because of diseases in storage can be identified from their seed or growing plants. Such tests can never hope to do more than measure *potential* disease because the expression of symptoms from tuber-borne inoculum depends so much on conditions at lifting and in store.

As in 1971–72 once-grown seed had much less gangrene than imported certified seed (respectively 0 and 6% of unwounded tubers; 2 and 33% of tubers wounded to express potential gangrene). However, this may merely indicate that recent growing seasons have been drier in East Anglia than in Scotland. The two King Edward stocks with most gangrene in store both had much infectivity when sampled in August. Similarly the worst crops for skin spot were predictable from August infection but as in 1972 this date was too early to detect silver scurf (*Helminthosporium solani*) accurately. Bacterial rotting of seed varied widely in the bucket test but was seldom related to the results in August when many more tubers rotted than in samples lifted in October. Increased rotting of August samples has been a consistent feature of these observations and is probably attributable to rots caused by soil-inhabiting *Pseudomonas* spp. (see p. 142 and *Rothamsted Report for 1972*, Part 1, 147). The increase was lessened but not eliminated by curing August samples for seven days at 20°C before submitting them to the bucket test. Most samples that tests indicated to have very little potential for particular pathogens developed little disease in store. Thus there seems hope of identifying the best and worst stocks but there are at present too many unpredictable intermediates to recommend the methods to major purchasers for storage, such as processing or crisping firms.

If the increasing flow to farms of seed stocks derived from rooted stem cuttings succeeds in its objective of decreasing disease incidence it should improve the situation by providing more stocks that we know will store well. In 1972 we took an opportunity to plant 'healthier' tubers alongside commercial crops to be sampled. On average, healthier Pentland Crown seed produced ware with less gangrene potential (11%) than

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commercial seed (23%) but both categories of King Edward seed had 5%. Skin spot incidence also differed, King Edward having respectively 14 and 23% of eyes infected on ware tubers from healthier and commercial seed and Pentland Crown 7 and 16%. There was less silver scurf from commercial than healthier seed of Pentland Crown. (Hide, Lapwood, Legg, Griffith and Bell)

Agronomic effects of healthier seed

Effects of fungicide on diseases and yield. There is now much evidence to support our conclusion (*Rothamsted Report for 1972*, Part 1, 147) that fungicides are required to prevent pathogens recolonising healthy tuber stocks as they are multiplied to commercial amounts. The fungicides most used are benzimidazoles or 2-aminobutane but their effects on produce after crop growth has been compared less than their effect on seed. The first two of a series of experiments involved five varieties on two farms with seed treated in October with 2-aminobutane fumigation (0·28 litre/t of tubers at the Department of Agriculture for Scotland) or in January with thiabendazole and benomyl (both 5-minute dips, 0·1% a.i. at pH 3). There was little difference in yield but benomyl and thiabendazole decreased *Oospora pustulans* and *Helminthosporium solani* more than 2-aminobutane.

Comparison of yields from commercial and healthier seed stocks. Continuing the experiment begun in 1972 to estimate the benefits of healthier seed we grew our healthier seed in comparison with ten certified and ten once-grown stocks of King Edward collected from farms in East Anglia. Table 19 shows that healthier seed yielded 10% (total) and 12% (ware) more than the averages of both certified and once-grown seed. (Hide and Bell)

TABLE 19

Comparison of yields from healthier, certified and once grown seed

Yield (t/ha)	Healthier	Certified	Once grown
Total	48·9	Mean 44·1 Range 40·7–47·2	Mean 44·5 Range 41·2–47·7
Ware (>4·4 cm)	38·0	Mean 34·1 Range 29·3–38·3	Mean 33·7 Range 29·7–36·9

Effects of spacing and fertiliser on King Edward and Pentland Crown. Earlier experiments (*Rothamsted Report for 1972*, Part 1, 149) showed that the proportion of ware-sized tubers yielded by healthier King Edward crops was increased by decreasing the plant population. Realising that the habit of growth and tuber formation of Pentland Crown, the commonest maincrop variety, is very different we included it in our 1973 experiment.

Table 20 shows that the yield of King Edward ware potatoes (>4·4 cm, 1¾ in) was 8% larger from 71 cm (28 in) rows than from 91 cm (36 in) rows. Doubling the usual fertiliser dressing increased yield by 11% in the narrow and 7% in wider rows. Decreasing the number of King Edward tubers planted from 37·1 to 22·2 thousand/ha increased ware yield a little in both wide and narrow rows but giving double fertiliser to the smaller population increased yields little further.

Pentland Crown gave larger yields of ware potatoes than King Edward (means respectively 57·3 t/ha, 22·8 tons/acre and 38·2 t/ha, 15·2 tons/acre). Unlike King Edward the yield of Pentland Crown was decreased by planting fewer seed tubers, especially in rows 91 cm wide. On average doubling the fertiliser increased ware yield by 9% and increased the yield of oversize tubers (>8·3 cm, 3¼ in) from 0·4 to 1·2 t/ha.

The 1973 experiment showed that with King Edward it was best to plant 22 000 tubers/

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TABLE 20

Effect of plant population and fertiliser on yields (t/ha, >4·4 cm) of King Edward and Pentland Crown

Kg fertiliser/ha[1]	Rows at 71 cm			Rows at 91 cm		
		1510	3020		1510	3020
		(a) King Edward				
Plants/ha ('000)	Spacing	t/ha		Spacing	t/ha	
37·1	(38 cm)	36·6	40·8	(30 cm)	35·1	34·4
29·7	(48 cm)	37·0	42·3	(38 cm)	34·9	40·3
22·2	(61 cm)	39·6	42·0	(48 cm)	36·2	39·0
		(b) Pentland Crown				
37·1	(38 cm)	56·1	61·4	(30 cm)	56·5	60·1
29·7	(48 cm)	56·1	61·8	(38 cm)	51·6	57·0
22·2	(61 cm)	55·5	61·8	(48 cm)	53·8	55·5
SE ± 1·464						

[1] Containing 13% N, 13% P_2O_5, 20% K_2O

ha in 71 cm rows because more fertiliser was needed to obtain the same yield in wider rows. Planting Pentland Crown in narrow rows also almost always gave the greater yield. (Hide with Widdowson, Chemistry Department and Moffatt, Farm)

Effects of irrigation on King Edward crops. Healthier King Edward tubers usually produce plants with more and smaller tubers than those from diseased commercial stocks. It has also been said that irrigating early, as we recommend to control common scab, may do the same. Plots planted with seed averaging 25 g or 126 g (spaced 38 cm apart in 71 cm rows) from healthier and commercial stocks were unirrigated, irrigated early (from 75% emergence, 22 May, at 15 mm soil moisture deficit (s.m.d.) until 'marble stage', 30 June, then at 38 mm s.m.d.) or irrigated normally (from marble stage at 38 mm s.m.d.). On 19 September normal-irrigation plots planted with commercial and healthier seed yielded respectively 13 and 26% more than unirrigated. Normal irrigation tended to increase the size of the larger tubers but early irrigation encouraged the formation of more tubers especially those of 3–5 cm. There was more *Oospora* and *Rhizoctonia* following irrigation of farm seed but less *Helminthosporium*. Irrigating did not affect the diseases of healthier seed. (Hide and Bell)

Tests measuring the effect of irrigation on gangrene in this experiment are not yet complete but results from the 1972 experiment (*Rothamsted Report for 1972*, Part 1, 149) show that 'early' or 'normal' irrigation increased only gangrene caused by *Phoma exigua* var. *foveata* whereas irrigating only in August (late) increased only rots caused by *P. exigua* var. *exigua*.

Of 200 isolates from pycnidia on stem lesions all but one were *P. exigua* var. *exigua* so the importance of stem infection needs further investigation. (Griffith)

The activity of fungicides against tuber pathogens

The absorption and movement of benzimidazole fungicides in tubers and soil. The rapid uptake of thiabendazole by potato tuber skin at pH 3, and the difficulty of re-extracting it were confirmed. It was found that methyl benzimidazole-2-carbamate (MBC), the major active principle of many related fungicides, was absorbed most at pH 3 but that tuber skin did not remove so much of it from aqueous solution as of thiabendazole. The amounts of thiabendazole and MBC (derived from applied benomyl) that can

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be extracted from treated tubers depends much on conditions, so differential extraction methods may provide the best way to relate fungicide content and biological activity.

Several compounds have been prepared to help demonstrate fungicide movement and activity in soil. The soluble hydrochloride salts of thiabendazole and MBC were made and the latter used in a soil drench experiment to test activity against tuber diseases. In soil leaching experiments (with G. G. Briggs) [2-^{14}C]MBC and [2-^{14}C]benomyl showed no significant downward movement during six months exposure in the field. Twenty-nine months after soil was treated with an unusually large amount of benomyl (17·8 kg a.i./ha) (*Rothamsted Report for 1970*, Part 1, 153), soils and potato haulms were assayed. No benomyl or MBC were found in haulm but 30–80% of the amount applied was re-extracted from the soil with acetone : *M* ammonium chloride (1 : 1 v/v) at pH 7. The MBC recovered from each of five plots was inversely related to soil pH but was not affected by changes in the pH of the extractant. The implication is that processes related to soil pH had altered the quantity of MBC recoverable. The efficiency of the assay was tested using [2-^{14}C]MBC. About 15% of the labelled chemical was lost on soil within 2 hours and no more within five days. A further 5% was lost during re-extraction of the MBC. Further treatment of the soil with 0·1*N* hydrochloric acid extracted only 18% of the remaining MBC but this had a lower specific radioactivity than expected. (Austin)

Survival of pathogens in treated tubers. In a complementary field experiment seed tubers with skin spot and silver scurf were treated with benomyl and thiabendazole. At the end of the growing season the remains of seed tubers were lifted and incubated in humid conditions. *Oospora* and *Helminthosporium* sporulated on the skin of untreated tubers only. However, when the internal tissues were cut away or had rotted to reveal the undersides of skin spots or the skin of treated tubers, both fungi sporulated profusely. Thus it seems that lethal or fungistatic concentrations do not penetrate tuber skin in even ten months. Furthermore, fungicide-treated seed tubers may conceivably produce healthy progeny yet still contribute inoculum residues to the soil when the crop is lifted. (Hide)

Potato aphids and top-roll. The symptoms of top-roll, often confused with those of leaf roll virus, develop on plants on which the aphid *Macrosiphum euphorbiae* has fed. However, tubers from King Edward and Majestic plants affected by top-roll in 1972 produced plants normal in appearance and yield in 1973. There were fewer aphids on potatoes at Rothamsted in 1973 than in 1972. *Myzus persicae* and *Macrosiphum euphorbiae* were the commonest species and they reached maximum numbers early (end of June), so top-roll affected fewer and younger plants than in 1972. Aphid populations quickly decreased and later growth on potato stems was normal even on plants that still showed top-roll symptoms on lower leaves. (Gibson and D. Boyes)

Aphid-catching glandular hairs transferred to *Solanum tuberosum* hybrids. Foliage of the wild potato *Solanum berthaultii* bears glandular hairs that, on contact, release a liquid that glues aphids to the plant. This character which could provide a useful mechanism of aphid resistance has been found in hybrids of *S. berthaultii* with *S. tuberosum* (cv. Pentland Crown) one of which is a fertile tetraploid and will be tested further. (Gibson)

The incidence of tuber diseases 1972–73

National survey of fungal diseases of seed tubers. There were fewer tubers affected with blight, gangrene and skin spot than in any other year since the survey began in 1963.

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Among the 2500 tubers each of King Edward and Pentland Crown only, respectively, 2 and 3 had blight (Table 21). Gangrene affected 3 and 6% of chitted tubers at planting or 13 and 18% of sub-samples wounded uniformly and stored cool. There was average incidence on King Edward of black scurf, powdery scab, common scab and *Oospora pustulans* (but fewer showed skin spots). (Hide, Griffith and Bell)

TABLE 21

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

Examined	Disease	King Edward	Pentland Crown
R	Skin spot (*Oospora pustulans*)	26/88	24/78
P	Gangrene (*Phoma exigua*)	3/44	6/62
P	Dry rot (*Fusarium solani*)	1/30	3/52
R	Blight (*Phytophthora infestans*)	<1/4	<1/4
R	Black scurf (*Rhizoctonia solani*)	23/96	26/94
R	Powdery scab (*Spongospora subterranea*)	18/80	2/46
R	Common scab (*Streptomyces scabies*)	29/94	12/80
Number of stocks examined		50	50

R = at receipt; P = at planting

Potato viruses diseases at Rothamsted. Most experiments planted with seed grown in 1972 at Rothamsted contained few plants infected with potato virus Y or leaf-roll (0·2% PVY and 0·1% LR in King Edward; none in Pentland Crown). One experiment included King Edward with 2% PVY and in these plots an early aphid invasion spread the virus considerably so that by mid-season 13% of plants showed the leaf drop streak primary symptom. Neither leaf-roll nor potato virus Y was detected in isolated crops grown to provide seed for 1974. (Govier)

Staff and visiting workers

Those appointed to the research staff were: M. J. Adams, D. J. Austin, A. J. Dabek (ODA Research Fellow to study virus diseases of tropical crops), M. E. Finney, P. Jones. Those who left were: Sara M. Davis (*née* Cook), and Vivienne Pearson. P. Bartlett, D. Boyes, Pauline Cross, J. E. Geary and Hazel E. Jenkins worked as sandwich course students from April to September.

Visiting workers included Dr. T. G. Atkinson, Lethbridge (Canada), Dr. S. U. Déspandé (India), Dr. S. Gianinazzi (Dijon, France), S. Misari (Nigeria) and Mr. S. Vorra-urai (Thailand). Mr. R. A. Hill and Mr. B. D. L. Fitt worked on Agricultural Research Council Scholarships. Dr. A. M. S. Pope completed the work on a Home-Grown Cereals Authority Grant on take-all. Dr. P. H. Gregory continued working at the invitation of the Lawes Agricultural Trust.

On behalf of the Overseas Development Administration, R. H. Kenten returned to Ghana on secondment to the Cocoa Research Institute. S. J. Eden-Greene was appointed to the department and then seconded to work on lethal yellowing of coconut in Jamaica. J. M. Hirst, D. Hornby, J. Lacey, D. H. Lapwood and C. J. Rawlinson attended the 2nd International Congress of Plant Pathology in Minneapolis in September. R. T. Plumb visited the Solomon Islands during March to advise on virus diseases of *Colocasia* and to collect potential vectors. J. Lacey lectured at The Prince Leopold Institute of Tropical Medicine, Antwerp, in April.

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