ROTHAMSTED RESEARCH

Report for 1981 - Part 1

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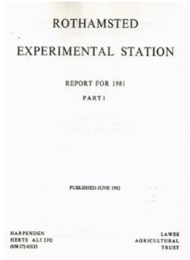
ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1981
PART 1

Entomology Department

T. Lewis

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TABLE 1

System utilisation

	1980		1981	
	4–70	4–72	4–70	4–72
	%	%	%	%
Production time				
Day supervisor	55·0	60·3	61·2	63·1
Night supervisor	25·2	23·6	26·0	24·0
Housekeeping	8·4	7·5	6·5	6·3
System work	3·8	5·0	3·8	4·2
	92·4	96·4	97·5	97·6
Non-production time				
Failures (all cases)	6·6	1·8	2·4	2·3
Engineering	1·0	1·8	0·1	0·1
	7·6	3·6	2·5	2·4
	100·0	100·0	100·0	100·0
Operational time (hours)	4219	4042	3985	3876
Working days	252	252	251	251
Operational time (day-hours)	16·7	16·0	15·9	15·4

TABLE 2

Distribution of work by Institutes

	ETU		JOBS		Work Units	
	1980	1981	1980	1981	1980	1981
Total	6 170 075	6 352 530	407 075	431 950	14 159 489	15 233 877
	%	%	%	%	%	%
RES						
Computer Dept.						
Systems	18·6	18·4	11·8	10·8	5·4	5·0
Applications	5·5	5·1	10·8	7·4	5·3	4·7
Total	24·1	23·5	22·6	18·2	10·7	9·7
Statistics Dept.	14·0	12·8	8·3	8·5	18·5	15·9
Other RES Depts.	12·3	9·9	5·6	5·4	13·8	11·2
Total	50·4	46·2	36·5	32·1	43·0	36·8
NIAE	10·7	11·7	12·2	11·7	8·9	11·6
GRI	5·5	7·0	5·7	9·6	6·7	8·0
IRAD	3·7	5·3	8·0	11·5	4·4	6·3
NVRS	4·5	5·2	6·2	6·4	5·5	5·8
MRI	4·8	4·1	2·7	2·2	7·2	6·4
NIRD	3·7	3·7	5·6	5·6	3·5	4·1
LARS	2·4	3·6	2·0	3·0	2·7	4·0
EMRS	3·8	3·3	5·2	4·1	4·3	3·9
GCRI	3·5	2·4	5·7	3·9	4·4	3·3
LL	1·2	1·3	2·3	2·4	1·6	1·9
Man. Services	0·9	1·0	1·3	1·4	1·0	1·1
WPBS	1·1	1·0	0·9	0·9	1·3	1·2
WRO	1·1	1·1	2·3	2·1	2·3	2·1
SSEW	0·7	1·4	1·3	1·0	0·9	1·7
Others	2·0	1·7	2·1	2·1	2·3	1·8
	100·0	100·0	100·0	100·0	100·0	100·0
Average per working day	24 484	25 309	1 615	1 721	56 188	60 693
Increase over 1980 total	+2·96%		+6·11%		+7·59%	

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Individual site workloads are as variable as ever. The work done by the Statistics and Molecular Structures Departments at RES has dropped markedly on System 4, though they both now use the P550 also. NIAE's load has increased substantially as has that of GRI and IRAD. Large changes in a site's load can often be traced to a small number of users and even to a single individual.

A third interactive stream has been introduced to accommodate the larger programs that users wish to use in this manner. This was possible following the enhancement of the 4-72 main memory for a very small cost thus allowing better utilisation of its cpu power, the most limited resource. Efficiency improvements have also been made to both systems during the year, estimated at a minimum of 10%, but only introduced in the fourth quarter.

Lost time has been reduced from 347 hours to 185 hours, the result of much improved availability on the 4-70 and less engineering work during scheduled hours. The number of failures (Table 3) has been reduced overall, the largest reduction being on the 4–70 hardware.

TABLE 3

System failure distribution

	1980			1981		
System	4–70	4–72	Hours lost	4–70	4–72	Hours lost
Software	20	49	14	28	51	17
Hardware	154	91	312	81	101	146
'Other'*	21	16	21	28	17	22
Total failures	195	156		137	169	
Total hours lost			347			185

* Power supplies, operator errors, etc.

Front End Processors. The two front end processors (FEPs) support interactive and batch systems separately. The interactive service is given priority at the expense of batch operation should one FEP fail, although this is reversed for short periods following any long failure to enable the five remote batch systems to receive output and send input. The number of failures on the interactive FEP system has increased to 1·3 per day and availability is 0·6% down at 97·3% (Table 4). While the batch FEP system failures have been substantially reduced by both hardware and software investigation and correction, the available time is below 92%. DPCE, who took over responsibility for maintaining these equipments just before the beginning of this year, have worked hard on them during the year, but further work will be necessary.

TABLE 4

Service availability via FEP

	Service		User Image*	
	1980 %	1981 %	1980 %	1981 %
Interactive 716	97·9	97·3	97·2	96·4
Batch 716	88·9	91·1	86·9	89·9
Interactive 716+4–70	96·2	95·7	95·0	94·5
Interactive 716+4–72	96·6	95·8	95·6	94·6
Batch 716+System 4's	86·3	88·8	83·5	86·9

* User image figure includes time allowance for recovery purposes.

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Prime. In comparison with the older technology of System 4, the operational attraction is reliability. There have been nine system failures in 11 months, plus a handful of device faults. It also requires little manpower to operate it. Detailed operational data is not yet available on the Prime but utilisation is estimated to be about 25% from week 9. The introduction of NVRS to the service has occasionally degraded the response and steps are in hand to avoid further development of this situation. The Molecular Structures Department has used the equivalent of approximately 254 000 etu on System 4, and the Statistics Department approximately 44 000 etu out of a total load of 525 000 etu (approximately 750 cpu hours).

Software

System 4. Little work will be done on System 4 beyond the end of the current year. Only those items which relate to future systems, new applications or essential extensions of existing ones will be considered. During the year several new and improved items were introduced, they included: BENSON plotter software to improve reliability and throughput; efficiency improvements to the operating system and some utilities; and job management alterations including a third RIRO stream. A more versatile interface to the '2780' protocol and file transfer with the P550 are nearing completion.

Prime. A service for RES Molecular Structures and Statistics Departments was introduced in March. Little work has been done on the system provided by the manufacturer, but some work has been done on the latest version known as Revision 18 and some of the missing management facilities are being inserted. The data management package INFO was acquired under licence and made available to NVRS. EMRS are also interested in using the INFO package for their research records.

Documentation. The Operations Advisory team are now responsible for the distribution of documents. These are listed in Appendix 1.

Microprocessor System Section

The Section was formed in April this year out of the original Telecommunications Section. The title reflects a new and important field of interest within the ARS but one which retains close links with telecommunications.

Microprocessors. Earlier this year the ARC Computing Committee supported a proposal that there should be a centre of expertise for the application of microprocessors to scientific work within the ARS. It was expected that this would encourage users to work to guidelines, if not standards, presented by this group and this enables a broader community of users to share and contribute both to hardware and software developments.

With the advice of Professor Martin Healey (University College, Cardiff), a member of the ARC Computing Committee, the following equipment was purchased. One North Star Horizon; two Superbrain QD systems; two MIDAS 3D systems; one MIDAS special; one Intersystems DPS-1 system; one Watanabe flat-bed plotter; one Data type Tektronix emulating VDU; one Lear Siegler serial printer; one Anadex serial printer; two graphics tablets; and one cassette reader.

This equipment uses the CP/M operating system, one of the most widely distributed systems available today. This gives users access to a large and growing number of languages and application packages, of which the following have already been obtained; FORTRAN, BASIC, PASCAL, WORDSTAR, DATASTAR and d-BASE II. The Midas systems also embody the S-100 bus, which enables a variety of equipment to be

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attached and seems likely to become a standard for the industry. The following lists the more important tasks already in hand.

Initial developments. Because of the pressure to complete outstanding tasks on the service network and also because of persistent staff losses, the effort available was less than one would have wished given the urgency of the tasks. All systems were configured for CP/M and staff, including those from other Sections, have been able to familiarise themselves with the various facilities.

Microsystems inter-connection. One of the first tasks was to devise a protocol for linking microsystems. This was accomplished by A. Windram (GRI), in collaboration with the Section on the methodology. The next task was to link these systems to larger computing facilities and a solution was developed from a package available from Dr R. A. Haskins, Loughborough University. The extended system allows CP/M based microcomputers either to emulate a VDU to a Prime or to permit the interchange of files between them.

Modifications to the Prime software was carried out by the Operations Section (Williams). This version is fully operational and is used between the Superbrain based at NVRS and the Prime 550 at Rothamsted.

This software is also the basis of further development, already in hand, which will include: attachment of microsystems to System 4, initially as VDUs; remote monitoring of other CP/M systems, which will be particularly useful for software and advice to users at other Institutes; a general purpose CP/M system which will speed up the assessment and testing of the ever increasing range of peripheral devices.

Peripheral connections. Work is also well advanced on the following:

Image data tablet. This is a technique which will enable spatial data to be tracked by a handheld 'pen' and the results transmitted to a local microsystem. This promises to be particularly useful in laboratory situations.

Printers. A single program has been written which will deal flexibly with problems which arise when matching a range of printers to a given configuration.

Flat bed plotting. A system has been designed and partially written to provide an interface between a high level language and a local plotter. It is expected that some of the existing System 4 routines may eventually be mounted on a microsystem.

The 5·25 in. and 8 in. diameter discs are increasingly used for 'off-line' data capture. This data must eventually be transferred to the mainframe and a system has been designed which will route such data to the System 4 via the Prime.

Another system will capture a store image of either of the network processors and be transferred to a microsystem. This will enable error diagnostics to be carried out off-line thus allowing a rapid restoration of the service.

The next phase. There are still many development opportunities ahead for these systems. The widespread interest was confirmed by the attendance of over 200 actual and potential users to the demonstrations which had been arranged for Rothamsted and ARC staff. One immediate result has been the purchase of CP/M Midas systems by Entomology and Soil Microbiology Departments where they are to be used to gather and organise experimental data directly.

These systems can also play an important role in meeting general application computing needs and will be particularly valuable when the experimenter wishes to perform an interactive analysis of the data. The availability of larger backing store systems opens up new opportunities for personal or laboratory databases. The emergence of

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network protocols will enable data to flow freely between linked systems. However, all CP/M systems suffer from the limitation of a maximum of 64 kilobyte memory and this, more than anything else, constrains their usefulness to modest FORTRAN application packages.

Larger memory systems ranging from at least one to 16 megabytes will be available in the new range of microsystems already beginning to appear on the market. Such systems may be sufficiently powerful to serve several independent users simultaneously; alternatively they could be cheap enough to become used as powerful personal computing work stations dedicated to a research team.

Telecommunications. Although microsystems have been given pride of place in the Report, the Section has also devoted considerable effort to finishing outstanding developments and incorporating new equipment on the established network. For most practical purposes the operational responsibility for the network has now been transferred to Operations but with support from the Section if a major problem arises.

Batch front-end processor. The outstanding work enabling files to be transferred from remote card, cartridge and paper tape readers was completed. This work, began in 1979, suffered badly through staff changes and the system was completed finally by the third programmer to undertake the task.

Work was also carried out to improve the performance and to remove many of the residual errors; a more comprehensive message system was devised and introduced.

Interactive front-end processor. All three remote concentrator systems are now in service and have proved to be extremely reliable. These were designed around and implemented on an early microsystem no longer in production. The established principles and lessons of this technique could be carried forward into contemporary systems but the need would have to be justified by future developments in the network. Improvements were made to the performance and operational convenience of the software.

Network. The backlog of equipment together with this year's purchases have been installed and no further significant changes are envisaged. The following is a list of peripherals permanently attached to the network: 68 hard-copy terminals, 21 at 30 characters s^{-1}, 47 at ten characters s^{-1}; 42 VDUs at 60 characters s^{-1}; ten serial printers; seven RJE stations having line printers; two letter quality printers; six paper tape readers; two card readers; four cartridge readers; seven drum plotters; and two microcomputer systems (connected via Prime 550).

Although the number of devices connected to the network has more than doubled since 1976, the average daily occupancy of 14 keyboard terminals fell by about an hour to 2·5 h day^{-1}. Whilst the work throughput of the system has increased the rate of increase of demand, experienced in the early years of the service, has not been maintained. Despite the increase in the number of devices users confirm that the system response has not been degraded and that lack of facilities and difficulties of access are no longer an impediment to growth. There have been several important changes in the service which have led to better utilisation of the facilities and these, in some sense, concealed the true increase in demand. Nevertheless the services seem to be on a plateau and the additional network investment has not apparently tapped new sources of work.

Applications Section

System 4. Although work for System 4 has perceptibly slackened during the latter part of this year, it remains our only general service machine.

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The GHOST system was adopted as our standard graphics package on System 4 before the period under review. It has been enhanced by the provision of high level routines to mimic some of the facilities of the old CIL package and to provide new facilities, the latter particularly in the field of three-dimensional representation. The performance of the Benson plotter has been improved. (Bicknell, Barrett and Summerfield, with Williams, Operations Section)

The GRASP data management system has been enhanced and two courses given. (Clarke, Lessells and Crouch)

Enhancements have been made to the standard editor EE and a new guide produced; minor improvements have also been made to the local implementations of the taxonomic information retrieval program TAXIR and the bibliographic retrieval program FAMULUS. (Hersom)

An attempt was made to mount the statistical program MINITAB but encountered technical difficulties. It was ultimately decided to await improvements in the system software which will allow the worst of these difficulties to be bypassed. This work is expected to be resumed in the New Year. (Hersom and Summerfield)

Improvements have been made to the system for handling the ARCMET database of historical meteorological data, and work started on systems to handle current meteorological data. (Clarke, Crouch and Beasley, with Ford, Management Services Section)

Prime 550. Although the Prime 550 is not a general service machine, some work has been done on it both as a matter of general familiarisation and in the interests of specific customers.

The GHOST-80 and SURFACE II graphics packages have been implemented on the Prime. (Bicknell, Barrett and Summerfield)

The database management systems GRASP and INFO have been made available on the Prime (the latter being mounted by the suppliers) and assistance given to NVRS, who have been using INFO for a trial project. (Clarke, Crouch and Lessells)

Microcomputers. All members of the Section have become involved with microcomputers during the year.

Although much of this work was in the nature of general familiarisation, some specific comparative investigations were made: of the performance of the standard FORTRAN program DECODE (used by the Soil Survey to produce readable text from coded field records) on System 4 and the micros, and of the data management systems SELECTOR and dBASE II. The Section also assisted with the Microsystems demonstrations. (Lessells, Crouch and Clarke)

Training and Advisory Services. Although the Training team has been at half strength throughout the year, every effort has been made to give an adequate service to users and the good reputation which this team has acquired over the years appears to have been maintained.

The video tapes of the standard two-day course 'Introduction to Multijob' course were updated. This course was given four times and the standard UCL three-day introductory FORTRAN course also on video tape, was given three times, both of these exclusive of occasional presentations to individual recruits. There can be no doubt that the decision to use video tape for these courses has proved justified, though it is still necessary for training staff to be in attendance to answer questions and to supervise the practical sessions. The tapes are particularly valuable in enabling new recruits to be trained individually on arrival without imposing an undue burden on the training staff. The standard two-day SNOBOL course was also given once and a new one-day course 'Introduction to Microcomputers Using CP/M' twice.

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The Programming Advisory Service has continued to do valuable work, handling over 300 enquiries throughout the year. Typical activities including debugging user programs, advising on the use of library packages and routines, advising on program design, and writing simple programs to assist users' work (e.g. by rearranging their data into a more suitable format). This important but unglamorous work has long been regarded as one of the strengths of the Department. (Thomas, Barrett and Crouch). There were six issues of the *Newsletter*, amounting in total to 148 pages of text, including several contributions from Institutes. (Thomas)

Miscellaneous Investigations. A new plotting phase was written for the simulation program CSMP. (Bicknell)

An extensive investigation was made to find a suitable data management system for an NVRS Gene Bank Project. This ultimately recommended the purchase of the INFO system mentioned previously. (Clarke, with Mr J. Gilchrist and Dr D. Astley, NVRS)

An active role has been taken in the FORTRAN Specialist Group of the British Computer Society. In particular, this has involved drafting work in connection with possible future FORTRAN standards. (Clarke)

A project has been undertaken to process the aphid data from the Rothamsted Insect Survey, to store and maintain it and to simplify the production of the weekly aphid bulletin. This work is initially being done on System 4 but will ultimately be transferred to a microcomputer. It is intended that it be operational for the 1982 season. (Barrett)

An attempt has been made to identify users' needs for the next range of ARS computers. (Beasley)

Rothamsted General Survey Program (RGSP). The current Mark 2 version of RGSP was released at the end of last year and the past twelve months has, therefore, been one of consolidation. Opportunities to exploit this package have been sharply limited by the small effort available on the project. Beasley returned to take charge of the Applications Section in late April and has acted in a consultative capacity since July with the assistance of Christine Lessells, a part-time worker. As a result only the present customers have been supported with no effort available for seeking out new customers for the current version.

Mark 2 has stood up reasonably well to a year of actual use, though inevitably a few errors have come to light and one or two of them have been rather difficult to locate and cure. Versions are now available for ICL System 4, CDC 7600, ICL 2900, Prime 550, IBM 370 and NCR B-series, and some work has been done on conversion for ICL 1900 and Data General Nova. These conversions have been done out of our control but in general appear to have been performed to a high standard.

The future of RGSP remains unclear and there is concern that the full value has not been obtained from the work already put in over past years. However, further development work, as distinct from the support of the existing program, would not be justified. The batch interface of RGSP is not attractive by modern standards and the provision of a conversational interface in the modern style would require extensive and probably complete re-writing of the program. To do this properly is beyond the resources presently available.

It is important that the lessons learned from RGSP are made known for the benefit of those writing and using survey programs in the future. A start has been made on this in papers which were invited for Dr F. Yates—Eightieth Birthday Issue of Utilitas Mathematica. (Beasley and Church, Statistics Department)

Paradoxically the cessation of development effort in RGSP might cause more notice to be taken of these lessons because in the competitive world of computer packages, com-

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ment by one producer on another's product is at least suspect even when it is objective and sensible.

The list of current RGSP customers is given in the Appendix 2.

Management Services

This seems likely to be the last full report of this Section because in 1982 the ARC Project Costing Scheme will cease, and be followed by the retirement of the Section Head, C. W. Fearne. Project Costing services to the Sea Fisheries Laboratory, MAFF and the Department of Agriculture and Northern Ireland will also cease. Pat Ford, the Data Controller for all these services is already being retrained to take up new duties as a Data Administrator of ARS databases beginning with the meteorological databank.

The Data Preparation team is now committed to a long term program of punching on behalf of the Soil Survey of England and Wales. This began in the summer and already accounts for a 12% increase in the number of cards punched and verified this year. The volume of data will increase further and is expected to double in the coming year. This additional load will be handled by the same staff through the improved productivity expected with new data entry systems which will replace the aged punched card machines. This team also continues to receive work from most Institutes and has received wide-spread praise for the accuracy and timeliness of their services.

Honorary Scientists

The Department enjoys the privilege of sharing its facilities with two Honorary Scientists —both former Deputy Directors of Rothamsted.

Dr F. Yates has devoted a considerable portion of his time to the design and development of the Rothamsted General Survey Program (RGSP) which has been a feature in the Annual Report for many years. (*See* Applications System)

Dr F. G. W. Jones, long an advocate for numeracy in biological research, has continued his modelling studies, using the computer to stimulate the spread of nematodes attacking root crops within fields, where their natural spread is modified by soil-moving harvesting machinery. The model is being extended to nematodes that attack above ground fodder crops such as lucerne.

Staff, conferences and other courses

W. Ip (ASO) left shortly after graduating in his 4 year, day release Studies in Computer Science. Christine Godfrey, Audio Typist and M. Driscoll and Leon Thompson, Data Processors, also resigned. Sandra Ellis for unavoidable reasons, resigned from the newly created post of Departmental Administrator, a post she only filled in January 1981. New staff included Dawn Johnson, Shorthand Typist, M. Hornby and Carol Stevens, Data Processors.

H. J. V. Gledhill was appointed the Oxford, Reading and West Herts. Regional Representative on the Council of the British Computer Society. Eight staff attended general interest computer conferences and another ten, participated in more specialist ones. Eight attended one of several management training courses and five followed a course on aspects of computer education.

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Publications

General Papers

1 Finney, D. J. & Yates, F. (1981) Statistics and computing in agricultural research. In: *Agricultural Research 1931–1981* Ed. G. W. Cooke, London: Agricultural Research Council, pp. 219–236.

2 Jones, F. G. W. (1981) Management of potato nematodes. *IXth International Congress of Plant Protection, Washington, 1979,* **12,** 480–484.

3 Yates, F. (1981) Badgers guilty. *Nature, London* **289,** 218.

4 Yates, F. (1981) Badger debate. *Nature, London* **290,** 183–184.

Research Papers

5 Jones, F. G. W., Parrott, D. M. & Perry, J. N. (1981) The gene-for-gene relationship and its significance for potato cyst nematodes and their solanaceous hosts. In: *Plant parasitic nematodes.* Ed. B. M. Zuckerman & R. A. Rhode. New York: Academic Press, 3, 23–36.

6 Perry, J. N. & Jones, F. G. W. (1981) Simulation of population models for cyst-nematodes, applications in agriculture. *Proceedings of AMS81, 1st IASTED Conference*, Vol. V. Lyon: AMSE, pp. 15–18.

7 Webley, D. P. & Jones, F. G. W. (1981) Observations of *Globodera pallida* and *G. rostochiensis* on early potatoes. *Plant Pathology* **30,** 217–224.

APPENDIX 1

Documents sent out 1981

Program Guides

PG/108	DEDPRT (in 1980 report but sent 2 February 1982)
PG/150/2	EE. An Editor
PG/157	TIGGER (restricted circulation)
PG/148/3	A Utility to provide information on the System
Brief EE Guide	RGSP guide

Program Manuals

RGSP ME II Part 1
RGSP 22
RGSP 25
RGSP 24
RGSP Mk II Qualifying document
NAG 8 Mini manual

System Guides

GSYS/29/2	Operators Guide to running the Online Benson Plotter
GSYS/33/2	Writing and Testing JOBINP MACROS
GSYS/23/17	Rewrite of Multijob Command list
GSYS/26/2	Amendment to Paper tape input/out utilities
GSYS/17/5	Amendment to SORT/MERGE program

6 Newsletters (total 148 pages)

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APPENDIX 2

Current RGSP Users

UK

Universities

Aberdeen
Bath
Edinburgh
Imperial College
Kent
Lancaster
London Computing Centre
Newcastle Upon Tyne
Reading
Sheffield
Southampton

Polytechnics and Colleges

Middlesex Polytechnic
Napier College of Commerce and Technology

Public Bodies

Hertfordshire County Council
Food Supply Analysis Group, Oxford
MAFF Computer Development Unit
Rutherford and Appleton Laboratory
West Midland County Council

Commercial Bodies

Barclays Bank Limited
NEGAS (British Gas Corporation)

Overseas

Australia

CSIRO
Department of Agriculture
University of Western Australia

Others

Statistical Institute for Asia and the Pacific (Japan)
University of Copenhagen
Data Processing Services (Fiji)
Data Processing Division (Hong Kong)

APPENDIX 3

Full title of Institute abreviations mentioned in the Report

EMRS	East Malling Research Station, Maidstone.
GRI	Grassland Research Institute, Maidenhead.
IRAD	Institute for Research on Animal Diseases, Newbury.
LARS	Long Ashton Research Station, Bristol.
NIAE	National Institute of Agricultural Engineering, Silsoe.
NVRS	National Vegetable Research Station, Wellesbourne.
SSEW	Soil Survey of England and Wales, Harpenden.

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Introduction

Across the broad spectrum of the Department's activities the year has seen encouraging progress in the large programmes on aphid biology and monitoring, cereal and legume pest control, and protein production from earthworms and farm waste. These topics especially have attracted considerable attention in research, advisory, farming and commercial circles, and are highlighted in this year's *Report*, while the studies on aphid genetics, moth population dynamics, pest assessment and pheromones have continued.

With the approaching retirement of L. Bailey in mid-1982, opportunity is also taken

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to survey the impressive contribution to honey-bee pathology made in the Department over the past 30 years.

Aphid biology and monitoring

With 10–15 year runs of data on pest aphids now becoming available at progressively more sites of the Rothamsted Insect Survey (RIS), attention has been turned to ways of interpreting current information and making it available rapidly for advisory purposes. The biological expertise in the Department is being complemented gradually with computing facilities and radar equipment which will be evaluated as a supplement to the Survey's suction trapping network.

The biological knowledge necessary to maintain these developments continues to be improved; two current studies on the biology of pest aphids and virus spread merit comment.

Approaches to the interpretation of RIS aphid data. After aphids from all trap sites have been identified to species, the data are entered into the System 4 computer via a hand-held MSI/77 datalogger. Date, site and species name are entered using a light wand and bar codes, while the numbers in each sample are keyed in. Programs have been developed to permit initial validation of the entries, and the production of output for easy checking of the entered data before they are appended to the main database. Another program enables the weekly aphid *Bulletin* to be produced directly from the computer record. This software is currently being rewritten to operate on a departmental Midas-3D microcomputer.

In 1980 an attempt was made to release the interpretation of current samples promptly and to spread this information rapidly through the agricultural industry. For this purpose Britain was divided into eight regions, each containing between three and five suction traps. Five economically important species were selected, namely *Aphis fabae*, *Phorodon humuli*, *Metopolophium dirhodum*, *Sitobion avenae* and *Rhopalosiphum padi*, for which samples were interpreted each week, immediately the aphids were identified. In 1981 this list was extended to include *Myzus persicae*, *Macrosiphum euphorbiae* and *Aulacorthum solani*, so covering the aphid pests of the three major arable crops, cereals, potatoes and sugar beet, as well as two of lesser importance, spring field beans and hops.

The initial interpretations involve a comparison of the current sample of each species in an area with the long-term average sample for that area, as well as the value for the previous year. An attempt is made to quantify these comparisons as follows: differences of up to one-third of an order of magnitude are termed 'similar', between one-third and two-thirds are termed 'slightly above' or 'slightly below' average, of between two-thirds and one order of magnitude are termed 'above' or 'below' average, and greater than one order of magnitude are termed 'much above' or 'much below' average. Where possible further specific information was included that would directly assist with decision making. For example, the control threshold for *A. fabae* on spring-sown field beans has been related to suction trap samples (Way, Cammell, Taylor & Woiwod, 1981), so providing timely warnings, with about 90% accuracy, of probable outbreaks in different regions; associations between trap samples and weather data indicate the timing of the migration of *P. humuli* to hops, generally accurate to within 2 or 3 days for the beginning of migration and 10 days at the end (*Rothamsted Report for 1980*, Part 1, 99); the number of *R. padi* migrating in the autumn, and the proportion transmitting barley yellow dwarf virus, as measured at three sites in Britain, give the 'Infectivity Index', which is a measure of the potential risk of infection of winter-sown cereals by the disease (*Rothamsted Report for 1980*, Part 1, 182).

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Once current data have been interpreted a report is issued and sent by telex to all the Regional Centres and subcentres of ADAS, and also to the ADAS Crop Pest and Disease Intelligence Unit at Bristol. From these locations the information is disseminated to farmers and others in the agricultural industry via TV, radio, the farming press, telephone information services, the post and by direct contact with farmers. The report is also circulated by post to some of the recipients of the *Aphid Bullein* for further dissemination. (Tatchell and Woiwod, with Barrett, Computer Department)

Spatial analysis and mapping of Insect Survey data. To interpret the aphid survey data adequately it is necessary to understand the spatial relationship between samples. An investigation has started into the use of 'regionalised variable theory', a statistical approach to spatial analysis widely used in the geological and mining sciences but rarely in biology. An important technique from this theory, 'kriging', enables optimal interpolations between samples to be calculated and errors to be associated with these estimates. Interpolated values can be mapped with their associated errors, thus defining areas of poor estimation and making it possible to investigate the effect of the addition or removal of traps on the accuracy of estimates of aerial populations. Initial results on aphid data from the suction traps using the Surface II program (Kansas Geological Survey) to map the data after 'kriging' have indicated the potential of this technique. (Woiwod)

Overwintering of *Myzus persicae*. The young potato crop is very susceptible to virus acquisition so the activity of aphid vectors, of which *Myzus persicae* is the most important, is critical at this time. The main sources of early *M. persicae* on potato are populations which have overwintered anholocyclically, in the active stages rather than as eggs. The effect of winter weather on aphid survival is being quantified so that, with a knowledge of the size of the population at the beginning of winter gained from the suction traps, and a continuous input of meteorological data, it may be possible to predict the timing and size of the spring migration in different parts of the country in time to assess the need for granular insecticides at planting in the spring. Brassicas were chosen as the over-wintering host plants for these initial investigations because on the scale required they are easier to sample than wild hosts.

A field of spring cabbage in Bedfordshire was found to harbour an average of 182 *M. persicae* per plant (*c.* 15 million ha^{-1}) in early November, falling to 2 per plant (0·16 million ha^{-1}) by early April. Population samples were taken approximately every 2 weeks from exposed plants and from plants artificially protected from wind and driving rain. The biggest difference between survival in the protected and exposed plants occurred during the wettest, windiest period of the winter although there was no overall significant difference between survival under the two treatments throughout the winter. This suggests that wind and rain may be directly important in the South Midlands only when more severe than usual. The decline in the population on exposed plants between sampling occasions could not be related directly to intervening rainfall, windspeed, temperature or to a combination of these factors measured on the site. The causes of mortality must therefore be sought in less obvious properties of the population.

M. persicae is only found on the older leaves of spring cabbage (and other brassicas) in particular on the oldest two or three leaves. By mid-January, all the leaves on which *M. persicae* had been present in early November had died. Thus, survival on brassicas necessitates continuous migration by walking from old leaves to younger ones as the winter progresses. A decrease in numbers on older leaves could always be identified with an increase in numbers on younger leaves, but the rise was rarely as great as the fall on

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any particular plant, the difference being the cause of the mortality being sought. Older aphids migrated in this way more successfully than younger ones, and those protected from wind and rain were more successful than exposed individuals. It appears that the conditions of major importance affecting the survival of *M. persicae* on spring greens (and probably other brassicas) are those that influence the success or failure of movement at the critical period before leaf abscission. Thus, the degree of physical contact between plants, and the presence of leaf and ground surface moisture, may be more important than the amount and intensity of rainfall and frost. The resultant functional relationship between weather and population change is thus a behavioural response with a very different relationship between weather and mortality than was formerly assumed. (Harrington)

Cereal aphids and barley yellow dwarf virus. 1981 was notable for the widespread and serious infection of crops by barley yellow dwarf virus (BYDV) which contributed greatly to reductions in yield in both wheat and barley this year. The epidemic was encouraged by large-scale early sowing in the autumn of 1980 (a consequence of good weather for cultivation) and a mild winter, especially in February, which allowed aphids that had migrated into the crops, to multiply, thereby increasing secondary spread of the virus.

Autumn migration of aphids was greatest in late September and decreased in October due to wet, windy weather. September-sown barley fields at Hexton, Bedfordshire, supported 50 aphids m^{-2} at the end of October, including both *R. padi* and *S. avenae*, and spraying with a systemic aphicide was advised. Field trials at Rothamsted (*see* Multidisciplinary Activities) showed that autumn treatment significantly increased yields in both wheat and barley, so this spraying was probably justified.

The consequences of BYDV infection can be greater than just causing yield loss through infection. Aerial photographs of wheat fields in July in East Anglia and Essex taken in 1976 and 1977 revealed dark circular patches in early sown crops which were attributed to the presence of virus. The virus had secondary effects which may have decreased the yield in infected plants by encouraging aphids and fungal diseases.

The effect of BYDV on aphid populations was studied at Rothamsted in 1979 and 1980 by artificially infecting winter wheat, oats and barley with a severe *R. padi*-specific isolate of the virus in the autumn, and monitoring the numbers of aphids in the crops the following spring and summer. In 1979 and 1980, *M. dirhodum* and *S. avenae* respectively were the most abundant species.

Significantly more aphids developed on the infected plants in both years. These results were attributable to a greater attraction of alates of both species to the virus-infected patches which are bright yellow in barley, reddish in oats, and yellowish-purple in wheat. Flight chamber studies on host preference, conducted at Imperial College Field Station, Silwood Park, showed that the alates of both *S. avenae* and *M. dirhodum* reacted very strongly to the visual stimulus of virus-infected leaves of oats and barley.

Subsequent reproductive performance of the aphids is also enhanced by BYDV infection although the effects are less clear cut. BYDV infection of the host plant increased teneral adult weight in *S. avenae* and *R. padi* on barley, wheat and oats, but in *M. dirhodum* adult weight was only increased on barley, decreased on oats and unaffected on wheat. These effects on the size of the aphids were accompanied by changes on their reproductive capabilities since aphids of equal size produced the same number of nymphs irrespective of host plant health. BYDV increased fecundity of *S. avenae* on all three crops. Fecundity of *R. padi* was increased on infected oats and barley but not on wheat, and *M. dirhodum* was unaffected by BYDV infection of barley and wheat but produced less offspring on oats.

BYDV infection increases the concentrations of some amino acids and carbohydrates

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in the tissues of infected plants, and this altered nutrition probably results in the observed changes in aphid size and thus fecundity, especially in *S. avenae*. The reason why different species, specifically *M. dirhodum*, are not affected in this way may be related to a preference for different concentrations of nutrients or because different nutrients limit their biological performance. Also, increases in concentrations of individual amino acids and carbohydrates may vary between crops thus explaining the lack of a consistent response from each crop species.

BYDV also affected the excretory physiology of the aphids. Both *S. avenae* and *M. dirhodum* feeding on infected plants produced significantly less (23 and 32% respectively after 5 days) honeydew than those feeding on healthy plants. If the rate of honeydew production is an indication of feeding rate, then aphids on infected plants ingest less sap than their counterparts on healthy plants, which may be another consequence of the physiological changes induced in the plants by the virus. To obtain the necessary quantity of essential nutrients, both *S. avenae* and *M. dirhodum* probably have to ingest more of the relatively less nutritious sap available in healthy plants and consequently excrete more honeydew.

Although less honeydew is produced per individual by aphids feeding on infected plants, the larger colonies which develop on them as a result of increased attraction of alates, and in some cases increased fecundity, produce more total honeydew than colonies in the surrounding healthy crop. Both BYDV infection and a coating of honeydew predisposed the ears of wheat and barley to infection with *Cladosporium* sp. of fungi (sooty moulds) which, together with stunting of plants by BYDV, were the cause of the dark patches previously recorded in the aerial photographs.

Evidence from Wageningen has shown that considerable yield losses occur as a result of interference of photosynthesis when honeydew and *Cladosporium* and other fungi block the stomata on leaf surfaces of cereals. Thus, although direct feeding damage by aphids and honeydew and sooty mould growth are in themselves yield depressants, BYDV aggravates their effects by encouraging their increase. (Ajayi and Dewar)

Pest control in cereals and beans

The speculative experimental approach to developing methods of pest control in cereals that rely less heavily on insecticides, first begun in 1979, is now beginning to produce results, which show the likely medium-term effect of pesticide use on beneficial insects and indicate that careful management of the crop and its associated flora is likely to decrease pest incidence. More progress has also been made in the evaluation of *Sitona lineatus* as a pest of field beans and on compatible methods of chemical and biological control.

Effects of pesticides and insect pathogenic fungi on cereal fauna. In 1980 and 1981 the effects of conventional pirimicarb, dimethoate and benomyl applications on the insect fauna of winter wheat were investigated as part of a collaborative experiment of the 'Integrated Control in Cereals Working Group' of the IOBC/WPRS. The bulk of the insect fauna was sampled using pitfalls traps and an insect vacuum net, and visual counts of cereal aphids and their natural enemies were made. Each treatment was replicated three times and the plots ($19 \times 13{\cdot}5$ m) were surrounded by polyethylene barriers in 1981 to prevent recolonisation by soil-surface predators after treatment.

In both years cereal aphid populations, predominantly *S. avenae*, were well below economic threshold levels at flowering when the insecticides were applied. Both pirimicarb and dimethoate reduced aphid populations by 95% within a week of application, but

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2 weeks after application some reinfestation was recorded in the pirimicarb plots, whilst numbers in the dimethoate plots continued to decline.

Dimethoate, but not pirimicarb or benomyl, greatly reduced the number of spiders and predaceous beetles (Carabidae and Staphylinidae) caught in pitfall traps, but the aphid-specific predators were not affected. Both dimethoate and pirimicarb reduced the numbers of adult aphid parasitoids caught in the vacuum net. This effect was recorded 24 h after treatment and other parasitoid groups were similarly reduced so it probably was not entirely the result of host aphid mortality. Benomyl had no effect on aphid natural enemies, perhaps partly because of the early timing of this treatment (GS (Zadoks) 30–31).

In 1980, distribution of the aphid pathogenic fungus, *Erynia neoaphidis*, was included as an additional treatment in the experiment. Cereal aphids were infected in the laboratory and then released at rates of 15 *S. avenae* and 86 *M. dirhodum* m^{-2} on 11 and 12 June. Infection of the natural *S. avenae* population increased from 1% on 16 June to 24% on 7 July, but no differences in the numbers of infected aphids were detected between treated and untreated plots. The dominant fungal species were *Entomophthora planchoniana* and *Conidiobolus obscurus* which killed 63 and 31% respectively of the total number of aphids infected. Only six aphids infected with *E. neoaphidis* occurred in the samples, five of which were from the treated plots. The reason for the failure of *E. neoaphidis* to establish is unknown, but most of the aphids released were *M. dirhodum* which may have had little contact with the natural *S. avenae* population because their preferred feeding sites on the host plant differ. In addition, fungal establishment was probably discouraged by the low overall aphid density and cool weather following treatment. This treatment was not repeated in 1981 because the natural cereal aphid population was even smaller than in 1980.

Herbicides and natural enemies. The effects of herbicide treatment on the insect fauna of winter wheat, particularly aphid natural enemies, were investigated in 1980 and 1981. In 1980, there were four treatments, each replicated three times: autumn herbicide (chlortoluron), spring herbicide (isoproturon + mecoprop), autumn plus spring herbicide, and untreated.

In 1981, only the spring herbicide treatment was applied to two varieties of winter wheat, Maris Huntsman and Kador, while similar plots were left untreated. Kador is consistently less susceptible to aphid attack than is Maris Huntsman. In both years, a dense ground cover of broad-leaved weeds, dominated by *Tripleurospermum maritimum*, *Stellaria media*, *Veronica arvensis*, *Galium aparine*, *Lamium amplexicaule* and *Myosotis arvensis*, developed in the untreated plots.

Cereal aphids were sparse in both years, and in 1980 there were no differences between treatments, but in 1981, despite extremely low populations Maris Huntsman carried more *S. avenae* than Kador in both treated and untreated plots.

Numbers of spiders caught in pitfall traps were similar in all treatments but numbers of carabid and staphylinid beetles differed between treatments according to species. Staphylinids were either unaffected or were caught in greater numbers in the weedy plots, the effect on *Philonthus cognatus* being most noticeable. Amongst the carabids, *Loricera pilicornis*, *Agonum dorsale* and *Amara* spp. were caught in greater numbers in weedy plots, whereas more *Pterostichus melanarius* and *P. madidus* were caught in clean plots.

More aphid-specific predators were recorded in the clean plots than in the weedy plots in 1980, but in 1981, numbers were too small to show any differences between treatments.

In 1980, twice as many *S. avenae* were infected with entomophthoraceous fungi in weedy plots as in clean plots. This may have been the result of a higher humidity in the weedy plots or the fungi may have spread to the cereal aphids from infected aphids on the

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weeds. The latter possibility was investigated in 1981 when populations of *Brachycaudus helichrysi* and *Cryptomyzus galeopsidis* occurred in the weedy plots. Up to 70% of *B. helichrysi* and 10% of *C. galeopsidis* were infected with fungi, confirming that these populations could serve as a reservoir of fungus inoculum early in the season. Unfortunately, in 1981 cereal aphids were too few to be sampled adequately in June, when infected weed aphids were most abundant. Some *S. avenae* were sampled in July but there was no difference in infection between treatments.

Survey of natural enemies. Aphidophagous predators and aphid parasitoids were surveyed in 1980 and 1981 to increase knowledge of their ecology. Similar numbers of adult Syrphidae (mainly *Platychirus manicatus* and *Episyrphus balteatus*) were trapped above winter wheat in both years, whereas adult lacewings (*Chrysopa carnea*) and Coccinellidae (mainly *Propylea 14-punctata* and *Adalia 2-punctata*) were much more abundant in 1980 than in 1981. In June–July 1980, lacewing larvae were unusually abundant on winter wheat at Rothamsted and similar in numbers to the other aphidophagous predators, but in 1981 they were all scarce. However, in 1981 larvae of *P. manicatus* were common on weeds infested with *B. helichrysi* within the crop and larvae of *E. balteatus* and *Syrphus ribesii* were abundant on hedgerow Umbelliferae, feeding on *Cavariella pastinacea*.

The aphid parasitoid *Toxares deltiger*, which was recorded from cereal aphids for the first time, attacking *M. dirhodum* at Rothamsted (*Rothamsted Report for 1979*, Part 1, 88) was one of the dominant parasitoids of *S. avenae* in 1980. In winter wheat, peak numbers of most adult parasitoids followed the cereal aphid population peak. However, *T. deltiger* reached its peak abundance before that of the cereal aphids, perhaps because it may have used an alternative host aphid in or around the crop early in the year. This possibility is being investigated. (Powell, Wilding, Dewar, Dean, Bardner, Edwards and Fletcher)

Monitoring and forecasting *Sitona*. *Sitona* adults move to pea and bean fields each spring. Dispersal from overwintering sites is mostly by flight and a few beetles are caught by the 12·2 m suction traps of the Insect Survey in the spring and also in late summer when they fly from crops to over-wintering sites. Both the earliest catch in spring and the peak catch may vary by more than a month, being earliest in warm, sunny seasons. Catches are greatest where peas and beans are grown intensively, notably in Suffolk and Essex. Unfortunately, it is unlikely that these traps can be used for either long-term forecasting or for the timing of control measures in the spring, as there is no correlation between late summer catches and the subsequent spring catches of weevils, and much of the population has already moved into pea and bean crops before suction traps detect them in spring.

Sitona have been recorded in the light traps at Rothamsted since 1974 and these offer a more promising tool for forecasting infestations. The autumn generation first appears in light traps between mid-August and mid-September; adults are then found intermittently until the following May or June. The common occurrence of adults in the winter months, December to February, suggests that given favourable temperatures they remain active throughout the winter, though their gonads are immature until April or May. Thus there is no inactive period spent in reproductive diapause, and since adults trapped as late as May and June may still be reproductively immature, it is difficult to decide what constitutes 'autumn' or 'spring' populations. For example, adults were trapped between 18 September 1975 and 8 May 1976. Until 24 January the longest interval between catches was 10 days (in mid-December); following a period of low temperature, there was a gap of 32 days before three were trapped in late February, with a further interval of 30 days before catches began again on 29 March, then continuing until 9 May.

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None of the individuals caught between 29 March and 9 May was sexually mature. 'Autumn' and 'spring' adults can therefore only be separated fairly arbitrarily. Nevertheless, over the seven autumn–spring comparisons now available, there is a relationship between numbers in autumn and in the following spring. Making some arbitrary divisions, depending on periods between trapping occasions in January to March, correlations vary, consequent on the dates chosen, between +0·82 and +0·91 ($P>0{\cdot}05$ to $P>0{\cdot}01$). In 1981 over 140 individuals were trapped between 21 August to 15 November, the largest number since records began, indicating large numbers next spring. If that proves to be so, there should then be enough evidence to justify a more detailed investigation of overwintering populations and the utility of light traps for their monitoring and forecasting. (Bowden and Hamon)

Establishment of natural mortality of *Sitona*. Most biological studies on *Sitona* have been done in spring-sown beans. Numbers of adults per plant are positively correlated with the area of plant stand and the earliness of planting, and negatively with the density of the plant stand, and this is reflected in the populations of larvae per plant. Larval numbers are also positively correlated with the weight of nodules per plant. Life tables for all immature stages in the crop have now been calculated, though the survival of overwintering adults has yet to be investigated. Beetles can lay over 1000 eggs in a 90-day period, but only about 10% of these give rise to larvae entering root nodules. Much of this mortality is because of failure to find vacant root nodules, but possible effects of predators and parasites at this stage remain to be determined. A study of ^{32}P-labelled adults in the field shows that newly emerged weevils are eaten avidly by large carabids such as *Pterostichus* spp. which are particularly common in the late summer in bean crops.

Surveys of pea and bean crops have shown that populations in all the areas where these are commonly grown are similar to those found at Rothamsted, confirming the view that *Sitona* is a major pest of peas and field beans. (Hamon, Bardner and Fletcher)

Control of *Sitona*. In the past 2 years a further ten field experiments have been done on the control of *Sitona* on beans, and six on its control in pea crops. Cooperation in multidisciplinary studies on factors affecting the yield of spring beans, winter beans and leafless peas has been continued (this *Report*, Part 1, 32); this work also shows that it is essential to control *Sitona* larvae to achieve high yields, and that control slightly increases the nitrogen content of the grain (0·5% d.wt).

Two other large-plot experiments with spring beans compared various soil applications of systemic insecticides with permethrin foliage sprays. These confirmed that phorate or carbofuran granules drilled with the seed at 1·17–2·24 kg a.i. ha^{-1} were effective in controlling larvae and increasing yields, and comparable with soil applications of aldicarb at the uneconomic rate of 10 kg a.i. ha^{-1}, used experimentally in the multidisciplinary experiments on peas and beans. Phorate granules are cheaper than carbofuran and in the three experiments in which they have been used have given a mean yield increase of 14% at 2·24 kg ha^{-1}. The economic threshold that justifies use of this material at average farm yields and current costs would be a minimum yield increase of 5%, which should be easily achieved. A further advantage of such systemic insecticides is that they partially control other pests, such as viruliferous aphids or free-living nematodes.

Soil applications before planting do not persist long enough to control *Sitona* attacking winter beans in spring and early summer. Foliage applications of a permethrin spray will kill ovipositing weevils and increase yields in both spring and winter beans, but are not always effective, particularly if applied after the weevil's spring invasion. The timing of this is unpredictable but data from 12 experiments over four seasons indicate that sprays

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should be applied before the end of the first week in May, which is likely to be before most eggs are laid. When this was done the average yield increase was 11%. Treatment with permethrin costs slightly more than with phorate. Another method is to broadcast systemic insecticide granules on the foliage of the crop and surrounding soil. This has proved effective for control of larvae on both winter and spring beans, but further evaluation of yield effects is needed. As with permethrin, it is likely that applications will need to be early.

Foliar sprays of cypermethrin, deltamethrin and fenvalerate were about as effective as permethrin, but demeton-S-methyl, omethoate, pirimiphos-methyl and bendiocarb were less effective. Seed treatments have also been tried. So far only phorate and bendiocarb have given effective control of larvae.

The effect of controlling *Sitona* in peas grown for dry harvesting has been investigated in collaboration with the Processor & Growers Research Organisation (PGRO). Two experiments were done at Rothamsted and three at PGRO. Good control of larvae was achieved with soil application of phorate either broadcast and cultivated in, or combine drilled, all at 2·24 kg a.i. ha^{-1}, and permethrin sprays at 0·05–0·15 kg a.i. ha^{-1}. At Rothamsted yield responses were erratic, because of difficulties in protecting against pigeon damage and in harvesting the crop. At PGRO phorate cultivated into the seed bed increased yields by 3–18%. Bromilow (CLU) has established that phorate used in this way does not result in detectable residues of phorate or its principal metabolites in the harvested peas, an important point in a crop for human consumption. Further work will be needed to establish whether control of *Sitona* on the various types of pea crop is justified economically, but surveys in 1980 and 1981 (with PGRO) have shown that most have populations of *Sitona* larvae comparable with those found on bean crops. (Bardner and Fletcher, with Griffiths, Insecticides and Fungicides Department)

The use of earthworms in waste disposal and protein production

The work begun in 1980, to investigate the possibilities of producing high-grade protein for animal feed from earthworms bred on waste, at the same time producing a useful plant growth medium, was expanded greatly in 1981 and is now one of the main research programmes of the Department, involving much collaborative work with other Rothamsted Departments, ARC institutes, universities, and commercial organisations.

Basic biology of earthworms feeding on wastes. Most biological data were obtained from *Eisenia foetida*. This species takes 7–8 weeks to reach maturity, after which it can produce two to five cocoons per week either after mating or parthenogenetically. Each cocoon can produce one to nine hatchlings, giving a potential for each adult worm to produce 15–20 young per week. The optimum pH for the worms is about 5·0 although they grow well up to a pH of 10·0.

The optimum conditions for worm growth and reproduction have been studied intensively, particularly in pig waste. The temperature and moisture content of the waste are the two most important environmental factors. The lethal temperature is about 35°C. Growth rates increase up to 25°C, the highest temperature so far tested. However, although the number of cocoons produced is also greatest at 25°C the percentage hatch and the number of young hatchlings emerging from each cocoon decreases with increasing temperature, so that the optimum temperature for overall production is lower. (Neale and Edwards)

Studies on optimal stocking rates showed that although individual worms grew more slowly at higher stocking rates, overall production was greater. (Jones and Edwards)

The link between microorganisms and earthworms is very close. There is good evidence

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that *E. foetida* feeds mainly on bacteria and protozoa, which grow on the decomposing waste. Cattle solids, pig solids, duck litter, and sewage cake were treated with infusions of microorganisms obtained from garden soil, garden compost and sewage and incubated at 25°C for 48 h prior to inoculation with worms (*E. foetida*). The infusions increased the weight gain of the worms compared with that of the untreated waste, the infusions from garden compost having the greatest effect. Clearly, inoculation of waste with appropriate microorganisms can increase its suitability as a worm breeding medium.

In other studies, bacteria and fungi in wastes with and without worms were isolated, identified and their densities estimated. *E. foetida* had no effect on fungal populations in the waste but greatly increased the numbers of Gram-negative bacteria from $8{\cdot}5 \times 10^6$ organisms g^{-1} in unworked waste to more than 65×10^6 organisms g^{-1} in waste with worms. Numbers of coliform bacteria also increased. The cause of this increase is being investigated by further studies of microorganisms during passage through the earthworm gut. Changes during passage through the gut seem to involve increases in numbers of microorganisms without much change in species diversity. (Bater and Edwards)

Food value of earthworms and feeding trials. *E. foetida*, *Lumbricus terrestris*, *L. rubellus* and *Dendrobaena veneta* were analysed for their total chemical composition, amino acid content, fatty acid composition and mineral elements. They all contained more of the essential amino acids than fish meal or meat meal, and several fatty acids which cannot be synthesised by terrestrial non-ruminant animals. They contain about 11% nitrogen, 1% phosphorus, 1% potassium, 0·7% calcium and 0·1 magnesium. (Edwards and Lofty, with Hill, Biochemistry Department, Cosimini, Soils and Plant Nutrition Department, and Cayley, Chemical Liaison Unit)

There is a considerable need for alternative sources of protein in fish farming. Feeding trials using earthworms produced at Rothamsted showed that trout grew better over a period of 10 weeks on protein diets of freeze-dried earthworms of the species *L. terrestris*, *L. rubellus* and *Allolobophora longa* than on commercial protein fish food meals. They did not grow as well on a diet of protein from *E. foetida* but did well with a 50:50 mix of *E. foetida* and commercial meal. Clearly, earthworm protein has considerable potential in fish farming if it can be produced economically. (Edwards, with Dr A. Tacon and Miss Elizabeth Stafford, Stirling University)

Freeze-dried worm protein was used for these fish-feeding trials but this is an expensive way of processing it. Investigations have begun into various ways of drying worms, preserving them in mild preservatives that do not affect their palatability, or using organic additives. (Edwards, with Dr J. Worgan, National College of Food Technology, Weybridge)

Earthworm production from different wastes. The laboratory studies into basic biology of *E. foetida* and on optimal environmental conditions and stocking rates for optimal reproductivity have been extended to semi-field and field pilot studies. These include productivity studies in boxes 0·25 m² by 15 cm deep, in pits 1 m square by 1 m deep (outdoor and indoor) and a pilot breeding system expected to produce up to 3 t of earthworms per month. Methods of reincorporating separated solids and activated slurries are also being investigated. (Edwards, Lofty and Bater)

The breeding of earthworms on pig waste is being tested at the integrated piggery at the MAFF Experimental Husbandry Farm, Terrington, using separated solids combined with activated sludge as a growth medium. All pilot studies indicate that a 10% conversion ratio of waste to worms is feasible, so that all the supplementary protein needs of pigs reared by this system could be provided from their own waste.

Worm populations are being built up at Rothamsted to provide material for pig feed-

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ing trials at the National Institute for Research in Dairying. (Edwards and Lofty, with Mr R. Q. Hepherd, NIAE, and Dr B. Pain and Mr G. Mitchell, NIRD)

Cattle waste composted by a patented process developed on an ARC contract at Birmingham University has been tested as a suitable growth medium for earthworms. The results were positive and methods of stocking and managing the compost for worm production are under way. (Edwards, with Dr K. Gray, Birmingham University)

Experimental studies on the production of worms from waste previously digested for methane production have begun at the Bore Place Farm Project, Edenbridge, Kent (Commonwork Enterprises). The system employs underground electrically heated beds in a polythene tunnel. The worms produced will be fed to fish and the processed waste used as a plant or mushroom growth material. (Edwards and Lofty, with Mr S. Crocker and Mr G. Bradley-Smith, Commonwork Enterprises, and Mr D. Knight, Open University)

Worms grow readily in poultry waste, especially that mixed with straw or wood shavings, once the ammonia has been removed by composting or washing. Pilot field studies have been set up to assess the best treatment of the waste, optimum depths and stocking rates. Chicken feeding trials are imminent at the Poultry Research Centre, Edinburgh. (Edwards and Lofty, with Mr J. Richards, Nickersons, Mr F. H. Gollings, Sun Valley Poultry Ltd, and Dr C. Fisher, PRC)

After being worked by worms, animal wastes, supplemented with appropriate nutrients, could provide an ideal casing material for mushroom growing. Conversely, spent mushroom compost, with the addition of animal wastes, could provide a good medium for growing worms. Both these systems depend greatly upon worm/microorganism interactions and these are being studied with the University of Aston. (Edwards and Lofty, with Dr W. R. Hayes, University of Aston)

Harvesting earthworms and waste residues. A rapid method of separating earthworms from waste media is essential for the development of an economically viable system of worm protein production and for the present development research projects. An earthworm harvester has been designed by the National Institute of Agricultural Engineering and built by a commercial engineering firm. It consists basically of a rotating cylinder 0·5 m diameter and 2·3 m long with two meshes opening out into a funnel-shaped end with a final diameter of 0·8 m. The waste is fed into a hopper and as the cylinder, which slopes down towards the funnel end, rotates slowly, cocoons and worm-processed waste are separated through different meshes. The worms, which cannot pass through the meshes, gradually pass to the end and collect in a heap to one side of the funnel. This machine can process large quantities of waste rapidly. (Edwards, with Mr. R. Q. Hepherd, NIAE)

The processed waste has a fine structure, high water-holding capacity and more available plant nutrients than the parent material upon which the earthworms were grown. It probably has potential as a substitute for peat. Most of the nitrogen is changed from the ammonium form to the nitrate form by worm activity. (Edwards and Lofty, with Cosimini and Johnston, Soils and Plant Nutrition Department)

Testing the toxicity of industrial chemicals to earthworms

Earthworms have been chosen as representative soil animals in the ecotoxicity programmes of EEC, OECD and FAO, and a toxicity screening test, with earthworms as the test organism, has been developed at Rothamsted for these organisations. The new EEC

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legislation requires that all new chemicals marketed in quantities of more than 10 t per annum be tested for toxicity to earthworms.

Initially, the suitability of published methods of toxicity testing to earthworms was investigated. These include feeding contaminated foodstuffs, body injection, forced feeding, immersion or topical application and soil methods. New contact and artificial soil tests were developed. The indicator species chosen was *E. foetida andrei* which, although a little insensitive to some toxins, has the advantage of being bred easily in the laboratory.

The contact test employs glass tubes lined with filter paper to which the test chemicals are applied in a volatile solvent. The solvent is evaporated and the paper rewetted with distilled water. A single adult worm is exposed in each tube to eliminate the possibility of toxins being released from other decomposing worms and interfering with the toxicity assessment. Mortality is recorded after a fixed period, typically 48 h.

For soil testing, an artificial sandy loam was designed to mimic the water retentive and absorbtive characteristics of a natural loam. It consists of 70% fine sand, 20% kaolinite clay, 8% shredded sphagnum peat and 2% $CaCO_3$ to raise the pH to about 7. The mixture is treated by applying the test chemical as a fine spray of volatile solution. When the deposit is dry, it is thoroughly mixed into the soil mass. Ten adult worms are placed in 400 g of treated medium with the four replicates and mortality assessed after 14 days. The contact test screens chemicals quickly and the soil test, which is proposed only on compounds that are toxic in the contact test, can be related to the results of field toxicity testing more readily.

The draft protocol and samples of four test compounds, together with the LC50 have been circulated to 60 government, university and industrial collaborating laboratories worldwide who are performing the tests to check their reproducibility, sensitivity and ease of use; so far the response is encouraging. Both EEC and OECD have indicated that they will accept this testing procedure. (Goats and Edwards)

Honeybee pathology

When research on honeybees began at Rothamsted in 1934, attention was directed mainly towards the diseases of honeybee larvae, the so-called 'foulbroods'. Most, if not all, the common infections, both of adult bees and of larvae, were believed to have been identified. All that seemed to be required was to establish the cause of European foulbrood and to develop methods of treatment for this and certain other diseases. The diseases considered to be most destructive were the foulbroods, and the effects of parasitisation of adult bees by the mite *Acarapis woodi* and by the microsporidian *Nosema apis*. Emphasis of research on diseases declined during the late 1940s in favour of what were considered to be more fundamental studies, a view encouraged by the intractability of the remaining problems with diseases. These, however, soon interfered with the new studies sufficiently to require further direct investigations, which produced many unexpected facts. European foulbrood was among the first to be investigated and has also provided some of the most recent results.

European foulbrood. The cause of European foulbrood, *Streptococcus pluton*, was first isolated and shown to be the primary agent of the disease, at Rothamsted in 1957. As anticipated, from the long history of attempts to identify the cause of European foulbrood, the bacterium proved fastidious, requiring yeast extract (home-made or Difco only were suitable), glucose or fructose, phosphate, a ratio of K^+:Na^+ greater than 1, anaerobiosis and CO_2. No growth, or exceedingly slight growth, occurs without any of these factors. This serves to differentiate the organism from all of the several secondary bacteria com-

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monly associated with European foulbrood. Serological studies further confirmed its unique nature. Nevertheless, confusion about European foulbrood still continues elsewhere, primarily because the essential cultural requirements of the causative organism have not been appreciated.

Recent work abroad showed that *S. pluton* shared Lancefield Group D antigens with the enterococci (*Streptococci*) which are frequent secondary invaders in European foulbrood and are often considered to be its cause. However, all of many strains of *S. pluton* isolated at Rothamsted from many parts of the world are closely related by specific antigens that do not occur in the enterococci. Moreover, chemical analysis of strains from *Apis mellifera* and *A. cerana* has shown that although they contain group A peptidoglycan based upon lysine, and straight chain mono-unsaturated and cyclopropane-ring-containing fatty acids, typical of the family Streptococcaceae, they have DNA base compositions of 29·0–30·0 mol% G+C. This is not characteristic of the genus *Streptococcus*, and the strains are now considered sufficiently distinct to warrant separate generic status. (Bailey, with Dr M. D. Collins, National Institute for Research in Dairying, Shinfield)

Work at Rothamsted with strains of *S. pluton* from *A. cerana*, that grew only feebly relative to those from *A. mellifera*, has shown that free cysteine or cystine, but no other amino acid, greatly stimulates multiplication of the organism when added to the medium. Moreover, this effect applies to the multiplication of all the strains from *A. mellifera*. Furthermore, added cysteine or cystine makes suitable for all strains of *S. pluton* a variety of yeast extracts or peptones that have previously been found unsuitable as substitutes for the special yeast extracts needed in the original medium. (Bailey)

These recent findings confirm that European foulbrood is caused by a unique organism, and will renew confidence in, and facilitate research aimed at its control.

Virus diseases. Adding to the numerous sources of confusion about European foulbrood were fairly recent reports from abroad that it was caused by sacbrood virus followed by secondary bacteria. However, surveys for virus infections in England and Wales (*Rothamsted Report for 1976*, Part 1, 132, and *for 1980*, Part 1, 93) have detected sacbrood virus, among others, in most seemingly normal colonies, so its presence in colonies suffering from European foulbrood is not unexpected. Experiments some years ago at Rothamsted (*Rothamsted Report for 1972*, Part 1, 223) showed that sacbrood and European foulbrood are independent.

Further surveys for virus infections have now shown that filamentous virus (*Rothamsted Report for 1980*, Part 1, 94) also is very common in bees in Britain and that its multiplication in individuals depends upon the multiplication in them of *N. apis*. In this respect it resembles bee virus Y and black queen-cell virus (*Rothamsted Report for 1980*, Part 1, 93–94), and as may be expected from its dependence on *N. apis*, it has the same annual cycle of incidence as the microsporidian, with most bees infected in early summer. None of these viruses are related, or even resemble each other morphologically. The reason for their close association with microsporidia remains unknown and is at present of unique interest in insect pathology. Their presence or absence may well explain the great variations in the severity of losses associated with *N. apis*. (Bailey and Ball)

A significant association has also been observed in field samples of dead bees in winter between bee virus X, which is distantly related serologically to bee virus Y, and *Malpighamoeba mellificae*. However, this association is due to the considerably increased mortality caused by the chance association of the two pathogens, which are both spread by faecal contamination, but frequently multiply independently of each other. (Bailey and Ball)

The knowledge that there are at least ten viruses in bees in Britain, and some 18 throughout the world, all of which have been identified and characterised at Rothamsted

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and many of which are very common, has, with other findings in recent years, considerably modified concepts of honeybee pathology. Until about the mid-century, the comparatively few pathogens that were known were believed to lead inexorably to severe losses or the death of whole populations once they became established. This attitude is still encountered and has not been without influence on views about the properties of insect pathogens in general. In fact, most pathogens of bees, including their viruses, are endemic; and, although they sometimes cause severe diseases and are always damaging, their incidence and the disease they cause usually pass unnoticed or are accepted as 'normal'. Consequently their eradication, once believed to be the only solution, although desirable, is unlikely. Nevertheless, their control in many instances is possible, if only by avoiding husbandry practices that aggravate them. Devising and improving control measures require information about the very diverse properties and natural histories of the pathogens. Much of this is now known, but past experience should indicate that far more probably remains to be learned.

Staff

The Department's European links were maintained on a wide front with staff attending seven IOBC/WPRS or EEC meetings on pheromones, and various aspects of integrated control of cereal pests, soil pests, diseases and weeds, farm management systems and ecotoxological testing of pesticides. They contributed to the proceedings, organised the meetings and participated in collaborative research projects.

L. Bailey was an invited speaker at a Symposium on European foulbrood held in Quebec. C. A. Edwards gave talks at several international conferences and workshops including 'Animals as Indicators of Environmental Contamination', University of Cologne, '1st International Congress of Soil Pollution and Protection', Cairo, 'Pesticides and Ecosystems', Cornell University, the Darwin Centennial Symposium, and the State University of New York, and visited worm breeders in Bologna, Italy. J. B. Free gave a paper at the International Beekeeping Congress, Acapulco, Mexico. T. Lewis visited the People's Republic of China and Hong Kong as a member of a Royal Society Delegation on Migrant Pests, lecturing to the Institute of Zoology, Chinese Academy of Sciences, Beijing, and several other Institutes of Entomology and Agricultural Science in Kirin, Nanjing and Shanghai. G. M. Tatchell and I. P. Woiwod visited pest monitoring systems and gave seminars in Michigan, Indiana, Kentucky and Pennsylvania.

In Britain G. Dean, A. Dewar, C. A. Edwards, W. Powell and I. H. Williams contributed talks or papers to various Society meetings and conferences.

Dr P. J. Cameron from DSIR, Auckland, joined the Department for 9 months, and Professor Zhang Zhi-li from the Plant Protection Institute, Beijing Academy of Agricultural Sciences, for 2 years, both to work on integrated systems of pest control.

R. A. French retired after 33 years and it is a pleasure to record his contributions to insect migration and monitoring studies over such a long period, as well as administrative assistance to several Heads of the Department. Hilda Goddard and Christine Moule left and Anita Elleray, P. J. Ives, Mahruk Mama and P. Townley were appointed. Gillian Frampton, A. J. Martin, S. F. Nottingham and C. R. Weber worked as sandwich course students and W. J. Airey joined as a Ph.D. student.

I. F. Henderson, N. Wilding, A. Dewar and Susan Parker were promoted. O. Ajayi, R. Harrington and H. Loxdale were awarded Ph.D. degrees, J. Bater and D. G. Garthwaite B.Sc. degrees, and M. Allen the HNC.

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