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# Report for 1978 - Part 1

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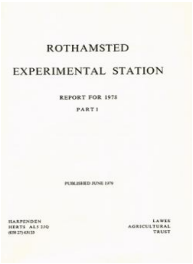
ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1978
PART I

# Statistics Department

## J. A. Nelder

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# STATISTICS DEPARTMENT

J. A. NELDER

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## Introduction

> 'Now research workers in both science and technology define ends which they wish to achieve and they need technology to achieve them. As there are specific pieces of technology depending upon the problem under study, so I propose that there are general technological principles that are applicable across wide areas of research; these principles, the technology of research itself, consist of statistical methodology. As statisticians, certainly as applied statisticians, we do best to think of ourselves not as mathematicians, nor as scientists, but as technologists.'
>
> M. J. R. Healy, 'Is Statistics a Science?'

A large part of our work is defined by our collaborators and develops according to their needs. A representative sample of our joint projects with other departments at Rotham-



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sted follows, together with an account of the work we do for other groups; these include other stations within the Agricultural Research Service (ARS), the Agricultural Development and Advisory Service (ADAS) of the Ministry of Agriculture, Fisheries and Food (MAFF), for whom we continue to provide a statistical service for the design and analysis of both plant and animal experiments, bodies such as the Fertiliser Manufacturers' Association (FMA), with whom we are involved in surveys, the Ministry of Overseas Development (ODM) for whom we run a biometric unit, and a small but important category of 'others', whose problems allow us to try out new methodology or to extend the use of existing methodology.

Two general projects are generated internally, though both are much influenced by our collaborative experience; these are the development of new statistical methodology, and the construction of general computer programs for data handling and statistical analysis.

## Practical applications

As usual, no attempt will be made to list all our collaborative activities. We begin with some examples from Rothamsted (see also the reports of the Botany and Soil Microbiology Departments).

**Matters entomological.** Following further experiments on the effects of pheromone-trap spacings on the flight behaviour of male pea moth (*Cydia nigracana*), work is in progress using atmospheric diffusion theory to build a mathematical model to explain recent field results. Studies have begun on the possible use of data-logging to collect suitable meteorological data. (Perry, with Wall, Entomology Department)

A long-term collaboration was begun on the design and analysis of experiments connected with field monitoring of this moth. Problems involved include population dynamics, spray trials, the evaluation of commercial systems, and sample size determination. (Perry, with Lewis and Macaulay, Entomology Department)

Routine updating of the large data set now accumulated from the insect survey continued. Summaries of both moth and aphid records were formed on magnetic tapes, and suitable updating procedures for these summaries were developed. (Perry)

The damage done by *Plutella maculipennis* larvae feeding on turnip has been investigated in the growth rooms. A model for this has been built under the assumption of logistic growth by the larvae. Estimates of the parameters governing feeding for maintenance and feeding for growth on plants of differing ages have been obtained. (Pearlman, with Barrow and Bardner, Entomology Department)

**Carbon flow through leaves.** A compartmental model has been developed to analyse the results of $^{14}C$ flux in *Helianthus* leaves for various degrees of water-stress. Appropriate models were set up for several biochemical hypotheses to predict the incorporation over time of $^{14}C$ into the intermediates of photosynthesis and photorespiration. It was necessary to postulate time-delays in the system to explain the data, and it was also concluded that there was a flow of carbon from storage into the photorespiratory pathway. (Pearlman, with Lawlor, Botany Department)

**Conversion of ammonium to nitrate N.** Non-linear curves were fitted to observations on the nitrification of injected aqueous ammonia (*Rothamsted Annual Report for 1977*, Part 1, 276–9). Whereas the decline in ammonium concentration was well described by a negative exponential curve, the build up and decline of nitrate with time was not well fitted by a difference of negative exponentials, such as would be predicted by a simple



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compartment model, but a ratio of quadratics was found to be a suitable empirical curve. (White, with A. J. Gibbs, Soils and Plant Nutrition Department)

**Collaborative work on ADAS experiments.** We continue to be involved with the planning, analysis and interpretation of many of the very substantial set of experiments done annually by ADAS, and some examples of this collaborative work on both plants and animals follows.

***The prediction of nitrogen response by soil chemical methods.*** Examination was completed of the effectiveness of five chemical methods measuring soil nitrogen for the prediction of nitrogen response in cereals. The hope was that, if an efficient method could be found, it would replace the present ADAS Nitrogen Index system, which is based mainly on previous cropping. Statistics of response from 69 field experiments using many levels of N were related, using multiple regression, to the values obtained by the chemical methods and to other explanatory variables. None of the chemical methods showed any relationship either with the estimated optimum N dressing or with the rate of response to it. About 13 years ago, D. A. Boyd investigated relationships between the response to fixed dressings of N, and measures of soil N by chemical methods, and concluded similarly that no useful prediction could be made on a country-wide basis. A written report has been made to the appropriate ADAS committee and a further report summarising both this and Boyd's work will be prepared for ADAS internal use. (Wimble, with Dr. K. Shaw, ADAS, Newcastle)

***Winter barley trials.*** Detailed investigation of the results of trials in 1977, testing rates and timing of nitrogen on winter barley in the presence and absence of fungicide, led to the production of a report for ADAS. This contained a description of the major effects noted in the experiments, fitted curves for the N response with statistics derived from them, and gave details of the statistical methodology employed. There was a notable effect of fungicide on the response to N, but evidence concerning the effect of timing of the nitrogen dressings was inconclusive. Examination of the 1978 results is expected to yield further information on these points.

There has recently been a swing in interest from spring barley to winter barley, because the latter offers a higher yield potential along with the advantages of earlier harvest, and because the greater disease problems associated with winter barley can now be counteracted by the use of fungicides. Experimentation on winter barley has in the past been limited, and there is now a need to devise new designs suitable for national series of experiments. (Wood, with Mr. P. Needham, ADAS, Cambridge)

***Potato cyst eelworm decline rate.*** Eelworm counts before planting and after the lifting of potatoes were recorded during 1971–78. Four lifting dates were used in each year and the eelworms of sub-species *Globodera rostochiensis* and *Globodera pallida* counted in a sample of tubers. The decline in eelworm numbers over the years for both species was apparent. During the growing season, however, the eelworm numbers increase so that a late lifting date means more bulk to the potatoes but also more eelworms. The relative changes in eelworm numbers have been tabulated so that farmers can be advised as to which of the four lifting dates is most suitable for the quality of potato to be produced. (Banfield and Sparrow, with Mr. D. Webley, ADAS, Bangor)

***Other ADAS crop experiments.*** Other series of experiments analysed and summarised during the year included:



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(i) the break-crop trials on the effect of 1- and 2-year breaks on the yield of winter wheat when compared with continuous cropping, (Banfield, with Mr. P. Bowerman, ADAS, Boxworth Experimental Husbandry Farm (EHF));
(ii) spring nitrogen requirements of winter wheat at Boxworth EHF where an unusual N response was expected, (Banfield, with Mr. R. Jarvis, ADAS, Boxworth EHF) and
(iii) the comparison of insoluble forms of phosphate on grassland, with an interim summary of the first 3 years. (Wimble, with Mr. G. Davies, ADAS, Bangor)

***Livestock experiments.*** We continue to provide the statistical support for work on the design and analysis of ADAS animal experiments. This work is increasing and the problem of assigning priorities when staff is limited has been greatly eased by the establishment of a joint steering group with ADAS for livestock experimentation. Our visits to Experimental Husbandry Farms (EHF) have increased, and have proved very useful in improving relationships with EHF staff and in increasing our awareness of their problems. The following paragraphs, referring to a variety of experiments on cattle, sheep, pigs, and poultry, exemplify this side of our work.

We have been consulted on the design, analysis and interpretation of the results of the second year of an investigation into the effect of a progesterone-releasing intravaginal device (PRID) on the calving-to-conception interval of dairy cows. This trial involved a total of 678 cows in eight herds. An attempt was also made to quantify carry-over effects using those cows from four herds for which there were 2 years' results. Fears have been voiced that the PRID reduces milk yield, but detailed milk records kept for one of the herds in this year's trial show no treatment effects so far on total milk yield over the 7-week period from the insertion of the progesterone-releasing device. (Altman, with Mrs. Bridget Drew, ADAS, Winchester)

A magnetic tape file has been constructed containing raw and derived carcass data from 89 trials, and this will be updated with any new carcass data submitted. Summaries of the results were used in a paper entitled 'The effect of breed, sex, age and system of production on quality in beef as revealed by a system of visual assessment', presented to a meeting of the British Society for Animal Production in March. (Altman, with Mr. B. M. Scott, ADAS, Bristol)

The effect of broiler-house environment on the efficiency of broiler meat production was tested with five batches of broilers in the phase-1 trials of this experiment. The trials were held in eight climate rooms at Gleadthorpe EHF which were especially built for poultry environmental work. Factors investigated were ventilation rate, room temperature and stocking density.

The first trial indicated that birds exposed to the highest ventilation rate ate more feed but that neither feed intake nor final weight was affected by a range of lower ventilation rates. Two of the trials indicated that birds kept at a high room-temperature (25°C) converted feed better than at temperatures in the range 17–20°C. The best feed-conversion ratio was obtained at high stocking density (20 birds $m^{-2}$) and high temperature (25°C). (Spechter)

We collaborated again with Dr. J. Allen of National Poultry Tests Ltd. and analysed the phase 2 data of the egg quality study on a period-by-period basis. This required processing of about 30 000 data cards.

In phase 2 of this experiment, egg quality was studied on several commercial farms as well as at the Milford experimental farm. Results in phase 2 generally confirmed those obtained in phase 1; that is, there were consistent differences between white- and brown- egg layers, but only minor differences between breeds within these two groups. (Spechter)

Exploratory analysis of the data from milk records of all the cows in Jersey indicated



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that the variability within and between herds would make the fitting of a satisfactory model eliminating the average effects of age, lactation number and month of calving impossible. We therefore concluded that the creation of a production index similar to that of the Milk Marketing Board would not be feasible. (Altman and Garnett)

Analysis continues of seven whole-lactation experiments on dairy cattle, including one complex experiment involving 220 spring-calving cows over 2 years. (Altman)

Four breeding systems for pigs are being compared at three EHFs and we now have received data for 721 litters over the first two generations. Criss-cross sows have produced larger litters on average than first-cross sows, but litter size has proved more variable than was expected when the experiment was designed, and data from more generations will be needed before any firm conclusions can be drawn. (Spechter)

The results of an investigation into the relationship in beef cattle between condition scores and those for carcass were reported at a conference in April, and a report is being prepared. A paper, with Mr. R. Hardy of Rosemaund EHF, entitled 'Production of 20–24 month beef from autumn Friesian and Hereford × Friesian calves' has been prepared, following the analysis of 3 years' data. (Altman)

**Surveys.** Fertilisers on fields, bacteria in milk, weeds in cereals, and nutrients in soils are all aspects of agriculture which have provided survey data in 1978.

***Fertiliser practice.*** The 1978 survey took the form first used in 1976, a representative sub-sample of farms being surveyed in June and July by Farm Research Ltd. on behalf of representatives of the Fertiliser Manufacturers' Association, so that preliminary estimates of use were available before the end of September. The other sub-sample was surveyed by ADAS staff, through the Regional Soil Scientists, during August and September. Despite some late returns, extended tabulations on the complete sample of nearly 16 000 individual field records were produced early in December.

Facilities for computer validation and for updating tables of preliminary results using the Rothamsted General Survey Program (RGSP) enabled the basic analyses to be done quite rapidly with a minimum of data-processing staff. Currently about 5% of all records are queried during validation and about 0·5% amended; this is an essential discipline in a continuing survey, although any effect of erroneous data on the estimates is minimised by excluding suspect values from the tabulations.

The main feature of the results for 1978, a year in which fertiliser use as a whole increased by a few percentage points, was an estimated increase of about 10% in use of N, P and K on winter wheat. Average N applications on winter wheat were 125 kg N $ha^{-1}$ and nearly a third of the crop had more than 150 kg $ha^{-1}$. (Church and Elsmere)

Work continued on the relationships between grassland management, fertiliser practice and intensity of stocking, using data from recent surveys. (Hills)

***Representative soil sampling.*** Since 1969 information about nutrient status has been obtained each year by ADAS Regional Soil Scientists from a small random sample of agricultural soils in England and Wales, using standard soil sampling and laboratory techniques. The same fields are re-sampled at intervals of 5 years. Aims are to estimate proportions of agricultural soils in different nutrient categories and to assess possibilities of monitoring for general changes. The work is on a minimum scale, designed to give useful estimates for the whole country rather than for individual regions; it began as part of the survey of fertiliser practice but is now continued independently.

Results for 1969–70 to 1974–75 have been reported for available P, K and Mg. There is no evidence of any change in average available P or in the proportions of soils at



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different P indices during this period, but average available K and Mg in the top 16 cm of soil are estimated to have increased by about 16 and 7% respectively. (Church)

***Milk quality.*** The report on the National Milk Quality Survey was completed and sent to the publishers at the end of November. The main findings have been presented in previous *Rothamsted Reports for 1976*, Part 1, 330 and (*for 1977*, Part 1, 301).

There is little information in the literature about the accuracy of the bacteriological tests used, so supplementary investigations, involving sampling from milk vats, were done at five ADAS laboratories, and Dr. Christina Cousins allowed us to use the results of two experiments done at the National Institute for Research in Dairying. Forty-six experiments provided about 1600 observations for statistical analysis.

Discrepancies of an order of magnitude in colony counts were attributed to manipulation errors. These might be eliminated if the processing could be automated. However, they should not be important if monitoring could be based, say, on rolling geometric means over 4 or 6 months.

Provided that milk samples are aggregates of smaller amounts taken from different parts of the vat, accuracy of the immediate colony count can be predicted from the total number of colonies counted; however, error estimation is less straightforward for the pre-incubated colony count. Replication of both sub-samples and dilution-tubes is needed to obtain reliable estimates of the pre-incubated colony count in bulk milk. It appears that disc readings of 1½ or less on the 90-min pre-incubated resazurin test on bulk milk are accurate enough without replication.

Of those bacteriological tests used in the survey it was concluded that the pre-incubated colony count was the most useful indicator of cleanliness of equipment, in spite of its acknowledged shortcomings (inaccuracy, expense, etc.). (F. B. Leech and P. K. Leech)

***National survey of grass weeds.*** Analyses of this survey of cereal fields on a random sample of 1153 farms throughout the United Kingdom were completed and the results reported in collaboration with the Weed Research Organisation (Paper 16). Estimates are given in the paper of proportions of cereal area infested with wild oats (identified *Avena* spp), blackgrass and couch, and of the occurrence of different levels of infestation. Regional differences in infestation, and differences associated with previous cropping and soil type, are examined and results compared with data from other surveys. Information is given on the extent to which individual herbicides are used to control grass and broad-leaved weeds in cereals, on roguing of wild oats, farmers' assessments of herbicide effectiveness and their attitudes to control or eradication of wild oats. (Church and P. K. Leech)

***Other surveys.*** For British Sugar, we advised on planning of a revised crop-reporting scheme based on a representative sample of growers, and analysed a survey of weed beet in the 1978 crop. We also helped the Central Veterinary Laboratory on the planning of a survey of anthelmintic use, and advised on aspects of data recording and analysis for a survey in Nigeria for the International Livestock Commission for Africa Small Ruminants Programme. (Church and P. K. Leech)

**Routine analysis.** The service we provide for the punching and verification of data and their subsequent analysis has again been widely used, with at least 133 workers from other departments submitting jobs, besides those originating internally. Data comprising 1·73 million items were involved, an increase of 19% on last year. All three major groups of users, Rothamsted, ADAS and ODM, showed increases, but the average turn-round



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time has been maintained, despite the increase in work-load, at 8 working days. (Dunwoody, Dyer, Smith and Todd)

Summaries of all the Rothamsted and Woburn field trials were again prepared for publication, and the standard of presentation was improved, as expected, by the acquisition of a daisy-wheel printer. The improvement in the schedule, begun last year, was maintained and the 1977 edition of *Yields of the Field Experiments* was published before the Annual Report for the first time. (Dunwoody and Todd, with McEwen, Field Experiments Section)

**Future equipment.** The machines currently in use for data preparation are coming to the end of their useful life, and the paper-tape equipment attached to the daisy-wheel printer is proving a cumbersome method of preparing and editing documents. We have therefore undertaken an extensive investigation into data preparation systems using magnetic media with associated electronic processing. Preliminary assessment indicates that while there exist specialist systems, on the one hand for numeric data entry and validation, and on the other hand for document preparation, few if any are equally adaptable for either, and most are very limited in the software provided. We have, therefore, extended our consideration to time-sharing small computers, which, with suitable software, could not only support these two tasks, but would allow software for them to be modified and other software, for example for graphical display, to be developed by us without difficulty. It has become very clear that, given the increasing general reliability of hardware, the quality of the software is paramount, in particular the necessity of having a well-designed transparent operating system. (Alvey, Dunwoody and Todd) We shall continue to need, of course, the facilities of the System 4–70, both for analysis and for archiving of data, and a system for such archiving, on magnetic tape, has already been introduced, with the intention of linking it to any new departmental equipment. (Todd)

## Theory

**Screening algorithm for fractional replicate designs.** Any fractional replicate design is susceptible to problems of interpretation caused by aliasing or non-orthogonality of estimated effects. Some sets of treatment combinations form very much better designs than others and the value of a particular design may be measured by such quantities as (i) the efficiency of estimation of terms in low-degree polynomial models (which may include interactions), (ii) the entanglements between such terms, and (iii) the generalised variance. An algorithm has been developed to calculate these quantities. It may also be used to examine aliasing and non-orthogonality when blocks are present, and to predict the effect of missing values in a full or fractional-replicate factorial experiment. (Zemroch)

**One-sixth replicates of $6^3$ designs** (*Rothamsted Report for 1977*, Part 1, 305). This design, introduced by Boyd, is now widely used in fertiliser trials, but as mentioned above, problems of interpretation may occur if the design is not carefully chosen. One-sixth replicates of a $6^3$ design may be constructed using $6 \times 6$ Latin squares by identifying rows, columns and letters with the levels of the three factors. This ensures that if an additive model of main effects is fitted, the estimated effects will be mutually orthogonal. Random selection of squares is often found to provide adequate designs, but considerably better designs can be derived from specially constructed squares. Some recommended squares have been tabulated, as have sets of six individually satisfactory squares which together form full replicates and may thus be used in series of experiments for which a joint analysis may be needed. (Sparrow, Wimble and Zemroch)



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**Confidence regions in non-linear models.** When the maximum likelihood estimates of parameters have been found the asymptotic dispersion matrix may be computed by inverting the matrix of second derivatives of the log likelihood function. In non-linear models it is misleading to assume that the Normal approximation is adequate for constructing confidence regions and significance tests. Detailed information is provided by contours of equal likelihood, and these likelihood-based confidence regions are often asymmetric and far from ellipsoidal in shape. Algorithms to compute the extreme values on a given contour of each parameter and any function of parameters, were developed and improved. An important advance was to note that the square root of the difference between the log likelihoods at the optimum and at any given point is approximately a linear function, thus speeding up the interpolations needed to identify points on a contour. (Ross)

**Combination of estimates of non-linear parameters.** If the same model is fitted to several sets of data it is of interest to obtain estimates of common values of some or all of the parameters. The exact procedure is to fit a composite model in which some parameters are common to all data sets and the remaining parameters are specific. For linear models it is possible to reconstruct the Normal equations using the information matrix for each data set, and to solve these equations to obtain combined estimates of parameters and their dispersion matrix, as follows:

Let there be $r$ sets of data with $p$ common parameters and $q$ specific parameters per set. Then the combined model has $p + qr$ parameters, and the Normal equations are obtained by summation of the Normal equations for each set. If the parameters of the $i$th set are $(\theta_1 \ldots \theta_p, \phi_{1i} \ldots \phi_{qi}) = \boldsymbol{\theta}_i$ with dispersion matrix $V_i$, then the right hand sides of the equations may be reconstructed as $V_i^{-1}\,\boldsymbol{\theta}_i$. The full set of equations then becomes

$$(\Sigma \mathbf{V}_i^{-1})\,\boldsymbol{\theta} = \Sigma\,(\mathbf{V}_i^{-1}\,\boldsymbol{\theta}_i)$$

where the component matrices and vectors are expanded with zero entries corresponding to $\phi$ parameters of other sets.

When models are non-linear the asymptotic dispersion matrix gives information about the likelihood parameter in the neighbourhood of the maximum likelihood estimates only. If the above procedure for combining parameter estimates is carried out a composite estimate may be formally defined, but a problem remains of deciding whether the approximation is adequate. Empirical evidence suggests that (i) if the common parameters are comparable in value, or (ii) if the parameter system is stable (so that the parameters are almost linear over a wide range), then the approximate solution agrees closely with the exact solution. Counter-examples suggest that the approximation is poor when the fit of the joint model is very poor. (Ross)

**Selection of tests for diagnostic keys.** The efficiency of a diagnostic key is usually measured by the average number of tests or, more generally, the average cost needed to achieve an identification. With keys constructed from incomplete information, identification of a taxon may be reached by more than one route. Instead of a single cost for each identification, there may be many possibilities, and there is no obvious best criterion of efficiency. For example, one could take the cost averaged over all possible identification routes, or the average over the taxa of the maximum cost of identifying each taxon, or the average over the taxa of the average cost of identifying each taxon, etc.

Whatever criterion of efficiency is adopted, algorithms for constructing maximally efficient diagnostic keys are unknown. One must be content with selecting tests sequentially for inclusion in the key, using some further criterion to determine the best available test at each stage. It has been shown that optimum methods of test selection vary accord-



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ing to the efficiency criterion. Earlier work by Gower and Payne (*Biometrika* (1975), **62,** 665–675) has been extended to allow selection between tests with different numbers of levels and with different costs. A paper has been prepared. (Payne)

**Multidimensional unfolding.** An account of this technique in multivariate analysis was given in the *Rothamsted Report for 1977*, Part 1, 303. Work continues, but the computational problems are still not satisfactorily resolved. It appears that other workers have also met difficulties with metric unfolding, indicating that the problem is still inadequately understood. Non-metric methods have proved no better, often giving trivial degenerate solutions. A resolution of the methodological difficulties, together with the provision of good algorithms, is worth pursuing, because the technique promises to be very valuable in practice. (Gower)

**Asymmetry in multivariate analysis.** Work in this area has been mainly confined to the explicit analysis of patterned skew-symmetric matrices, continuing and extending the earlier work of Gower and Laslett; a paper is in preparation. During the course of this work an algorithm of Faddeev was rediscovered and generalised. This algorithm basically computes the characteristic equation of any square matrix, but also gives inverses, generalised inverses and, for given eigenvalues, expresses the eigenvectors in a convenient form. A paper has been prepared. (Gower)

**Variance-mean relationships in ecology.** A study was completed of the problems involved in the use of variance-mean relationships in ecology, with particular reference to the power law. Various methods of fitting this model were compared to assess their ability to overcome problems of weighting and of bias and random variation in the independent variable. A new method of estimating the parameters was introduced. (Perry)

## Statistical programming

**Genstat.** The number of licensees for this, our major program, is now 71, of which 36 have been added during the year. The new licensees come from the United Kingdom (17), the rest of Europe (11), Australia (6), United States of America (1), and Hong Kong (1). Most of them are universities, institutes of technology or government research establishments. (Alvey and Watson)

During the year ten versions of the release 4.01 of the program were completed and two more were in preparation, to add to the ICL 4.70 and IBM 370 versions completed in 1977. The machine ranges concerned and the convertors with their institutions are listed below (Table 1).

Again we are greatly indebted to all the convertors for the time they have devoted to this work. While we try continually to reduce the amount of special coding required for a conversion, local difficulties still arise and require special treatment. We have developed several tools to ease the conversion process and these have increasingly proved their worth. The major one is the conversion program, which picks the appropriate set of marked alternatives in the code, and prepares an initial version for the convertor. The conversion program has been refined to allow alternatives common to a set of machine ranges to be easily specified, and to allow the lengths of alternative sections to be unequal. Other tools are special programs which generate for a new machine the special tables required for looking up words rapidly in a list. (Simpson)



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**TABLE 1**

*Genstat: machine ranges and convertors*

| Machine | Convertor | Site |
|---|---|---|
| CDC 7600 | Mr. J. Lloyd-Jones | University of Manchester Regional Computer Centre |
| CDC Cyber 76 | Dr. R. I. Baxter | CSIRO, Sydney, Australia |
| CDC 6000 | Dr. P. Baghurst | Waite Agricultural Research Institute, S. Australia |
| ICL 2900 | Dr. J. Read and Mr. B. Fletcher | Edinburgh Regional Computing Centre |
| DEC–10 | Mr. J. Byrne | University of York |
| Univac 1100 | Mr. J. Wasniewski | RECKU, Copenhagen |
| Siemens | Dr. J. v. d. Vooren | Glasshouse Crops, Naaldwijk, Netherlands |
| Burroughs B6700 | Dr. B. G. Cox | University of Otago, New Zealand |
| ICL 1900 | Dr. P. Griffiths | Oxford University Computing Laboratory |
| PRIME | H. R. Simpson | Rothamsted Experimental Station |
| | Mr. J. Parkinson | Prime, Bedford |
| In preparation: | | |
| SEL | Mr. D Rice | Chemical Defence Establishment, Porton Down |
| DEC–20 | Mr. I. D. Griffiths | Trent Polytechnic, Nottingham |

***New facilities.*** Version 4.02 was released at Rothamsted in December, after extensive internal testing, and work began on testing the IBM version at Cambridge. This latest version has as its main extension procedures for optimisation, principally for use in fitting non-linear models. The syntax and underlying procedures are based on the ideas of MLP, the Maximum Likelihood Program; they extend the existing possibilities for fitting generalised linear models to models with non-linear parameters. These new facilities have been used in a program for producing response curves, including linear, quadratic and cubic polynomials, split-line regressions, the modified Mitscherlich curve, inverse linear, modified inverse linear and inverse quadratic polynomials. Improvements have been made to the regression output, and new functions added to calculate probabilities and percentage points for the chi-squared and variance-ratio distributions. A new directive, 'ENVIRONMENT', allows the user to discover useful properties of the environment in which the program is running, including, for example, the channel numbers for the various input and output devices. Finally, efforts have been made to increase awareness of the usefulness and power of macros for extending the scope of Genstat (Paper 10). Macros for producing probability plots for uniform and Normally distributed data have been written, together with another for permuting, combining, or deleting levels of factors classifying a table. Nine new macros have been added to the Genstat macro library, which is distributed with the program: five are useful in discriminant analysis, while the other four are for correspondence analysis, the analysis of asymmetric matrices, simulated 3-dimensional plotting, and supplementing the standard output from the directive for canonical variate analysis. (Alvey, Banfield, Bassill, Gower, Lane, Ross, Simpson and Todd)

***Documentation.*** The Installation Guide describes the operations required to produce versions for other machine ranges and gives detailed instructions for mounting Genstat at sites. A new edition of the Implementer's Manual gives a detailed account of the internal structure of the program, the programming conventions adopted, and specifications of the basic utility subprograms. (Simpson)



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The *Newsletter* continued to be published twice a year, and the *Manual* was updated to accompany the release of version 4.02. (Alvey and Watson)

***Support.*** Courses on the use of Genstat were given during the year at the Universities of Birmingham, Bristol, Edinburgh and London, the Lanchester Polytechnic (Coventry), Toegepast Natuurwetenschappelijk Onderzoek in Wageningen and The Hague, and at the University of Copenhagen. The length varied from 1 to 3 days, and a useful set of standard examples and course material has been developed. (Alvey, Banfield, Lane and Simpson)

The Danish course was perhaps the most successful yet, with more than 50 attending. We are particularly grateful to Mr. J. Wasniewski of The Computer Centre for Research and Education (RECKU) of the University of Copenhagen, for conversion of the program, Professor S. Johansen, Head of the Institute of Mathematical Statistics who organised the course and Dr. J. H. Gunn, Director of RECKU, who provided computing facilities.

Genstat was presented at the two courses on statistical computing organised by the Civil Service Department at Sunningdale (Alvey and Nelder). We continue to owe much to the site co-ordinators at all Genstat sites who deal with many day-to-day queries on the use of the program, and we are encouraged by some reports on the use of Genstat for the analysis of designed experiments and for fitting generalised linear models, prepared by members of the Biometrics Unit at Cornell University, USA.

***Future developments.*** Work began during the year on a major addition to Genstat in the form of a set of directives for time-series analysis, using autoregressive-moving-average (ARIMA) and transfer-function models. The work is being done in association with Dr. G. Tunnicliffe-Wilson of the University of Lancaster, who will provide the basic algorithms, with the interpreters and extensions to the compiler being written here. The first directives have been written and tested, and we look forward to a powerful addition to the system. (Lane and Pearlman)

**Generalised linear interactive modelling (GLIM).** Release 3 (*Rothamsted Report for 1977*, 307) was distributed by the Numerical Algorithms Group (NAG) (Oxford) beginning in the summer, and by the end of the year 107 copies had been delivered to organisations in 12 different countries. The program is available on 15 different machine ranges, with two more versions in preparation. (Baker and Nelder, in collaboration with NAG) Initial reaction to the new version, with its accompanying revised manual, has been favourable, though users have not been slow to point out further extensions which they would like to see implemented. Work has begun on specifying the extensions necessary to fit conveniently and efficiently the models which underlie the retrospective case-control studies of medicine, and the hazard-function models now widely applied to survival data. (Baker and Nelder and Professor J. Whitney, visiting scientist) In collaboration with Professor M. Stone of University College, London, Baker has developed a set of macros for the analysis of a type of pharmacological assay involving data from agonist–antagonist studies for the estimation of the dissociation constant of the antagonist. This involves a non-linear curve in the concentration ratio and allows for the introduction of blocking factors and covariates, and for non-Normal errors.

A programmer's guide, giving details of the internal structure of the program and its subprograms, has been issued by NAG. The notice-board and program guide for the Rothamsted implementation were re-written. (Baker)

Work has begun on the transfer of the Genstat algorithm for the analysis of designed experiments to provide an alternative kernel to GLIM, and to allow it to be used inter-



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actively in relatively small machine partitions. We are grateful to J. D. Beasley of the Computer Department for initial work on the code, and to Dr. B. Murphy of the University of Western Australia, Perth for continuing the exercise in consultation with us. (Baker, Nelder and Payne)

**Maximum Likelihood Program (MLP).** Version 3.05 was released at Rothamsted in May, and has since been implemented on the IBM 370 at Cambridge and the CSIRO CDC Cyber 76 at Canberra. Two licences have been taken out. The main new features this year included general expressions in derived variates and users' models, definition of scalars and variates for working space, a function SAVE, which allows output to be stored in a special file to become input to other programs, and a new function to compute moving averages. Inverse interpolation was added to the curve-fitting facilities. The syntax was revised to improve consistency, and the code was extensively revised to facilitate conversion to other machine-ranges and to improve efficiency. An entirely new manual is nearing completion. (Ross, Payne and White, with Mr. R. A. Kempton of the Plant Breeding Institute)

**Genkey.** Version 3.01 has been converted for the ICL 1900 range by Mr. A. Sumner of Reading University, for the IBM 360 by ourselves, and for the CSIRO Cyber 76 machine by Mr. R. Lamacraft. The first user licences have been issued. New facilities include a diagrammatic form of output to list irredundant test sets, and improvements to the output of keys in words. An algorithm was devised to select sets of tests for probabilistic identification. This is appropriate when most of the taxa have variable responses to the tests, making certain identification impossible. The method requires prior probabilities of the taxa to be assigned, as well as the conditional probabilities of obtaining each test result with specimens of each taxon, so that Bayes's theorem can be used to test results. The algorithm selects a set of tests to achieve identification with $x\%$ confidence for $y\%$ of specimens (where $x$ and $y$ are parameters set by the user). A probabilistic diagnostic table can then be printed for the tests in the set. The algorithm has been successfully tested using data provided by the National Collection of Type Cultures, Colindale.

An algorithm to produce polyclaves has also been incorporated. A polyclave consists of a deck of cards, one for each result of each test. A position on the cards is allocated to each taxon. Each card has holes punched in the positions corresponding to the taxa that can give the test results concerned, so that if the cards for any observed set of test results are superimposed, the taxa that can give those results can be detected by holding the cards to the light to see which positions have holes punched in every card. (Payne and White)

**Other programs.** A program (STAB) for the analysis of simple surveys has been written which allows a range of RGSP facilities to be used without writing Fortran. The user submits one document for an analysis which specifies both the form of his data and the analysis required. The program is at present experimental and is limited to input of card-image (numeric and character, fixed-field) data. However, it processes files with up to two levels of hierarchy including up to ten card types. In addition to standard RGSP facilities for decoding and grouping variables, STAB provides arithmetic instructions which take appropriate action when values of variables are unknown or inadmissible. (Church, with J. D. Beasley, Computer Department)

Version 2.06 of the cluster analysis program CLASP was implemented on the IBM 370 at Cambridge, and the first licence has been issued. (White)



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## Commonwealth and Overseas

By the end of the year the Unit sponsored by the Ministry of Overseas Development (ODM) was again fully staffed, after more than a year without a head. Demands on the service have continued unabated, however, with visits here from workers overseas, visits abroad by our own staff, and a steady flow of data and requests for analyses by post.

**Visits abroad.** During May and June Janet Riley visited the International Institute of Tropical Agriculture (IITA) to study the inter-cropping experiments being done at various sites in Nigeria. Useful contacts were made with scientists there and at the Institute for Agricultural Research, Samaru (see below).

In November D. A. Preece visited Barbados and Trinidad to assess the Biometrics project there. This project, which is funded by ODM has two main activities: (i) to study the factors influencing the precision of field experiments in the Caribbean, and (ii) to study experimental design and analysis when resources are limited. A report has been submitted to ODM.

**Analysis.** We received data on a variety of crops during the year from 16 countries, as Table 2 shows.

**TABLE 2**

*Origin of overseas data by country and crop*

| | |
|---|---|
| Bolivia | Cotton |
| Botswana | Sorghum, maize, cowpea, wheat, barley |
| Falkland Islands | Grass |
| Fiji | Legume, grass |
| Ghana | Maize, sorghum |
| India | Sunflower |
| Malawi | Legume, tobacco |
| Malaysia | Oil palm |
| Nepal | Maize, sorghum, wheat, soya bean |
| Nigeria | Maize, cowpea, sorghum, soya bean |
| Papua New Guinea | Cocoa |
| Sierra Leone | Rice |
| Solomon Islands | Sweet potatoes |
| Sudan | Sorghum |
| Tanzania | Cotton, cassava, maize, soya bean, sugarcane |
| Zambia | Sunflower, star grass, lucerne |

Notes on several of the large jobs follow.

Results were received from Malawi of a large experiment to investigate the growth of tobacco at each of six levels of applied fertiliser and with or without the application of ethylene dibromide to the soil. The experiment was conducted on six tenant farms for 3 years and the leaves were cured in tenant-style barns. There is little local information on the optimum level of fertiliser, and there is serious doubt whether the benefit from the use of ethylene dibromide warrants the cost of its application. This experiment aimed to supply information on these points, it being particularly desirable to have recommendations available for the Blanket A–1 variety before it is widely grown in Malawi. Initial analyses have shown that increased fertiliser application increases yield but that the beneficial effects of ethylene dibromide vary at different sites. A season × site analysis is to be undertaken and, possibly, a study of the extent of attack by nematodes. (Riley)

We were asked to investigate the variation in the yields of sweet potatoes grown in the Solomon Islands with respect to six climatic variables. The data supplied were the



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monthly yields of tubers and vines over a period of 5 years, together with the monthly means of the total rainfall, solar radiation, hours of sunshine, minimum and maximum temperatures, and relative humidity. Linear regression techniques were used to find the best subset of the climatic variables, with lags of up to 4 months; these accounted for most of the variation in the two yield components. (Ryder)

The experiments whose data we received from the Falkland Islands provided a change from the crop experiments that we usually handle. The first investigated the trace element variability of pasture and soil. Administration of selenium to ewes is known to influence both the number of lambs born per ewe and the sex ratio of the lambs born. If such a response were recorded in the Falkland Islands, it could be related, at a later date, to the selenium levels in analysed pasture and soil. Ewes were divided into adult and young ewes and each group was given selenium or cobalt or no supplement. Responses were measured as ewe prolificacy, lamb survival and ewe body condition. The analysis indicates that age of sheep was the major factor determining the variation in response, rather than the dietary supplement.

The second experiment measured the response of four soil types, representing an altitudinal transect, to a varying range of lime and phosphate, and tested the response of a range of species sown under these conditions. The third experiment studied the seasonal growth and dry matter production of *Cortadena pilosa*, the dominant Falkland Island sward. Sward production was measured at 3-weekly intervals together with the relative change in proportions of green and dead parts of the sward throughout the season, and changes in soil pH. (Riley)

Other pieces of work involved the continuing analysis of large-scale oil-palm variety trials from Malaysia, fertiliser and variety trials on sunflowers from Zambia, and the completion of the analysis of a series of experiments from Tanzania on the effects of planting time and fertilisers upon sugarcane varieties. (Riley and Ryder)

**Intercropping.** The intercropping survey has been continued, and the catalogue of the available literature involving intercropping or competition now includes over two hundred references. A bibliography is to be written once the catalogue is as up to date as possible. Janet Riley has been invited by ODM to join a team of statisticians, headed by Professor S. C. Pearce, who will investigate the problems associated with the intercropping system of farming with the aim of producing new methods of analysis for experiments involving mixtures of crops. The team is to concentrate on data produced by scientists at the IITA, Ibadan and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) at Hyderabad. Although much work is being done at various centres all over the world, yet data are still often collected from one species only, the yield of the secondary crop being ignored. Thus, the development of statistical techniques for analysis of the joint growth of two or more crops is being hampered by lack of data.

Contacts with workers involved in intercropping have been made in Tanzania, Libya, Sri Lanka and St. Lucia. Similar work is also known to be in progress in Kenya, Nepal and Colombia, and contacts will be sought in these countries for the furtherance of the project. (Riley)

**Covariance analysis.** In the technique of covariance analysis, yields from designed experiments are adjusted for variation in concomitant variables such as initial plant stand, with a view to increasing precision by removing the effects of their uncontrolled variation. The technique, while potentially powerful, is also full of dangers for the unwary. Textbook accounts of covariance analysis for factorial experiments are often inadequate, even for statistically knowledgeable readers, and it is not uncommon for experimenters to ask for



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inappropriate covariance adjustments. Work has begun to produce an expository account of the technique as applied to complex designs. (Preece)

**Visitors.** Mr. O. G. Molina, head of the Biometrics Section at Centro Nacional de Tecnologia Agropecuaria, El Salvador, spent 3 weeks with the Unit in August, studying the organisation of field experiments and the biometrical services offered by the Unit. A further 20 visitors were received during the year, including Miss R. K. Chungu, Director of the Mount Makulu Research Station, Zambia, and workers from Bolivia, Botswana, the Falkland Islands, India, Malawi, Papua New Guinea, the Sudan, Tanzania, Tuvalu, and Zambia.

## Staff and Visiting Workers

F. B. Leech retired in July after 26 years in the Department. Mary G. Hills retired, for family reasons, after 23 years. Patricia J. Wherry left in January.

D. A. Preece joined the Department as Head of the ODM Section in September. Gina L. Smith and Catherine M. Garnett were appointed.

R. W. Payne is spending a year at the Division of Mathematics and Statistics, CSIRO, in Adelaide in an exchange with Dr. A. G. Constantine from CSIRO, Adelaide, who arrives in April 1979.

J. A. Nelder gave a course of lectures on statistical computing at Imperial College in February and March. In September he gave a presentation of Genstat to the International Agency for Research on Cancer in Geneva, and an invited paper to the Fisher Conference on Design of Experiments in Cambridge. In November he attended an ISO Fortran Experts' Meeting in London, and in December gave an invited paper at the IFIP Working Conference on Performance Evaluation of Numerical Software, held in Baden (Austria). He was a member of the Scientific Program Committee of the 3rd Symposium on Computational Statistics, held in Leiden in August, where he presented an invited paper (Paper 23). He was accompanied by J. C. Gower and C. F. Banfield, who contributed Paper 10, G. J. S. Ross (Paper 30), and R. J. Baker and P. W. Lane (Paper 9).

N. G. Alvey delivered a talk on 'Input and output for statistical programs' to members and students of the Department of Statistics and Operational Research at Brunel University.

H. R. Simpson gave a seminar on Genstat at the Danish Institute of Mathematical Statistics in Copenhagen in July.

Lectures and demonstrations on GLIM were given at the 3rd Symposium on Computational Statistics, Leiden, and also at the Universities of Durham, Bath and Newcastle, by R. J. Baker.

Jill F. B. Altman attended a seminar by students and staff at Newcastle University in February, where she presented a paper on 'The planning of experiments with large livestock'.

J. C. Gower attended the Psychometric Society Conference in Uppsala, where he presented an invited paper. He visited the USA in August, primarily to help organise the IFIP meeting on Statistics, Computing and Medicine, which it is hoped will take place in Iowa in 1979. Whilst in the USA he gave seminars at The National Institutes of Health, University of North Carolina, Bell Telephone Laboratories and the State University of Iowa.

J. N. Perry attended the conference of the Mathematical Ecological Workshop of the Biometric Society, at the University of Sheffield, and the annual meeting of the Society for Experimental Biology at the University of Reading, presenting a paper on each occasion.



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D. A. Preece attended the 1-day Colloquium on Combinatorics, held at the University of Surrey, where he presented a paper. He also gave an invited paper on 'The randomisation of treatments superimposed on an existing design' at the Fisher Conference on Design of Experiments, Cambridge.

G. J. S. Ross attended the European Meeting of Statisticians in Oslo, where he was an invited discussant on non-linear modelling, and on cluster analysis.

R. H. Wimble conducted a half-day lecture/seminar with ADAS Plant Pathology Fieldsmen at Reading, and he, R. W. Payne and C. J. Dyer gave talks at a lecture and discussion meeting with ADAS plant pathologists at Cambridge. He also gave a talk on experimental design to ADAS soil scientists at Reading.

Our visiting scientist, Dr. I. A. Rubanov from the Plekhanov Institute of National Economy, Moscow, left the Department in June. Professor L. P. Lefkovitch of Agriculture, Canada and Professor J. B. Whitney of the University of Waterloo, Canada, joined the Department for 1 year in June and September respectively. We had seven other short-stay temporary workers in the course of the year.

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