ROTHAMSTED RESEARCH

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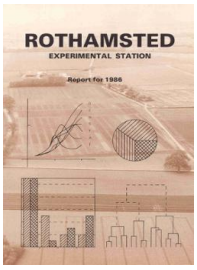
Full Table of Content



Survey Work in the Statistics Department

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Survey work in the Statistics Department

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Abstract

Sample survey work in the Statistics Department began just before the 1939–45 war. Major series of surveys and some of the more recent work are described, as is our involvement in the development of software for survey analysis since before 1960. Information from recent fertilizer surveys on the timing of N applications to winter cereals is summarized.

Introduction

Some use was made of sampling methods in the 1930s to get more objective estimates of crop yield in England and Wales than those provided by crop reporters (Yates, 1936). Crops were sampled at a number of 'crop-weather' stations but, although these sites were widely spread, no attempt was made to survey randomly chosen sites. The first large-scale involvement of the Statistics Department in sample survey was just before and during the war and was concerned with assessing natural resources (Barnard & Plackett, 1985). The application of sampling methods to Censuses of Woodland in 1938 and 1942 showed clearly that their use enabled urgently needed information to be made available much sooner than would have been possible by complete census, and for the results to be based on careful measurement rather than solely on subjective judgments (Yates, 1949). Other early work was in the analysis of the National Farm Survey of England and Wales (Ministry of Agriculture, 1946). This was in fact a census, because details were needed for individual holdings, but general summaries (the results by counties, farm types, etc.) were rapidly produced from a stratified subsample of returns at minimum cost and a year or two sooner than would have been possible using complete census data.

Surveys of how farmers use fertilizers, which were begun in 1942 as an aid to planning fertilizer allocation schemes in wartime, showed from the outset the value of combining information from experiments and surveys (see Finney & Yates, 1981). Experiments showed how crops responded to fertilizers under different circumstances, and surveys showed how farmers actually used fertilizer supplies and thus what benefits they were likely to be getting in practice and where advisory efforts should be concentrated. These surveys have been continued, on an annual basis since 1969, and the Department has had a leading role in their planning and coordination and in the interpretation of results. They are more fully discussed below.

The flexibility and economies offered by the use of sampling methods and the scope for their adoption in agricultural surveys were illustrated by referring to the early work of the Department in a seminal paper by Yates (1943), in which he also drew attention to the need for further research, especially in methods of analysis for survey data. In 1947, Yates attended the first session of the United Nations Subcommission on Statistical Sampling, which identified the need for a manual on sampling to assist the programme for the 1950 World Census of Agriculture, and this led to publication of *Sampling Methods in Censuses and Surveys* (Yates, 1949). The title of this pioneering book hardly conveys its scope, as this and subsequent editions (Yates, 1981) include much guidance on the practical problems involved in planning and organization of sample surveys and their analysis, as well as concise statements of the mathematics of sampling.

Subsequent work of the Statistics Department has ranged, for individual surveys, from consulting on sampling, questionnaire design or analysis to continuous involvement with all these aspects together with pilot testing, instruction of interviewers, and critical analysis and

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interpretation of results. Rothamsted has never had its own field survey staff and all surveys have been undertaken in collaboration with other organisations, so a particularly important aspect of survey planning has always been the elucidation of possibly conflicting survey aims and their reconciliation with available resources. This paper describes some major surveys with which the Department has been involved and gives some recent results. We also discuss software used for survey analysis.

Surveys of the potato crop

Surveys of maincrop potatoes in England and Wales, initiated by the Agricultural Improvement Council and done in 1948–50, provided the first extensive information on farmers' practice for this crop. As well as recording details of the seed used, planting dates, cultivations and fertilizer use, etc., hand dug samples were taken pre- and post-harvest to give objective estimates of yield as a check on Ministry of Agriculture official estimates which were at that time based on subjective judgments by crop reporters (Boyd & Dyke, 1950). In both 1948 and 1949 the hand-dug samples showed yields up to about a fifth higher than the official figures. By 1958, when a similar survey of nearly 1000 farms in Great Britain was done by the Potato Marketing Board (PMB) in collaboration with the National Institute of Agricultural Engineering and Rothamsted, the PMB had its own system of pre-harvest crop-check weighing, based on a panel of farms. This was in turn changed to a system based on a fully representative random sample of farms following further surveys under the same sponsorship in 1963 and 1968 (Potato Marketing Board 1960, 1965 and 1970).

In addition to encouraging the routine use of improved methods of yield estimation, this series of surveys identified aspects of growers' practices which differed from recommendations, drew attention to the needs for further experimental work and monitored changes in practice. For example, use of sprays for blight control increased from 5–10% in 1948/9 to about half the maincrop area in 1958 and the area treated with herbicides increased from almost zero to nearly half the crop between 1963 and 1968: in each case the later surveys estimated the areas on which individual chemicals were used.

In reporting the first surveys Boyd and Dyke (1950) referred to results from seven experiments on planting date, all of which showed yield reductions with late planting of maincrop potatoes. The survey data showed that planting dates ranged widely even within regions and that earlier planting was associated with better yields. These results pointed to the need for further experiments to examine more thoroughly the possibilities for increasing yields by earlier planting (Dyke, 1956). Other surveys done in collaboration with the PMB provided estimates of the quality of stored maincrop potatoes and of the relative importance of different defects that could cause a potato to be rejected (Church, Hampson & Fox, 1970).

Livestock surveys

In the quarter century following the war, several livestock surveys were analysed at Rothamsted. Most of this work was done by F. B. Leech, who was a qualified veterinary surgeon and had previously been employed in the Colonial Service in Africa and at the MAFF Central Veterinary Laboratory. Leech described methodology for disease surveys in a co-authored book (Leech & Sellers, 1979) in which he made a distinction between investigational and economic surveys. By an economic survey he meant one whose aim is to determine the importance of different categories of disease, whereas an investigational survey is one designed to reveal the natural history of particular diseases or disorders. He believed that investigational surveys, where substantial numbers of diseased animals could be given detailed examination, were very useful for veterinary research work.

https://doi.org/10.23637/ERADOC-1-27

Between 1948 and 1955 a number of local surveys were done which provided economic information on disease but had little investigational content and could not answer questions on the extent of national problems. In the decade following 1957, five national surveys of animal disease were done in collaboration with MAFF (Leech, 1971). They consisted of two surveys of diseases in dairy herds, a survey on losses in breeding ewes, a brucellosis survey and a calf mortality survey. The surveys of diseases in dairy herds and breeding ewes were designed only to estimate the extent of disease problems. The brucellosis and calf mortality surveys were primarily investigational. In the brucellosis survey, detailed information was collected and laboratory tests were made on individual animals; in the calf mortality survey, results of post mortem examinations were retrieved. These last two surveys gave information on the extent of problems, but were also useful in examining the mechanism of disease. For example, results of the calf mortality survey confirmed previous laboratory experiments which indicated that feeding colostrum by pail has much larger effects on calf mortality for some breeds than for others. In both instances, animals in the survey provided subjects for laboratory work, their choice by random sampling ensuring that those examined were reasonably representative of the population of interest (Leech, Vessey & MacRae, 1964; Leech, MacRae & Menzies, 1968).

In the last decade, research effort on livestock has been concentrated on experimental work, with fewer surveys being done. The Department has been involved in a survey of the use of anthelmintics for cattle (Michel *et al.*, 1981) and in a behavioural study of calves under different rearing systems in collaboration with Bristol Unversity Department of Animal Husbandry and MAFF, in which differences in calf behaviour between rearing systems were modelled, taking account of possible differences between observers. (Webster *et al.*, 1985).

Fertilizer practice

Since 1942 the Department has had a leading role in planning and coordination of surveys of how farmers use fertilizers on individual crops (Yates, Boyd & Mathison, 1944; Yates & Boyd, 1964; Church & Webber, 1971; Church & Lewis, 1977). Aims of these surveys have ranged from assessing priorities for fertilizer imports and the allocation of scarce supplies in wartime, to monitoring trends so that industry can predict future needs and advisory effort can be directed to situations where practice differs from recommendations based on experiment.

These surveys have been done in collaboration with ADAS (formerly NAAS). From 1957 onwards representatives of the Fertiliser Manufacturers Association (FMA) have made an increasing contribution as co-sponsors. Their sponsorship enabled the series of surveys to be extended to Scotland in 1983, and since 1985 representatives of the FMA have funded all of the field work, with ADAS soil scientists continuing to be substantially involved in planning and interpretation of results (Chalmers & Leech, 1986). Duplicated reports on fertilizer use on farm crops have been prepared at Rothamsted after each survey, and since 1974 a paper on the use of fertilizers in England and Wales has appeared in Part 2 of the Rothamsted Report.

Initially, surveys were done in compact districts regarded as homogeneous for soil and farming type, the emphasis being on obtaining information useful locally for advisory meetings. Since 1969 there has been more concern to obtain good estimates each year of average fertilizer use per hectare and of the proportions of area under individual crops getting different amounts of nutrients and types of fertilizers, in order to monitor trends over the whole country and provide comparative estimates of use for major regions and types of farm. This has been achieved by surveying fully representative stratified random samples of farms, stratification being by farm type and size. The survey has been done annually in England and Wales, on about 600 farms between 1969 and 1973, 1350 between 1974 and

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TABLE 1

Fertilizer use on tillage crops and grassland (kg ha^{-1})

	N			P_2O_5	K_2O
Tillage	Straight	Compound	Total		
1970	29	59	88	56	61
1975	36	50	86	46	51
1980	77	44	121	49	54
1985	134	27	161	56	63
Grassland					
1970	42	30	72	30	22
1975	67	32	99	24	20
1980	69	50	119	27	26
1985	70	62	131	24	32
All crops & grass					
1970	36	43	79	42	40
1975	54	40	94	34	34
1980	73	47	120	37	40
1985	102	44	146	40	48

1984, and about 1200 since 1985. Since 1983, around 250 farms have been surveyed in Scotland.

Table 1 gives figures for N, P and K application rates for tillage, grass and all crops and grass at five-year intervals between 1970 and 1985. On the tillage area, use of P and K was somewhat reduced in the mid 1970s but has since recovered to earlier levels. On grass, the use of K has increased by about half over the last 10 years; use of P declined by about a quarter in the early 1970s, and has stayed at much the same level since then. There have been major changes in N use, with usage on tillage and grass approximately doubling over the last 15 years. The rate of increase in N use has slowed down recently with very little change in the total N applied between 1984 and 1986. The increased use of straight N fertilizers (i.e. those which contain no other nutrient) accounts for nearly all the increase in total N since 1970. On tillage crops use of compound fertilizers has been declining. These changes in the types of fertilizer being used are partly due to the move from spring- to winter-sown cereals. The proportion of cereal area devoted to spring barley declined from 54% in 1975 to 14% in 1985, while the proportions in winter wheat and winter barley increased from 29% to 54% and from 6% to 27% respectively.

There is currently much interest in the timing of fertilizer applications on winter cereals. Experiments show that autumn N rarely gives a useful response; it is therefore unprofitable and also an avoidable hazard to water quality. Table 2 gives percentages of N fertilizer applied to winter cereals throughout the growing year. The percentages applied in the October to December period and in February have consistently declined between 1983 and

TABLE 2

Timing of N applications to winter cereals

	% of total N applied in							Total N
	Aug	Sept	Oct–Dec	Jan	Feb	Mar–May	June–July	(kg ha^{-1})
1982–83	0·1	2·5	6·1	1·5	13·0	75·9	0·9	170
1983–84	0·1	3·4	4·5	0·6	10·7	79·9	0·8	173
1984–85	0·2	2·5	3·4	0·2	8·7	83·7	1·4	176
1985–86	0·1	1·6	3·3	0·5	7·8	84·1	2·7	172

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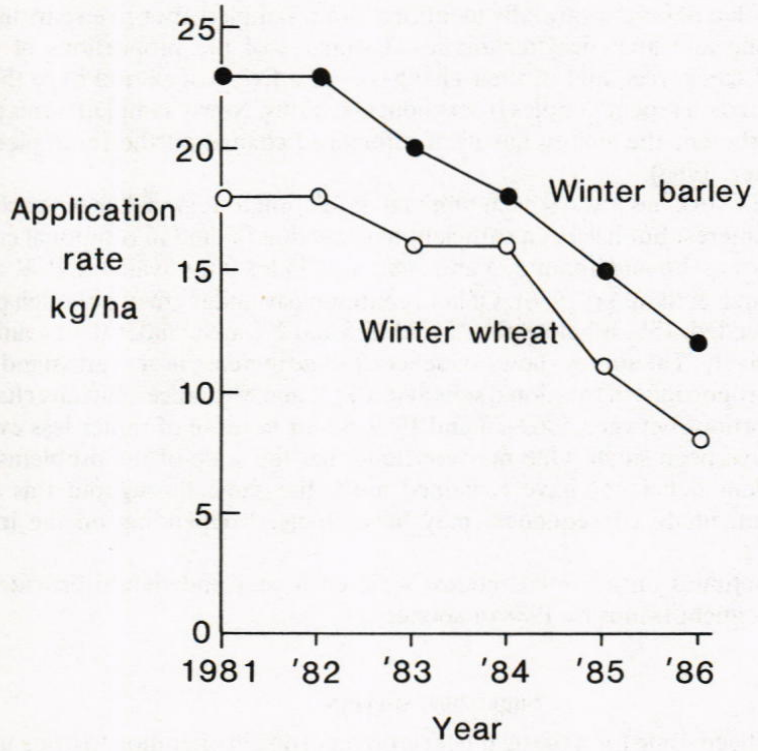

FIG. 1. Compound N use on winter wheat and winter barley.

1986. Nearly all autumn and winter applications of N are in compound form, so the reduction in N applied at this time is reflected in a reduction in the amount of compound N used on winter cereals (see Fig. 1). Between 1983 and 1986 the area of winter wheat and winter barley receiving compound N has dropped from 66% to 44% and from 78% to 52% respectively. Current ADAS fertilizer recommendations are that autumn N should not be applied to winter cereals except for directly drilled crops where use of up to 25 kg ha^{-1} may be worthwhile. In 1986, only about 7% of winter wheat and 9% of winter barley got compound N at or above this level, compared with 14% and 19% respectively in 1983. The latest survey thus shows current practice on winter cereals moving much closer to that advised. It is also encouraging that the use of N in February is declining.

Soil status

Concern is often expressed about the pH and nutrient status of agricultural soils in England and Wales, and figures are quoted showing the proportions of advisory samples, taken by ADAS or fertilizer companies, which are acid or have low nutrient levels. Advisory samples are unlikely to be fully representative of agricultural land as a whole. More seriously, changes in the proportions of advisory samples showing deficiencies may have more to do with how advisory work is targeted, whether sampling is charged for and, possibly, whether small changes are made in techniques than with any general tendency for soils to improve or deteriorate.

From 1969, ADAS soil scientists in collaboration with Rothamsted, have done an annual Representative Soil Sample Survey based on 120 or so farms subsampled from the Fertilizer

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Survey lists. Sampled fields are carefully identified and resampled after five years using the same soil sampling and analytical techniques. Estimates of the proportions of soils in different nutrient categories, and of their changes over a five year period have therefore been obtained based on repeat samples from about 600 farms. Newly sampled farms provide some check on whether the survey has itself influenced change on the resampled farms (Church & Skinner, 1986).

The scale of this work has always been minimal in relation to regional or other contrasts thought to be of interest but has been sufficient to show that of land in rotational cropping about 12% is below pH 6 and about 6, 3 and 2% are at index 0 for available P, K and Mg respectively (Church & Skinner, 1986). Of land continuously under grass, although possibly ploughed and reseeded, 15% is below pH 5·5 and 15·5 and 2% are at index 0 for available P, K and Mg respectively. The survey shows evidence of some increase in acid grassland, and of decreases in the proportions of rotational soils at low P, K and Mg indices, but any changes in the quoted proportions between 1969–73 and 1979–83, or in those of rather less evidently deficient soils, have been small. One may conclude that the scale of the problems of soil acidity and nutrient deficiency have remained much the same throughout this period, although their immediate consequences may have changed depending on the levels of production sought.

This survey continues on a similar modest scale each year and should provide useful evidence on subsequent trends by 1988 or sooner.

Sugar beet surveys

There has always been some form of sugar beet crop reporting in operation to bring together information based on the experience and local knowledge of British Sugar field staff. Some has been needed largely for administration, some for issuing warnings about pests and diseases and some for its scientific interest. Different procedures were developed somewhat independently to meet these needs. The present series of Specific Field Surveys was begun in 1979 (Maughan, 1982). It represents the most recent attempt to coordinate these procedures, increase their efficiency and minimize the total work involved. Fieldwork and basic analysis of the surveys are done by British Sugar, and they are planned through a joint Working Party with Broom's Barn on which the Statistics Department is represented. We also undertake supplementary analysis of the data for which our general purpose software (RGSP, see below, and Genstat, see Gower, 1986) are well suited.

A fully representative random sample of about 650 sugar beet fields is now visited three times a year. Crop variety, details of planting and harvesting procedures and the machinery used, use of fertilizers and chemicals for pest, disease and weed control are recorded and subjective assessments made of incidence and severity of damage to the growing crop by different pests and diseases, soil conditions, etc. In addition, at the end of months from May to August more objective measurements are made by examining samples of plants for disease, nutrient deficiency and bolting. Plant populations are estimated by sample counts at the end of June, leaf diameters at the end of May and June, and yields from hand-dug pre-harvest samples are taken over eight weeks from the middle of August.

As illustrated in particular by recent articles in the British Sugar Beet Review (Cooke, 1986; Turner, 1986; Longden, 1986; Dewar, 1986), information from these surveys on how the crop is grown and on the incidence of pests and diseases is used to place advisory work based on experiments in context and as a background for further research. The other major objective is to provide forecasts of the total sugar beet crop each year so that campaigns can be planned at individual factories and over the country. An empirical method of predicting yields from pre-harvest samples has been devised using historic data and successfully applied since 1982 (Church & Gnanasakthy, 1983).

https://doi.org/10.23637/ERADOC-1-27

This series of surveys also provides an exceptional opportunity for looking at relationships between crop yields and growers' practices for a random sample. Such relationships must always be interpreted with great caution for two main reasons. First, if we examine many possible relationships some are likely to appear well established entirely by chance. Secondly associations may not be causal but due to other inter-related factors. For example, yields may be higher on crops treated with pesticides even when pest incidence is negligible because growers using pesticides also use more of other inputs. The higher yields may result from these other inputs, or the inputs may be afforded because growers are operating on land with above-average yield potential. In as far as the relevant data are recorded, one may examine such possibilities and attempt to allow for them.

If consistent associations are found over a series of surveys and these appear stable when likely disturbing factors are taken into account, the survey evidence may be regarded as at least a useful supplement to that from experiments or it may point to the need for further experimental work. For example, data from these surveys for 1981–85 show, in agreement with experimental evidence, that growers using more than 125 kg N ha^{-1} get no more sugar yield than those using less, and this remains true after allowing for yield differences attributable to varieties, regions, soil textures and date of sowing (Church, Armstrong & Turner, 1986). While the evidence from experiments is more fundamentally sound, growers aware that they often operate under conditions quite different from those in controlled experiments are likely to be more convinced when survey data are also available.

Rothamsted General Survey Program (RGSP)

Surveys are typically hierarchic in structure, containing, for example, detailed information about variable numbers of individual fields within farms. Individual survey records may also be incomplete, or contain erroneous or suspect data. These characteristics pose special problems in analysis. The Department has been involved in development of software for survey analysis since first generation electronic computers became available for statistical work (Yates & Simpson, 1960; Yates, 1973; Finney & Yates, 1981); the present version of the Rothamsted General Survey Program (RGSP) results from evolution over more than 20 years with continuing surveys, such as the Survey of Fertilizer Practice, providing a test of progress.

Although not 'user friendly' by present standards, and requiring some use of Fortran except for simple applications, RGSP provides flexible facilities for reading survey data from hierarchical files, validation and manipulation of the basic variables and for tabulation, manipulation and printing of well-annotated tables. The experienced survey analyst can readily produce valid estimates of sampling error taking account of survey structure, and tabular summaries can be interfaced to Genstat for further critical analysis (Yates, 1980; Beasley, Church & Yates, 1980; Church, 1982). Despite the proliferation of tabulating and 'report-generating' packages mostly geared to market research or commercial applications, we are aware of none which offer quite this combination of facilities and RGSP continues to be used for most of our survey analysis work. We are considering the possibilities for producing a micro version of RGSP, at the same time making some modifications which would make the package easier for ourselves and others to use. A possible modification is the incorporation of a more explicit 'data dictionary' to keep track of labelling throughout a series of analyses, possibly by interfacing to a suitable database management system as well as to Genstat.

Future developments

The largest survey on which we are currently working is the Survey of Fertilizer Practice. Commercial information on an annual basis continues to be very valuable to FMA members

https://doi.org/10.23637/ERADOC-1-27

who sell fertilizer in an increasingly competitive market. ADAS also find the survey data very useful for their consultative work and for providing a basis for decision making on what are increasingly sensitive environmental questions. Both bodies would like to have more ready access to the data, with easier provision for obtaining regional information. We are currently looking at the possibilities of using a database system to respond more speedily to queries that arise, and to make subsets of the data available for further analysis.

The dichotomy between investigational and economic surveys discussed in the section on livestock surveys, and the recent work on sugar beet, raise the question as to what extent surveys should complement experiments. The investigational type of survey is very closely related to experimental work, and we would welcome further involvement in this area.

Apart from Yates' own work during the war the Department has been little involved in the past with aerial photography. Such techniques are now used to monitor crop growth and map the distribution of crops. We anticipate such monitoring will be increasingly done using satellite data. This has already been done within the AFRC. The Macaulay Institute for Soil Research in Aberdeen have an image processing system that has been used to estimate crop areas; G. G. Wright (1985) used LANDSAT satellite data to estimate the distribution of winter oilseed rape in eastern Scotland. Application of standard statistical methods to these data can lead to misleading results, and there is a need for further research to ensure their correct interpretation. In particular, many discrimination techniques currently applied do not make adequate allowance for spatial correlation between observations, and can seriously overestimate the accuracy of discrimination.

We continue to be interested in all aspects of the design, analysis and interpretation of surveys and a particular area of current concern is the development of facilities for validating survey information effectively at the time it is actually being recorded. Such facilities offer a real prospect of substantially improving the reliability of survey records and of reducing the effort, and sometimes speculative procedures, involved in subsequent data screening.

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