# THE EFFICACY OF AGRONOMIC RESEARCH IN NEW ZEALAND

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## ABSTRACT

One hundred papers describing the results of agronomic trials published in recent volumes of the Proceedings of the Agronomy Society, the New Zealand Journal of Experimental Agriculture, and the New Zealand Journal of Agricultural Research were surveyed. The information given on objectives, treatments, environmental factors, durations and numbers of trials, crop responses, methods of analysis, and conclusions within each paper was analysed.

We found that: (i), the intended users of research results were rarely identified; (ii), the objectives of the research were not always stated explicitly; (iii), experimental designs and methods of analysis were often inappropriate; (iv), soils or climatic data were rarely used to aid interpretation of results; (v), trials were inadequately replicated in time and space; (vi), firm conclusions were absent in the majority of papers. These results suggest a need for changes in agronomic research procedures. We discuss changes in research objectives and organisation, in statistical procedures, in the use of environmental information and alternative models, and in methods of publication and education. Adoption of different procedures in these areas could increase the efficacy of research.

## INTRODUCTION

A considerable effort is devoted to agronomic research in New Zealand. The number of trials on aspects of crop and pasture production carried out within the Ministry of Agriculture and Fisheries each year is well in excess of 1,500 (B.R. Keenan, pers. comm.). When we add a smaller, but probably not dissimilar number, for the trials carried out by DSIR divisions, by universities, and by private organisations, the magnitude of the research effort becomes apparent.

Despite this effort there is a strong undercurrent of dissatisfaction over the effectiveness of much agricultural research. This dissatisfaction surfaces in calls for changes in the organisation of research (Cumberland, 1978; Elworthy and Langer, 1978; Pinney, 1978; Wallace, 1978; Lynch, 1980) and in criticisms of the scientific paper as a means for communicating research results (Cumberland, 1978; Pinney, 1978; Moss, 1980).

But should we be concerned only with defects in organisational structure and in the communication of results? Elsewhere it has been argued that the usefulness of much agricultural research is reduced by overemphasis on scientific value and statistical significance and neglect of practical and economic implications (Anderson, 1971; Rose, 1975; Ebersohn, 1976; Dillon, 1978). Do these criticisms apply to research in New Zealand? Are we using the most appropriate methodologies? There has been debate over the existence of a 'technology gap' between what is known and what is applied. Might there be another gap, perhaps more important, between the research which is done, and the research which could be done? We believe that these are important questions for agricultural scientists. In this paper, we raise these questions in relation to the agronomic research carried out in New Zealand.

## THE CONTEXT OF AGRONOMIC RESEARCH

We shall distinguish two classes of agronomic research. The first is research which is designed to add to knowledge about phenomena by way of exploratory surveys or experiments to elucidate mechanisms. Although this 'basic' research makes important contributions to agronomic thinking it will not concern us here. Instead we shall concentrate on research which is designed to influence management decisions. We chose this emphasis because we believe that agronomy is a practical, problem-oriented science and that the first job of agronomists is to help solve the management problems faced by farmers, the ultimate consumers of research results.

The nature of the management problems studied in agronomy can be displayed using a generalised functional equation which relates a desired output, such as crop yield, Y, to a set of input factors, $X_1 \cdots X_n$. We write

$$Y = \mathbf{f}(X_1 \cdot\cdot X_a; X_{a+1} \cdot\cdot X_\rho; X_{\rho+1} \cdot\cdot X_\upsilon; X_{\upsilon+1} \cdot\cdot X_n) \quad (1)$$

to indicate that Y is a function of four sets of input factors or variables (Dillon, 1978). These are:

(i) **Agronomic decision variables,** $X_1 \cdot\cdot X_a$. These are inputs over which a producer has some control, e.g. sowing date, fertiliser rate, grazing frequency ...

(ii) **Uncontrolled, predetermined variables,** $X_{a+1} \cdot\cdot Xp$. These are factors which the producer cannot control but which are, in principle, able to be determined at the beginning of the production process, e.g. soil nutrient supplies, soil water properties, day length ...

(iii) **Uncontrolled, unknown variables,** $Xp_{+1} \cdot\cdot X_u$. Variables which cannot be controlled or predicted with precision, e.g. rainfall, temperature, pests and diseases ...

(iv) **Genotypic variables,** $X_{u+1} \cdot\cdot X_n$. Physiological factors dependent on genotype, e.g. sensitivity to tempeature, photoperiodic threshholds ...

Division of input factors into four classes focusses attention on the diverse sources of variation in a production process. From the viewpoint of management, the four classes can be collapsed into two: controllable factors, and uncontrollable factors. The management problem is then to manipulate the controllable factors in order to attain some objective such as maximum yield, maximum profit or minimum risk of loss. Theory for determining optimum levels of controllable inputs has been developed in agricultural economics (e.g. Dillon, 1978) and hinges upon knowledge of responses to input factors. If these responses are well defined, the manager's optimisation problem is relatively easy to solve. In practice this is not so and the choice of the optimum levels of controllable inputs must be made in the face of uncertainty caused by uncontrollable inputs, factors such as rainfall or temperature which often may dominate the production process. Agronomists therefore have two basic tasks: first, to define responses to controllable inputs and, second, to provide sufficient information for the optimum levels of these inputs to be determined despite the uncertainty stemming from uncontrollable inputs.

Many difficulties stand in the way. Foremost is the absence of adequate theory. Although 'basic' research has provided many insights into the mechanisms underlying crop growth, nutrient uptake, responses to climatic factors, etc., very few of these concepts have sufficient generality to help agronomists in management-related research. The agronomist must therefore proceed by empirical investigation of responses in field trials.

Trials must include a range of treatments in order to define responses to controllable inputs. These treatments may involve both qualitative and quantitative factors (Barlow, 1966). Qualitative factors are decision variables such as methods of cultivation, methods of harvest, or crop cultivars, which cannot be placed on a numerical scale. Where input levels can be scaled, as for fertiliser rates, seeding rates, or quantity of irrigation water, the decision variables are quantitative. An elementary consideration in investigations of responses to quantitative factors is that a trial should contain at least three factor levels so that curvilinearity of response is detectable (Anderson, 1971; Dillon, 1978). With two levels, only mean or linear responses are distinguishable and an economic analysis would indicate that the optimal input is either zero or infinite (Anderson, 1971). Obviously this stricture does not apply when responses to qualitative factors are under investigation, for here the manager requires only the information that the response to one method is superior to that for other methods.

Once responses to qualitative or quantitative decision variables have been determined, the agronomist must define the conditions under which these trial results hold. Trials are performed at given sites, in given years, and with some controllable variables at fixed levels (the total number of decision variables is too large for all to be included in a practicable experiment). Since a different response to treatments should be expected whenever any other input (uncontrollable or controllable) varies (equation 1), the general validity of the responses in a trial is always in question. Agronomists adopt various strategies to overcome this problem. For example, the effects of controllable inputs which are not included as treatments may be set aside by ensuring that these are at non-limiting levels; climate and site effects may be removed either by repeating the trial over a range of sites or seasons (e.g. Barlow, 1966), or by including these factors as independent variables in analyses (e.g. Stauber and Burt, 1973), or by the use of empirical mechanistic models (e.g. Sands *et al.*, 1980). To varying degrees, these strategies are successful.

Since management-related agronomic research is centred on the determination of responses to inputs and on definition of the conditions under which these hold, it is reasonable to suppose that agronomists should pay particular attention to these problems and that this should be evident in published papers. With this in mind, we undertook a survey of recent papers describing agronomic research in New Zealand. Our objectives were to determine how the problems of response definition and generalisation were tackled, and to assess the effectiveness of the methods used for this purpose.

# METHODOLOGY

We analysed 100 papers from recent issues of the Proceedings of the Agronomy Society of New Zealand (PASNZ; 34 papers from volumes *7, 8* and *9*), the New Zealand Journal of Experimental Agriculture (NZJEA; 39 papers from volumes *6, 7* and *8*) and the New Zealand Journal of Agricultural Research (NZJAR; 27 papers from volumes *20, 21, 22* and *23*). The survey covered papers which dealt with 'management-related agronomic research'; i.e., papers **based on field trials and oriented towards crop or pasture management with *controllable variables* as treatments.** We excluded papers which were based on laboratory or controlled-environment experiments, which involved investigation of factors (e.g. soil structure) or processes (e.g. N fixation) which are not normally controllable, and which were clearly designed to provide information for other scientists (e.g. reviews). Papers on 'non-agronomic' topics such as soils, horticulture, turf research, pests, diseases, animals and plant breeding were also excluded. After this selection, 43%, 30% and 9% of the papers from the chosen volumes of PASNZ, the NZJEA, and the NZJAR remained for analysis.

The conceptual model underlying the analysis is that displayed as equation (1). We asked the following questions about each paper:

1. What is the objective of the paper?
2. Which controllable, management inputs are being studied and at how many levels?
3. What information is provided on uncontrollable climatic inputs?
4. What information is provided on uncontrollable site (or soil) factors?
5. For how many years and at how many sites are trials repeated?
6. What forms of output data appear?
7. What method of analysis is employed?
8. What conclusions are reached?

# RESULTS

### Objectives

We classified statement of objectives in the papers in three ways (Table 1). In 71% of the papers an explicit statement of the objective of the paper was made using forms such as 'The objective of this paper is ...'. In 22% of the papers explicit statements were lacking but objectives could be found by reading between the lines. In seven out of the 100 papers, even this was impossible.

**TABLE 1: Classification of statements of objectives in surveyed papers.**

| Statement of objective | Number of papers PASNZ | NZJEA | NZJAR | % of total |
|---|---|---|---|---|
| explicit | 18 | 30 | 23 | 71 |
| vague | 12 | 9 | 1 | 22 |
| not stated | 4 | 0 | 3 | 7 |

### Management-decision variables

Almost half the surveyed papers contained comparisons of species or cultivars (Table 2). Trials involving fertiliser rates were described in 40% of the papers. The modal number of treatment levels in fertiliser trials was two (Table 2). In trials on sowing dates, plant populations, irrigation treatments and harvest treatments, more treatment levels were often employed. The category 'irrigation treatments' includes trials involving timing of irrigation, frequency of irrigation and amount of irrigation. Similarly, the category 'harvest treatments' includes timing, frequency and severity of harvest. 'Management methods' cover qualitative treatments such as methods of cultivation, sowing, harvesting, spraying or grazing.

**TABLE 2: Management-decision variables investigated in surveyed papers. The comparative effort devoted to each variable is indicated by the number of papers reporting research. The modal number of treatment levels is given for quantitative decision variables.**

| Management-decision variable | Number of papers* reporting research | Modal numbers of treatment levels |
|---|---|---|
| cultivars or species | 49 | - |
| nitrogen fertiliser rates | 23 | 2 |
| phosphorous fertiliser rates | 7 | 2 |
| other fertilisers | 10 | 2 |
| sowing dates | 14 | 2,3,4 |
| plant populations | 19 | 2,5 |
| irrigation treatments | 14 | 2,3,5 |
| harvest treatments | 25 | 5 |
| management methods | 34 | - |

*Note that many papers deal with more than one decision variable.

### Climatic information

Papers were classified into four classes on the basis of the climatic information included (Table 3). Many papers contained no climate or weather information. Brief comments on weather during trials appeared in 24% of the papers. Some form of averaged temperature, rainfall or solar radiation data appeared in 29% of the papers and derived data, such as degree-days, were given or used in a further 10% of papers.

**TABLE 3: Information given on climate during trial.**

| Information on climate | PASNZ | Number of papers NZJEA | NZJAR | % of total |
|---|---|---|---|---|
| none | 13 | 15 | 9 | 37 |
| comment | 5 | 10 | 9 | 24 |
| climatological data | 9 | 12 | 8 | 29 |
| derived data | 7 | 1 | 1 | 10 |

### Soils information

The soil type for trial sites was identified in most papers (Table 4). If any chemical (e.g. pH, soil test data) or physical (e.g. soil water contents) properties of the soil were mentioned, this was recorded.

**TABLE 4: Information on soil at trial sites in each paper.**

| Information on soil | PASNZ | Number of papers NZJEA | NZJAR | % of papers giving information |
|---|---|---|---|---|
| type identified | 25 | 38 | 24 | 87 |
| any chemical properties | 6 | 10 | 11 | 27 |
| any physical properties | 5 | 3 | 3 | 11 |

### Durations and numbers of sites

More than 70% of the trials described lasted for only one or two years (Table 5) and more than 80% were carried out at only one or two sites (Table 6).

**TABLE 5: Durations of trials described in papers.**

| Duration of trial years | PASNZ | Number of papers NZJEA | NZJAR | % of total |
|---|---|---|---|---|
| 1 | 18 | 20 | 15 | 53 |
| 2 | 8 | 6 | 6 | 20 |
| 3 | 4 | 5 | 3 | 12 |
| 4 | 4 | 8 | 3 | 15 |

**TABLE 6: Numbers of sites at which trials described in papers were carried out.**

| Number of sites | PASNZ | Number of papers NZJEA | NZJAR | % of total |
|---|---|---|---|---|
| 1 | 21 | 24 | 22 | 67 |
| 2 | 4 | 9 | 1 | 14 |
| 3 | 2 | 4 | 0 | 6 |
| 4 | 7 | 2 | 4 | 13 |

### Crop performance

Crop yield data were given in nearly all the surveyed papers (Table 7). Information on yield components or composition (e.g. botanical composition of mixtures and compositional indices such as root: shoot ratios) and on quality (e.g. chemical composition or nutritive value) was given in about half the papers. Comparatively few papers contained data on crop development (phenology, growth rates, or a time-series of yield data).

**TABLE 7: Information given on crop performance under trial conditions.**

| Information on climate | PASNZ | Number of papers NZJEA | NZJAR | % of papers giving information |
|---|---|---|---|---|
| phenology | 6 | 8 | 4 | 18 |
| yield | 32 | 36 | 24 | 92 |
| yield components or composition | 14 | 20 | 17 | 52 |
| quality of yield | 14 | 19 | 13 | 46 |
| growth rates or time series | 6 | 12 | 9 | 27 |

### Method of analysis

The central method of data analysis employed in a paper was used as a basis for classification. In 87% of the papers, this method was an analysis of variance (Table 8: the 'analysis of variance' category includes a few papers where data were presented simply as means) designed to compare responses to treatments. Regressions, correlations, etc., were used as subsidiary methods of analysis in many of these papers. A regression analysis was the central method of analysis in nine papers. Included in this group were papers describing trials which had been designed to yield response surfaces or data for a time-series analysis. Trials based on concepts of physical processes, or mechanistic models, were described in four papers.

**TABLE 8: Basic method used for data analysis in papers.**

| Method of analysis | Number of papers PASNZ | NZJEA | NZJAR | % of total |
|---|---|---|---|---|
| analysis of variance | 29 | 35 | 23 | 87 |
| regression | 3 | 3 | 3 | 9 |
| mechanistic model | 2 | 1 | 1 | |

**Generalisations**

Three categories of generalisation were distinguished in the surveyed papers. In 38% of the papers, a firm conclusion (e.g. 'the best practice is to ...' or 'the optimum date is ...') relating to at least one of the management-decision variables studied was reached (Table 9). In 42% of the papers, these generalisations were tentative and in the remaining 20% no conclusions were given.

**TABLE 9: Classification of the generalisations made in surveyed papers.**

| Generalisation | Number of papers PASNZ | NZJEA | NZJAR | % of total |
|---|---|---|---|---|
| strong or quantative | 14 | 14 | 10 | 38 |
| tentative | 13 | 17 | 12 | 42 |
| not made | 7 | 8 | 5 | 20 |

## DISCUSSION

This survey reveals a number of deficiencies in agronomic research in New Zealand. One serious inadequacy is that only two treatment levels are used in many trials involving quantitative decision variables (Table 2). As a result, responses cannot be defined satisfactorily. We found, for example, that firm recommendations on application rates were made in only two of 31 papers describing fertiliser trials — a result which is not surprising given that the modal number of treatment levels in these trials was two.

Inadequate provision for a range of treatment levels is probably a direct consequence of the way in which research objectives are set. Statements of objectives were vague or absent in 29 of the surveyed papers. Although explicit statements of objectives were made in the remaining 71 papers, 47 of these were general declarations of interest (e.g., 'to investigate' or 'to study' the response to a factor) rather than specific objectives (e.g., 'to determine the optimum level' for a factor).

The key to failure in setting specific objectives and in providing for a range in treatment levels may lie in the imprecise way in which potential consumers of research information are identified. We found that target consumers were specified in only five of the papers in the survey. Since there is a range of potential users of response information (advisers, economists, engineers, farmers, planners, scientists), with differing requirements, this is a serious deficiency. Without targeted consumers, objectives are likely to be vague, and with vague objectives, trials may not be designed to provide clear definitions of responses to management variables.

These deficiencies are highlighted further when the methods of analysis employed in surveyed papers are considered. The basic method of analysis in more than 80% of the papers was an analysis of variance (Table 8). Such analyses enable testing of hypotheses about the presence or absence of treatment effects and are particularly appropriate in trials involving qualitative decision variables. An analysis of variance is also appropriate during exploratory stages of research where it is necessary to establish which variables, amongst many, are important. There were relatively few trials in either category in the survey: only 30% of the papers surveyed dealt exclusively with qualitative variables, and four or more factors were screened in only nine papers. Thus, most papers described single-factor, two-factor, or three-factor trials involving quantitative decision variables. Since the existence of responses to most of these variables is not in question, it seems clear that many of these trials should have been designed to define the nature of responses and for analysis using regression, rather than analysis of variance methods.

Obvious deficiencies exist in the presentation and use of climate and soils data: most papers did not contain data on soil physical and chemical properties (Table 4), and only 40% contained climatic data (Table 3). It could be argued that these data need not always appear in papers since they could be obtained from other sources if trial location and soil type (not identified in 13 papers — Table 4) were given. However, if generalisations are to be made, recognition must be given to the impacts of climate and soil factors on observed responses, and this requires data in some form. Ideally, these data should be used as an integral part of the method for analysis. We found that this was done in only ten papers (regression analyses, 5; degree-day scaling, 3; in mechanistic models, 2). Recognition of the importance of environmental factors without use of data was more common: in 25 papers, authors cited atypical seasons or other climate-related problems as a cause for ambiguities in their results.

Some difficulties in making generalisations about responses could be overcome if trials were repeated sufficiently in time and space. Firm rules on numbers of repetitions cannot be given (Barlow, 1966), but trials at two sites in two years would be a minimum (and probably inadequate) basis for generalisation. More than half of the trials in the surveyed papers did not meet even these criteria (Tables 5 and 6).

Perhaps the most sobering result in the survey is the finding that definite conclusions were absent in the majority of papers (Table 9). If firm conclusions are lacking it is reasonable to rate a paper as unsuccessful. On this basis, about 60% of the management-related research surveyed was unsuccessful. This result was obtained by relating statements in 'Discussion' or 'Conclusion' sections to the objectives (stated or surmised), while avoiding, as far as possible, judging whether the conclusions seemed justified. Had we made such judgments on the grounds, for example, that a firm conclusion about a weather-sensitive process should not be made using data from a single year, the proportion of papers rated unsuccessful would have increased.

In concluding that many papers are unsuccessful, we do not mean to imply that these papers, or the trials upon which they were based, are valueless. Most papers contain useful bits of information, and all trials have educational value to the researcher or others who observe them. But these are meagre returns for research effort. Gems of information buried in a paper are likely to go unnoticed and the existence of an expert, educated through many trials, may be of little use to an adviser or farmer who is at the other end of the country.

## INCREASING THE EFFECTIVENESS OF RESEARCH

It is clear that much thought and effort could and should go into improving the effectiveness of agronomic research in this country. We see no simple recipes for this improvement but suggest the following avenues are worth investigating:

1. **Objectives and consumers.** Failure to set specific objectives and to identify consumers flaws much agronomic research. We should pay much closer attention to the requirements of consumers. In some cases, these requirements have been set out. For example, agricultural economists have written extensively about the information needed from agronomic research (Anderson, 1974; Dillon, 1978). In other cases, requirements seem vague. Do agronomists know what advisers want? And, of equal importance, have advisers worked sufficiently at spanning the gap back to agronomists, at appreciating what science can and cannot offer?

2. **Statistics.** Statistical methods have been, and will remain, vital to the progress of agronomic research. But which methods? At present, we rely heavily on analyses of variance and pay scant attention to alternatives. There is an extensive literature on the design and analysis of response-surface experiments (e.g. Mead and Pike, 1975), and on the appropriateness of such experiments for agronomic research (Anderson, 1971; Dillon, 1978), but these methods have been employed rarely in New Zealand (e.g. Dougherty *et al.*, 1979). It is clear that we should make wider use of this methodology.

We should also pay attention to the interpretation of trial results. Convention requires that objective measures of 'significance' be attached to data, and this leads to a profusion of P-values, LSDs, and letters for Duncan's test. Unfortunately, these statistics are often applied mechanically with little consideration of practical significance (Dillon, 1978; Douglas and Dyson, 1980). Alternative methods are available (Officer and Dillon, 1968; Carmer, 1976) and their use should be investigated. We should also develop a greater appreciation of the statistical bases of tests of significance for these are frequently misused by agronomists (Mead and Pike, 1975; Petersen, 1977).

3. **Environmental inputs.** We are lax in presenting information on climate and soils. However, little will be gained by improving the collection and presentation of data of environmental factors if we do not know how to use these data to aid interpretation of results. We have a long way to go in this respect. If we maintain our present preoccupation with the static, linear, analysis of variance model, there will be little scope for advance, for this model does not cater for climate or soil inputs (Rose, 1975). There would be much greater scope for the use of environmental inputs as an aid to interpretation if some other models were employed in the analysis of trials.

4. **Alternative models.** The range of models which could be used in the analysis of agronomic trials is large. A variety of statistical, physical, mechanistic, simulation, predictive and optimisation models are available (Bofinger and Wheeler, 1975; Dillon, 1978; Jeffers, 1978). In some, environmental factors are emphasised (e.g. Sands *et al.*, 1980), while in others management variables play a central role (e.g. Cornforth and Sinclair, 1979). Since models are tools for thinking, no one approach can serve all needs. However, the most useful models for management-related research are likely to be those which place ideas on mechanisms of crop response in an economic context (e.g. Stauber and Burt, 1973; Ritchie, 1976). We should strive to develop models of this sort and to move away from over-reliance on a limited number of statistical models.

5. **Organisation of trials.** The development of alternative models is a long-term strategy for increasing the effectiveness of research. In the short term, we should pay some attention to the organisation of trial work. It is clear that many trials are not carried out at an adequate number of sites or for sufficient years, and this implies too many trials with too few agronomists. Although national trials appear to have fallen from favour, we believe that they could help rectify this situation, provided objectives were defined with precision. The Agronomy Society has already sponsored one set of national trials (Taylor *et al.*, 1976); it could take the lead again.

6. **Publication.** Some simple changes would improve the quality of published papers. It is clear that editors, reviewers, and 'Instructions to Contributors' should require explicit statements on objectives, consumers and conclusions from authors. 'Materials and Methods' sections should also be altered. The essay style is not an efficient way to provide information on trial methodology. Much of this information could be given in tabular form so that a reader could see trial details at a glance. Standardisation of a 'methods' table would aid the comparison of results from different trials and might also ensure that significant information is not omitted — which occurs frequently with the current style of presentation.

But more fundamental changes are also required. We stated earlier that the first job of agronomists is to help solve management problems, yet many of the suggestions made in preceding sections would lead to more 'scientific' papers and these could well be less accessible to those wishing to apply the results of trial work. To resolve this conflict, we suggest parallel publication of results — once as a paper for scientists to assess and build upon, and once in a form which suits those who will use the results.

This suggestion is not new: the NZJEA was set up for the publication of field trial results, with advisory officers and scientifically-minded farmers as readers (Collins, 1973), while the NZJAR was intended for 'basic and some applied research' (Collins, 1973), and the PASNZ for the dissemination of the results of agronomic research amongst scientists (Lynch, 1971). But the suggestion has yet to be implemented, for, despite different objectives, the style and quality of papers describing management-related research is similar in the three journals (Tables 1, 3-9). It is clear that the roles of these journals need re-evaluation and that some market research would not be amiss in the case of NZJEA.

7. **Education.** Many of the deficiencies in agronomic research may arise from inadequacies in the basic training of agronomists. If the agronomic research of the future is to be more effective, the agronomists in training must be taught to use a wider range of approaches to their subject. At present, students are exposed mainly to a biometrical approach and, to judge from the literature, exposure to biometrics alone may lead to sterile research. To our knowledge, neither Massey nor Lincoln currently offers a wide-ranging course in methodology to those graduates who will pursue research careers. We urge the introduction of such courses, perhaps based on the texts of Bofinger and Wheeler (1975), Dillon (1978), and Jeffers (1978).

## CONCLUSION

We believe that there is much scope for increasing the effectiveness of agronomic research and we have suggested some areas in which improvements could be made. We cannot supply any simple recipies. We must develop alternatives and modifications to our current approaches. We must strive to give agronomy a firmer scientific foundation and, at the same time, to forge links with those who use research results. And we must do this with a sense of urgency. The computer revolution is beginning to impinge upon agriculture (Ritchie, 1976; Anon., 1980; Sangster, 1980) and with this will come demands for models and quantitative information, demands which our current methods of research are not well fitted to meet.

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