PROPOSALS, RESULTS & RECOMMENDATIONS OF TECHNICAL EVENTS SERIES - NO. 315

PROCEEDINGS OF SEMINAR/WORKSHOP
ON
APPLIED AGRICULTURAL RESEARCH TECHNIQUES

IICA

INTER-AMERICAN INSTITUTE FOR COOPERATION ON AGRICULTURE

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PREFACE AND ACKNOWLEDGEMENTS

In keeping with its policy of institution strengthening, the Inter-American Institute for Cooperation on Agriculture organised and sponsored, in collaboration with the Ministry of Agriculture, Guyana, a seminar/workshop on "Applied Agricultural Research Techniques".

The seminar/workshop, which was held from September 29 to October 1, 1982 at the Park Hotel, Georgetown, Guyana, was attended by some thirty-one (31) participants drawn mainly from the Ministry of Agriculture.

Papers presented at the seminar/workshop are included in these proceedings. All papers were edited for clarity but the subject matter remains the responsibility of the writers.

Thanks are due to the Chief Agricultural Officer, Mr. E. Hubbard who declared the seminar/workshop open. The text of his address follows. Thanks also to the lecturers and participants who all contributed to making the seminar/workshop a success.

REPierre

OPENING ADDRESS by Chief Agricultural Officer, E.A. Hubbard

Cde. Chairman, Lecturers and Colleagues:

I think it appropriate at this time to outline the policy of the Ministry of Agriculture as regards research. The Ministry considers that research must be applied research aimed at solving existing problems in the field. Guyana as a developing country does not have the manpower and other resources to engage in basic research at this stage, or research projects to bolster the ego or satisfy the personal goals of the researcher.

In implementing this policy, the approach will therefore need to consider both short-term as well as medium- to long-term solutions, e.g. work on a continuum - long- and short-term. I trust that these points will be borne in mind during and after this seminar/sorkshop.

The workshop is intended to at least partially correct a deficiency which has plagued us for some time, that is, inadequate or insufficient guidance and supervision of young graduates. That statement is not intended to vilify the senior, more experienced members of staff. The fact of the matter is that with increasing seniority there is an excessive increase in administrative duties of one sort or another. This results in the deficiencies mentioned before as well as greatly reducing the research output of the experienced staff.

Efforts are in train to deal with the problem of the administrative load. These have involved, firstly, recommendations submitted by IICA which were developed from a seminar involving staff of the Ministry of Agriculture and IICA, and secondly, proposals submitted by ISNAR.

These are still to be discussed with representatives of Agencies involved in Agricultural Research for final recommendations to be submitted to Cabinet. It is my fervent hope that we will thus solve this problem.

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Finally, thank you for the invitation and it is a pleasure to declare this seminar/workshop open.

IDENTIFYING AGRICULTURAL RESEARCH PRIORITIES

by

A.V. Downer

INTRODUCTION

The identification of priorities for research in Agriculture is an activity which has not, so far, attracted a great deal of attention in Guyana. Indeed, agricultural research as a whole has received less attention and consideration than has been implicitly required by the stated national ambitions of self-sufficiency in food and fibre or agro-industrial development. It is therefore, undoubtedly, a constructive step that there should be, at this point in time, a workshop/seminar on "Applied Agricultural Research Techniques". That the identification of priorities in agricultural research should form part of the exercise emphasizes the constructive intent. However, if only because the relatively low level of appreciation generally afforded efforts at research and the management of research, and perhaps also because of the obviously weak contribution of agricultural research to the development process, useful and coherent discussion of this topic promises to be a formidable task.

The nature and gravity of the task as reflected in the fact that the division of the world into developed and developing countries is 'de facto' on the basis of the level of efficiency with which countries, by their own efforts, satisfy their requirements for food, fuel and fibre. In the developed world the efficiency of the production system is high, in the developing world efficiency is low. It is in the developing countries that the predictions of Malthus promise to become realities. It is in the developing world that the preventive measure of progressive 'industrialization' has either not been practical or has failed to impact positively. It is in these countries that research in agriculture has not been constructive even though in almost every case the immediate objective of development has been increased food production. In many cases, the real problem has been the definition of the mechanisms by which the desired increases in production can be realized. In some cases the operation of the mechanisms has not been understood. There is, nevertheless, growing acceptance that increased production can be

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obtained if the productivity of the factors of production can be increased through the application of the findings of research. Alas, the understanding of the implications of research does not enjoy similar currency.

This paper attempts, within the context of the workshop, to:-

- discuss and put into perspective some concepts of development and development planning;
- outline the considerations which influence the conduct and management of agricultural research; and
- specifically, provide guidelines for, and illustrate, the process by which priorities in agricultural research can be identified.

The Framework of Development Planning

It seems desirable, at this point, that definitions of development and some related concepts should be provided in order to describe the background against which agriculture and agricultural research need to be viewed effectively. UNESCO has from time to time defined "development" as "the process of growth and change which a community undergoes over time in all aspects - cultural, social, educational, scientific, technological, economic, etc. - of its evolution"(15). Dalton (7) considers "development" to comprise "a set of structural, social and economic transformations which changes production, income, and peoples' life-styles (location, groupings, relationships, health, habitat, work discipline and place)". Pursuing, for the moment, the more pragmatic terminology of Dalton we can consider "production" or the "production system"(16) as comprising:

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- modes (feudal, capital or social);
- forces or means;
    - raw materials, instruments;
    - labour;
- social activities or relations;
    - level of production (in terms of access to means and/or organization of labour);
    - circulation of production;
        - distribution;
        - reproduction (of the population as well as of the ability to produce);
    - differentiation or tendencies and mechanisms for accumulating power; and
- infrastructure (network of laws, religions, etc.).

Transformation in production can obviously be induced by change in one or more of the four components of the system. For our purposes here, a desired change in one or the other component can be regarded as a developmental goal.

It is conventional that a given community sets its own developmental goals and these have been construed as "representing directions determined by set valuations and criteria satisfying basic needs, income distribution, full employment, etc. - at the broadest level".

Governments, in the pursuit of development, do in fact set goals - growth, equity, self-reliance, etc. - and attempt to control the extent of interaction towards these goals while discharging certain basic functions in relation to:-

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- Food and Agriculture;
- Education;
- Health;
- National Resources;
- Science and Technology;
- Social Security and Welfare;
- National Defence;
- Communication;
- Industry; and
- Creativity and Innovation.

Brady (5) recommends that "while the setting of social goals is usually accomplished by political leaders and national planners, scientists and science administrators should provide background information for those decision-makers, not only for the determination of social goals but for agricultural goals as well". In the developing world the importance of the contribution of scientists and science administrators is maximal in relation to the setting of agricultural goals largely because of the significance to agriculture of:-

- the interaction of life and living processes in the physical structure and functioning of society (17):-
  - Ecosystem (which dictates the quality of the natural resource);
  - Production system (by which natural resources are converted to, or used in the production of wealth);
  - Economic system (by which wealth is transformed and its distribution ordered in terms of social and political order); and
  - Social activities which control the functioning of the production system.

Goals having been set, it is usual to state the objectives, that is to specify anticipated achievements in various sectors of activity - agriculture, education, health, industry, etc. - through the application

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of given development strategies which set rules for determining alternative courses of action (agricultural development, industrial development, etc.). In a given sector, plans for achieving an objective "specify quantitative targets to be aimed at over given periods and the related mix of resources to be committed".(15) It is noteworthy that planning is a prerequisite for each programme of action, particularly where general economic progress, using to the maximum existing resources, is desired (1). The programme is in essence part of an annual breakdown by objectives and/or implementation structure.

The process of designing a set of programmes and strategies by which the goals and objectives are to be attained is referred to as policy-making and "covers everything relating to the preparation and taking of decisions of concern to the state, together with monitoring of their execution, evaluation of results of government activities and possible feed-back from decisions taken".

Policies may be established by several means - political, legal, institutional, social, etc. - but must have certain attributes. A policy should:-

- relate and integrate all needs that exist, and may, therefore, encompass several goals (environmenatal, social, political, etc.);
- respect local, regional and national ambitions;
- encompass linkages, both:-
    - vertical (food and agriculture, health, transport, education, environment, industrialization, etc.), and horizontal (national science and technology development);

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- assure that new production bases are firmly established by:-
  - maintaining declining costs;
  - ensuring that increased profits are used for capital formation;
  - progressively extending new technology to a greater variety of uses and new regions of the country; and
- satisfy requirements of:-
  - a legal framework; and
  - recognizable instruments (both explicit and implicit).

Thus, the optimum approach to policy formulations is through co-ordination of efforts at all levels (15). Agricultural policy tends therefore to be a mix of policies related to marketing, trade, resources utilization, technology, employment income distribution, etc.

While the listed attributes of a given policy facilitate the acceptance of that policy, the implementation of the policy requires the existence of definite administrative modes or institutions. Bosson and Varon (4) list these as agencies for:-

- Policy planning and general administration;
- Resource inventory;
- Education;
- Research and development;
- Industrial activity (production per se);
- Finance; and
- Marketing.

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In much the same way as the individual agencies function in implementing policy, they contribute to the formulation of policy through their efforts at elaboration of their specific objectives, plans and programmes. We can therefore speak freely of an Agricultural Research Policy and of an Agricultural Research Programme.

Formulating a Research Programme for Agriculture

The common element in the definitions of development cited earlier is "change" and Behrman (2) asserts that science and technology constitute the driving forces for change in all sectors when a nation's economy begins to move from an agricultural to an industrial base. Research employs the scientific method to add to the body of knowledge. The additional knowledge may be put to use in one or more of the policy-implementing agencies - education, research and development, or industry. In the last form of use the knowledge has immediate practical application to the process of production and is described as technology.

Before the industrial revolution, increases in agricultural production were consequent upon increases in the areas cultivated. Since then industrialization has come to signify the technological component of development and cultural modernization (7). Industrialization has permitted increased production through increased productivity of the factors of production and through expansion of the number of uses to which raw materials can be put.

In the more restricted context of agriculture development, the agency charged with responsibility for research and development has, as its primary task, the translation of relevant policy statements to an operational plan which reflects the ideological, economic and technological aspirations of the nation. In addition, the elaboration of an operational plan for research requires information on the structure and performance of

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the agricultural sector since the objectives of the plan will be determined by the stage of economic development already attained (14). Such information may be gleaned from an examination of:-

- the production system;
    - farm system (structure);
    - farming systems (technologies used);
- market development ; and
- relevant institutions.

Ray *et al.* (13) concluded from an analysis of the Indian experience that land reform and market reform were the institutional sources of change which were most significant for agricultural development. These were followed by co-operatives, credit and commodity development.

Agro-economic surveys which attempt to obtain data on the structure, performance and impact of the production process, farmers' objectives, and interactions between the two factors can also contribute to the identification of the principal factors limiting production and productivity and provide some estimate of the implications of change in either factor. The first step in the elaboration of an operational plan therefore needs to be the recognition of the philosophy that research should serve to:-

- identify the factors which limit improvement in production; and
- eliminate those limiting factors.

Embracing this philosophy is not always practical. The low level of availability of data of the nature required is considered by

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Brady (5) to constitute the greatest weakness in the formulation of research programmes in the developing world. He suggests that this weakness is compounded by equally poor levels of co-ordination and of continuity, if only because:-

- researchers in developing countries, understandably in some cases, tend to imitate researchers in more developed countries; and
- applied research is generally carried out on small outlying stations which are poorly staffed and equipped, and programmes at these stations are not usually co-ordinated into national programmes.

There are few, if any, long range plans and/or programmes which can effectively utilize trained researchers let alone permit them to train others to take their place.

If, however, the appropriate data is available, direction can be had in terms of:-

- general orientation of the baseline for research; and
- specific orientation of programme activities in relation to products, the transfer of technology and resource development.

Thus the data constitutes the structural basis of the research programme and facilitates management of the process of implementation while defining strategies to be adopted.

At the national level, given strategies define directions for different sectors and define the most adequate responses to contingencies (15). At the research and development level, strategies may prescribe

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emphasis on:

- technology, in relation to:-
    - specific commodities; or
    - specific areas;
    - factors of production e.g. mechanization;
    - economics of development;
        - sequential; or
        - accelerated;
- strategies for the elimination of limiting factors may emphasize:-
    - agronomic studies;
    - use of improved germplasm; or
    - improved economic policies.

Having specified objectives and defined strategies for research activity the operational plan needs to be broken down into annual activities and grouped into projects. There may be several activities which apparently merit inclusion in one or other project but the capacity of the machinery for implementation may not accommodate them all. How then does the research manager decide which activities warrant inclusion?

Identifying Research Priorities

As Schuh (14) points out in his discussion on the identification of priorities, "development needs vary with country and with regions within a particular country. Moreover, the problem of analysis to determine what priorities ought to be, is almost never-ending since analysis must be location-specific". Table 1 attempts to show some of the relationships among the stage of development attained, national goals and research goals

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within the agriculture sector. The relative positions of industrial inputs and germplasm in the table imply the need for parallel research in other sectors of the economy. In this broader context, Behrman (2) states that "in order to manage change, a nation must be able to manage science and technology. The smaller the resources the more accurately must they be targeted". Arnon (1) expressed his opinion differently; "because development programmes must be implemented in carefully considered stages, it is necessary to determine priorities".

Having examined the Indian situation Ray _et al._ (13) advocate that in order to establish sound priorities, information is needed as to:-

- expected benefits;
- costs; and
- time requirements,

for each line of research considered. Brady (5) was rather forthright in his view that "there is much to be desired in agricultural research priority setting, especially that of national research organizations. He listed as criteria for setting priorities and ascertaining which projects should be initiated, estimates of the:-

- relative significance of the different constraints;
- feasibility of removal of those constraints;
- cost of research to remove constraints;
- probability that such research might be done by others; and
- urgency of the research.

He advocated strongly that administrators must prevent "urgent problem-solving" from dominating research programmes.

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While Brady's criteria are firmly pragmatic they do not reflect the benefits likely to accrue from agricultural research to the administrative model for education. The criteria proposed by Ray _et_ _al._(13) should, therefore, not be ignored since benefit/cost and time frame analysis will be of significance in this context.

Identification of priorities will, in addition to the criteria alluded to above, be influenced by the availability of resources, in terms of personnel, funds, and expertise as well as by the stage of economic development attained. Arnon (1) described models for determining priorities:-

1. With limited personnel, he indicates that:-
   - concentration, at least initially, should be on areas where improved technologies will give the best results;
2. With limited funds:-
   - technologies requiring more local inputs may be indicated; mechanization, for instance, may not be practical;
3. With limited expertise:-
   - concentration on chemical and biological improvements, not dependent on farm size, such as use of fertilizers, biocides, high yielding varieties, etc., will allow progressive expansion across the sector;

     or

   - concentration on a specific and particularly promising commodity (e.g. a cereal staple), thereby favouring larger segments of suitably endowed regions or certain sectors of

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the rural population at the same time increasing the area to which new technologies are applied.

Arnon (1) further suggests that if, in a traditional society, research is to be done at the farm level, priority should be given to projects which increase the efficiency and productivity of the existing labour used in agriculture. He suggests the following as appropriate activities:-

- use of improved varieties (in terms of yield, disease resistance, etc.);
- improvement of land preparation;
- improvement of techniques of sowing;
- better crop rotation; and
- more effective use of fertilizers.

At the broad national level, priorities for agricultural research may be reflected by the prescribed goals:-

- equity - higher income levels for farmers required;
- security - import substitution, post-harvest systems; agro-industrial development; and
- health - specific commodities to be emphasized.

The national science and technology policy may influence research priorities:-

- post-harvest systems;
- energy sources utilized; and
- environmental quality.

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Priorities for Agriculture Research in Guyana

Guyana does not differ from other developing countries in its need to actively strive for economic development. It may differ to some extent, however, in that agricultural development is the major vehicle towards the ultimate goal. It has been argued that policy statements have not been as explicit as might have been desired. One can perhaps identify components of a national agricultural policy from the following statements:-

- Agriculture is the basis for economic development;
- Feed, clothe and house the nation;
- Self-sufficiency in food and fibre;
- Redistribution of income through co-operatives;
- Produce or perish; and
- Import substitution;

in conjunction with the current foreign exchange stringencies and the National Science policy. Taken together, these components add up to a policy-mix not very unlike that alluded to earlier.

Like the national policy, the mechanisms for its implementation are fairly easily recognized; however, the efficiency with which respective functions are discharged leaves much to be desired. This is particularly true of agricultural research and development activities probably because of the currently employed strategy of "urgent problem-solving" rather than long-term programming towards the realization of specific and constructive objectives. The cost of the extant strategy is tangibly reflected in the currently ambivalent status of the Food Crop Production and Marketing Programme which was conceptualized initially as an aid to Research Programming (11). The first objective of the Food Crop Production and Marketing Programme was to accelerate the commercialization process within

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the sector by motivating farmers and improving production skills at farm level. The relevant research priorities had been empirically defined and described previously (9, 10). The second objective was to facilitate industrialization within the sector by ensuring adequate supplies of relevant raw materials through reliable production and marketing statistics and analyses. The importance of statistical data in research programming has also been described previously (8, 12).

Before attempting to identify priorities for agricultural research in Guyana it would be desirable to distinguish clearly between research and scientific technological services. It would be desirable also to charge one administrative mode with specific responsibility for agricultural research (11). As a first step in identifying research priorities, ideology, national goals and resources available for agricultural research and development should be put into perspective. Research goals should then be identified, a research policy outlined and appropriate strategies developed. There should be no serious objection to the view that research activities in Guyana will and should impact on both the production and education functions. The question, rather, is to which priority should be given. Since the aspect of education which is relevant here is that which concerns the reproduction of the ability to produce, it would seem that support of the production function should be the primary objective of research efforts. Locations and commodities should also be identified because of limitations in available expertise.

Because of the obvious existence of durability in Guyanese agriculture, research objectives need therefore to include both commercialization and industrialization of the agriculture sector. The research policy should therefore be specific as to:-

- what research is to be done (increased productivity of labour, land or germplasm);

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- where research is to be done (on farms, research stations, in laboratories, etc.);
- by whom research is to be done (institution); and
- when research is to be done.

The research programming for commercialization of the sector can thus include in relevant locations projects aimed at:-

- improvement of production systems;
    - timeliness of farm operation;
    - improvement of land preparation;
    - improved techniques of sowing;
    - improved cropping patterns;
        - row cropping vs broadcast;
        - plant population;
        - single, mixed or multiple cropping;
        - rotation of appropriate crops;
    - improved protection against weeds, pests and diseases;
    - improved methods of harvesting and post-harvest handling, e.g. drying, grading, etc.;
- increased productivity;
    - water management;
    - soil management;
        - fertilizer use;
        - crop rotation; and
        - improved varieties (adaptation trials).

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For industrialization, the research programme might give priority to projects aimed at:-

- improved germplasm (breeding programmes); and
- post-harvest systems, e.g. storage, transportation, processing, etc.

While limitations in financial resources and the objective of increased productivity of labour would influence the amount of research activity expended on mechanization, Arnon's (1) discussion on the consequences of premature mechanization and the Guyanese experience in rice production should be given due consideration. In this regard the premature adoption of high yielding varieties (1, 13) should not be ignored.

In conclusion, I would like to commend to you a few excerpts from Blumenschein's (3) "Research Guidelines in the EMBRAPA system". I translate EMBRAPA here loosely as the Brazilian Authority for Agricultural Research. Blumenschein (3) described the purpose of EMBRAPA as "seeking solutions to the problems of the Brazilian farmer", also as "creating, adapting and improving technologies which become not solutions imposed, but options and alternatives for rural producers in the diverse ecological conditions of the Nation". He depicts the research strategy as one where the researchers are constantly involved with the producers, consumers, extension personnel, in summary, with the direct users of technologies developed. Given the circumstances which now obtain, it may be possible in the near future for more and more Guyanese agriculturalists to see at first hand that the first priority of agricultural research is that it be seen to contribute to increased production in its various aspects.

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TABLE: 1 SOME RELATIONSHIPS BETWEEN STAGE OF DEVELOPMENT AND RESEARCH GOALS

1. Stage of Development of Agricultural Sector	TRADITIONAL	COMMERCIAL	INDUSTRIAL
2. Characteristics of Sector			
2.1 Production factors used	Land Family labour and skills	Land Hired labour Industrial inputs (chemicals, energy) Technical assistance Credit	Land Paid management Industrial inputs Technical assistance Credit Tailored germplasm
2.2 Disposal of produce	Consumed on farm	Sold (fresh)	Processed
3. National Goal		Commercialization 100% - Sale of produce - Hiring of labour	Industrialization 100% - Presentation of produce
4. Structural Analysis of Sector			
4.1 Percentage of			
- National production	?	?	?
- Total agricultural land space	?	?	?
- Farms	?	?	?
4.2 Average size of farms	?	?	?
4.3 Major enterprises			
4.4 Farming systems used			
5. Research Goal		Increased productivity of physical and chemical resources, inputs, etc.	Increased productivity of biological resources

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SOME BASIC CONCEPTS IN APPLIED AGRICULTURAL RESEARCH

by

A.M. Pinchinat

(Outline only)

INTRODUCTION

Applied Agricultural Research

- Endeavours to discover or understand facts about farming using the scientific method
- In practice it amounts to research oriented towards improving farming systems through technological changes, involving the farm (crop, animal farms) and the farmer
- Essentially it comprises three levels of activities
  - Description, characterization and analysis of organised observations about farming (constraints and potential)
  - Experimentation or the testing of hypotheses under controlled or uncontrolled conditions (researcher or farmer managed trials)
  - Assembling of techniques to be used by farmers (technology generation)

INSTITUTIONAL RESEARCH POLICY

The research organisation must establish and clearly define its applied research policy as being at least: (See Ref.1)

- Farmer-based (agro-socio-economic considerations)
- Problem-solving (food, income, labour, other)
- Comprehensive (whole systems, plant/animal) and anticipatory
- Interdisciplinary (team work)
- Complementary (agriculture/other sectors)
- Iterative (continuous evaluation/revision)
- Dynamic (progressive, ready to change)
- Responsible to society (well-being of farmer and consumer, whole family)
- Objective (unbiased)
- Scientific (organised, pursuit of truth)

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The scope of the research programme must be consonant with the institution's mandate

- Commodity range
  1) Single
  2) Multiple
- Geographic
  1) Countrywide (national)
  2) Macro-regions (watershed, other)
  3) Micro-regions (community, farm groups)

Technical assistance (from international centres and the like) must be channelled and applied through the National Agricultural Research System (NARS)

Role of private research agencies

PROBLEM IDENTIFICATION

Based on:

- National Agricultural Plan (macro-level)
- Horizontal diagnosis of farming systems in the light of the national plan and scientific opportunities (institutional/ regional level)
  A guide for gathering basic data may be used (See <u>Ref. 2</u>; <u>Appendix 1</u>)
- Vertical diagnosis of relevant problems, as prioritized by farmers and scientific judgements (micro-level)

APPLIED ON-FARM PLANNING

- On-farm research activities are planned according to ranked problems and opportunities as perceived by farmers and the research team, from the preliminary diagnosis of farming systems divided into homogeneous groups (Recommendation domains)

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- Farmer's participation in the planning and programming is a requisite.

- Planning takes into account the extent to which the farmer's environment and management can reasonably be changed using as reference among others:
  - Resource availability (biophysical, socio-economic)
  - Support services
  - Socio-cultural idiosyncrasy
  - Government policies (market, prices and others)

RESEARCH DESIGN

Basically farming systemsresearch can be divided into: (See Ref.3)

Exploratory On-Farm Research

- Diagnosis (survey, trends)
- Case study
- Trial (small plots)
  1) 2^n (1= farmer's system)
  2) Plus or minus (microplot technique, others)
  3) Superimposed (simple researcher-managed treatments placed over a range of farmer-managed conditions)

Site-Specific On-Farm Trials

Agronomic Regional Trials

- Evaluation of data from on-site trials over a homogeneous agro-socio-economic recommendations domain

Agro-socio-economic Trials

- Are selected agronomic trials tempered by socio-economic considerations? Importance of plot size (economic and practical)

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Farmer-managed Trials

- Farmers become the primary evaluators of a new technology which must be:
  1) Simple enough to be understood by the farmer
  2) Compatible with the farmer's ability to use his own resources
  3) So designed as to permit the farmer to readily observe meaningful differences among treatments

  No control, but measurement of variation sources

  Multi-locational to facilitate validation on the broadest scale

RESEARCH DATA ANALYSIS

Analysis includes at least the statistical meaning of:

- Biological performance (biomass yield)
- Actual resource requirements
- Economic and financial feasibility
- Socio-cultural acceptability

Importance of each factor in this arrangement will vary as control intensity of the research shifts from researcher to farmer

DIFFUSION OF RESEARCH RESULTS FOR MASS ADOPTION

- Inputs from extension services and other agencies involved in promoting agricultural technological changes should be sought and obtained at all levels of the Farming Systems Research/Demonstration (FSR/D)
- May run pilot production programmes to encourage and speed up mass adoption of the improved technologies, introducing adjustments as guided by local conditions

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- Adjustments may affect the technology per se, the support system, or both. These are expected to be few and slight, since the technologies would have been so developed as to fit, as much as possible, representative farming systems of selected recommendation domains

CONCLUSION

Farming Systems Research/Demonstration (FSR/D) implementation may have several implications for traditional agricultural research, among which the following stand out:

- Socio-political commitment and goal-orientation
- Choice of prime clientele (farmers, farms and farming operations)
- Personnel administration flexibility
- Budgeting adaptability
- Operation decentralization
- Staff in-service training and work reorientation (early stages)
- Team approach emphasized over unipersonal work
- Additional human and financial resources may be needed but research efficacy (impact) should improve
- Time, from research initiation to technology release, may be longer but impact should be greater and more readily measurable
- Governments' full and effective support will be needed for sustained research programme.

APPENDIX 1

SUMMARY: BASIC DATA GUIDE FOR AGRICULTURAL DEVELOPMENT PLANNING

GENERAL COUNTRY INFORMATION

- Geographic, historical and political background
- Government organisation
- General statistics
- Agricultural statistics
- Agricultural policy
- Support services

PROJECT AREA

Physical Characteristics

- Location and area
- Climate
- Soil resources (physical, chemical)
- Surface water resources
- Plant resources
- Animal resources
- Mineral resources
- Tourism

Socio-economic Characteristics

General Support Services

- Transportation/communication
- Water
- Electricity
- Education
- Health
- Storage
- Agro-industries

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Agricultural Production Support Services

- Research (public, private)
- Extension (public, private)
- Credit (public, private)
- Insurance
- Farmer organisation
- Others

Institutional Linkage and Co-ordination

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EXPERIMENTAL DESIGNS I

ESSENTIAL PRINCIPLES OF EXPERIMENTAL DESIGN THEORY

by

J.R.D. Ford

INTRODUCTION*

Before getting into the essential principles of the theory of experimental design it is important to detail briefly how the applied researcher is being conceived in the experimental environment. The applied researcher has two major characteristics and asks two basic questions.

Firstly, the applied researcher is a theoretical thinker who is also involved in 'dirty fingernail' work. As a theoretical thinker the researcher has accepted the discipline and the importance of logic and theoretical principles. The researcher accepts that his world is much more the world of inductive reasoning than deductive reasoning and that chance is much more critical in the former. Thus the agricultural researcher's world can be said to start with a group of observations and on the basis of specific observations he decides what can be concluded. Secondly, the researcher must be involved in 'dirty fingernail' work because a field understanding of different variables affecting the subject of his analysis is necessary. This is necessary if the researcher is going to have a dynamic and creative effect on the subject. It is also important in his analytical, evaluative and interpretational work in the latter stages of the research process.

The general research question characterizing the work of the applied researcher is usually formulated as follows: "If X is done, how will it affect Y?" X is usually an input, a process or a practice and Y is a response, an output or an enterprise. For applied research work this question is broken down into even a more practical form and becomes two questions:

1) A "Yes/No" question. Is this new variety superior? Should the crop be sprayed? Is this drug effective?

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* *A definition of terms used in this paper appears in Annex 1.*

2) A "How much" question. How much fertilizer should be applied? How much chemicals should be utilized? How much feed?

These are the applied researcher's questions. To answer them you need an experiment. In 1935, Ronald A. Fisher wrote a book and laid the foundation for a set of statistical theory utilized in carrying out experiments. The subject has come to be known by the title of the book "The Design of Experiments". Applications of this body of theory are found today in research in the natural sciences, engineering and nearly all branches of the social sciences. We will consider the major principles of the theory utilizing examples and explanations from the area of agriculture.

PRINCIPLES OF EXPERIMENTAL DESIGN

The principles of experimental design are rooted in statistical analysis which seeks to establish an objective basis for evaluation. This objective basis of evaluation is critical because two basic conditions of experimentation are generally assumed. Firstly, it is assumed that experiments are comparative experiments. In agriculture the interest is not usually in absolutes but rather in comparisons. Thus, the interest is not in how much a particular variety may yield, but rather how much it will yield when compared with other varieties under similar conditions. Experimental design theory must therefore ensure that accurate recommendations are made as to which is the superior, best variety.

A second assumption is the existence of large uncontrolled variability. Particularly in agricultural experiments the same results are not expected when two experimental units receive the same treatment. Two fields (same size) of cowpea would hardly be expected to give the same exact yield. Several factors are responsible for the variability

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observed - soil fertility, land preparation differences. Thus the problem exists in deciding if the difference (variability) observed is merely a chance effect of uncontrolled variation or what is referred to as a true difference.

Experimentation refers to 'controlled experiments' where efforts are made to reduce experimental error. In a 'controlled' experiment some factors are varied while others are held constant. In economics, we say "let X increase, ceteris paribus" - variables other than X do not change except as predicted by our theory. However, in reality, only the factor whose effect is being investigated can be controlled exactly. In order to isolate and estimate uncontrolled variation, different designs are chosen for the experimentation process. Designs range from the simple to the complex and are based on three principles. These principles are determined by commonsense considerations as well as the need to have experimental data for the operation of statistical tests.

The first principle is replication. This simply refers to the repetition of the same treatment on different experimental units. (Two experimental units are treated alike.) The function of replication is to provide an estimate of experimental error and a more precise measure of treatment effects. Replication not only allows for the calculation of experimental error but also reduces it because you are dealing with an average of many results as opposed to one result. How many times you need to replicate an experiment is a function of the variablity of the data and magnitude of the differences you want to detect.

The second principle underlying experimental design is randomization. This is the use of a random process to assign experimental units to treatments. This process of randomization ensures that all units considered have an equal chance of receiving a treatment.

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The function of randomization is to ensure unbiased estimates of treatment means (eliminates the experimenter's biases) and experimental error. It is important that an objective basis of randomization be chosen if the estimate of experimental error is to be valid.

The third principle is referred to as local control. This principle of experimental design is intended to reduce experimental error through particular groupings or formations (designs) of experimental units. This principle is sometimes said to negate the second principle because once it is introduced the arrangement ceases to be a wholly random one. Essentially, this principle assists in eliminating compounding by averaging out variation between experimental units.

These three principles are inherent in all experimental designs. A discussion of the more useful experimental designs in the next section clearly brings out their importance.

EXPERIMENTAL DESIGNS

Experimental designs refer to the ways in which experimental units are grouped or classified. As indicated earlier, experimental designs range from the very simple to the quite complex. The intention in this section is to show the gradual development of designs to increase isolation of treatment effects. Three designs which are considered the more accessible (useful and relevant) presently are introduced in some detail while three additional designs are introduced briefly to indicate the differing levels of complexity which designs can assume. Each design is dealt with systematically below.

Completely Randomized Design

Assign treatments at random to a previously determined set of experimental units (for an area of ground in the field these would be experimental plots).

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Example 1

Treatments	REPLICATIONS 1	2	3
1	1	3	6
2	5	4	9
3	7	8	2

The number of experimental units = No. of Treatments X No. of Replications.

What can we test here?

(1) 2 different fertilizers (one level), to measure yield increases on a particular crop.

(2) 2 different hormones (single dose), to determine their effects on weight gaining ability of livestock.

Therefore, including the control, we have three treatments. Assume the need for three replications - then nine (9) experimental units (9 plots of land, 9 heads of livestock) being worked with. Assign the plots/livestock numbers 1 - 9 and select them randomly to receive the treatments.

Advantages of this design

(i) Efficient where minimal variability between experimental units exists (age, location, etc.).

(ii) Flexible with regard to physical arrangements of the experimental units.

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(iii) Maximizes degrees of freedom for estimating experimental error (variance).

(iv) Minimizes the F value for statistical significance.

Disadvantage of this design

(i) Often identifiable sources of variation among experimental units do exist. In such a case other designs are usually capable of reducing the variability (experimental error) and hence allowing more precision in measurement of treatment effects.

In the simple case of a randomized design we have only two sources of variation:

(i) among experimental units within a treatment (unaccounted experimental error).

(ii) among treatment means (mean of treatments 1, 2 & 3).

Randomized Complete Block Design

Assign treatments at random to a group (block) of experimental units. A block should consist of experimental units that are as uniform as possible (age, weight, vigour, yielding ability - any characteristic providing uniformity within the classification). Now, what is the purpose of blocking? Randomization would have dealt with a fertility gradient running across the field by eliminating its effect from treatment comparisons. However, residual error may still be quite large and lead to real treatment differences being judged insignificant (deluged by residual error leading to a low F value). Thus, if known or suspected trends (characteristics) exist they should be isolated and removed from residual error. Blocking does this and thereby increases the chances of detecting real treatment differences.

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Example 2

	BLOCKS		
Treatments	1	2	3
A	A	C	B
B	B	A	C
C	C	B	A

Low fertility ⟷ High fertility

The number of experimental units = 9 (No. of Treatments X Blocks).

The replications of example 1 become blocks.

Treatments are assigned at random to the units within each block. Note that the number of experimental units in each block is equal to the number of treatments and each treatment occurs once and only once in each block. These are the main characteristics of the randomized complete block design.

What can we test here?

(i) 2 fertilizers (one level), yield increases for a crop. The blocks are three different levels of soil fertility.

(ii) 2 different hormones (single dose), effect on livestock growth. The blocks are three different ranches.

Advantages of this design

(i) The greater the differences between blocks, the greater the contribution to precision in detecting treatment differences. Under the completely randomized design residual error would have been inflated.

/...

(ii) Block characteristics separated out, hence effects not confused with treatment effects.

Disadvantages of this design

(i) Number of treatments should be as few as possible. (The number of experimental units in each block must be the same as the number of treatments. As block size increases, so does the within block variability).

(ii) Degrees of freedom for experimental error are reduced by the number of degrees of freedom for blocks. Thus, if there is no appreciable difference between blocks, a completely randomized design can be more efficient than a randomized block design. There is, therefore, a tradeoff between a decrease in the error sum of squares and a decrease in the error degrees of freedom.

If no block differences, this design will not contribute to precision in detecting treatment differences. However, the majority of agricultural experiments are arranged in blocks as the latter disadvantage decreases as the size of the experiment increases.

Latin Square Design

Assign treatments randomly by grouping into columns as well as rows. Under the Latin Square design randomization is restricted further. Experimental units are organised here into two categories other than treatments. As we have moved from the completely randomized experiment to the Latin Square increasing variability has been removed from experimental error and associated with other effects. In the randomized block, variability from rows was isolated. In the Latin Square design variability, due to columns, is also being separated. If there is no appreciable variation associated with the columns this design will not

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measure treatment effects more precisely than the randomized complete block design.

Example 3

COLUMNS (Tractor Operators)

Row (Time Periods)	1	2
1	A	B
2	B	A
3	B	A
4	A	B

Columns - 2 different tractor operators.

Rows - 4 different times the machine tested - each operator tests each machine twice.

A & B - are the treatments, in this case two different makes of tractors - treatments occur the same number of times in each row and column.

What can we test here?

(i) Efficiency of two tractors in a job, isolating two important sources of variability - tractor operators and time of testing. (They become measurable sources of variation that are independent of the machines and can be removed from the total variability of the experiment - reducing experimental error).

(ii) Two seed treatments - on individual rows in experimental area - a seeder with two planter units is to be used - to remove any planter effect (different seeding rates), each seed treatment is assigned to each seeder unit in each of the two blocks (each treatment seeded the same

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number of times by each seeding unit).

Advantages of this design

(i) Increased variability removed from experimental error.

(ii) More precise comparison of treatment effects than the randomized block design once there is appreciable variation associated with the columns.

Disadvantage of this design

(i) A Latin Square requires at least as many replications as there are treatments and therefore is not practical for experiments with a large number of treatments. Further, with more than seven or eight treatments the rows and columns tend to be too long and the efficiency of the design suffers.

EXTENSIONS OF PROCEDURE - FACTORIAL EXPERIMENTS

Factorial experiments are very important because they save time in exploratory work and are really the only satisfactory way of detecting interactions between factors. Interactions are said to occur when the performance of one factor is affected by the presence of other factors. Time is saved in that more than one factor is being tested in an experiment and particular factors can be selected from this procedure for further analysis.

Split-Plot Design

Assign the treatments of one factor randomly to main plots (arranged in any of the above three designs) and treatments of the second factor randomly to sub-plots within each main plot.

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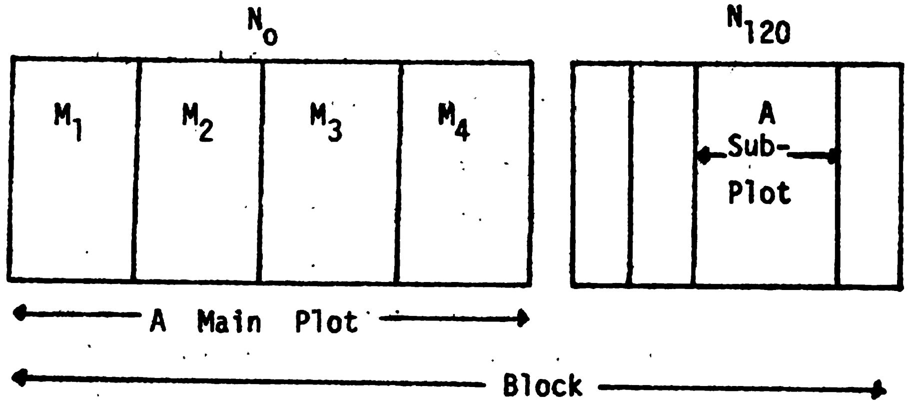
Example 4



What can be tested here?

(i) Nitrogen fertilizer at 2 levels and green manures of 4 types. Number of treatments = 8. With regard to nitrogen levels, the experiment is a randomized complete block with 2 treatments.

(ii) Two breeds of livestock, two levels of feed, two different feeding times (not necessary to have an additional split for each factor).

Advantages of this design

(i) Improves precision for comparing the average effects of treatments assigned to sub-plots.

(ii) Improves precision for comparing the interactions (if they exist) between sub-plot treatment and a given main plot treatment.

(iii) Useful for factorial experiments (two or more factors investigated simultaneously) where precision of estimations of some effects is deliberately foregone to increase precision in estimating other effects.

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Disadvantages of this design

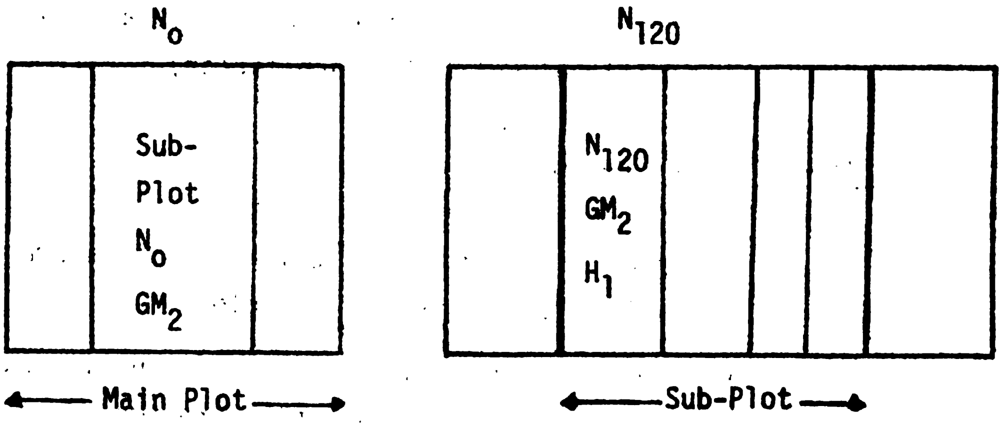
(i) Precision sacrificed in estimating average effects of the treatments to main plots.

(ii) Split-plot design variations impose restrictions on the error term used to test treatments, hence skill and experience available in assigning factors should be utilized. The main plot error is usually larger (greater variation among widely spaced main plots) and the sub-plot error smaller (closely spaced sub-plots).

Split-Split Plot

Adding a third factor by splitting sub-plots of a split-plot design results in a split-split plot.

Example 5



Main Plot - Fertilizer level (N_o)

Sub-Plot - Green Manure - N_o, GM_2

Sub Sub-Plot - Dates of harvest - N_{120}, GM_2, H_1

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What can be tested here?

(i) As in example above.

Advantages of this design

(i) Useful when it is desirable to keep treatment combinations together.

(ii) Facilitates field operations (fewer plots to manage).

Disadvantage of this design

(1) The additional restriction on randomization introduces a third error term which can make mean separation quite complicated.

Split Block

This is a variation of the split-plot design. In the split block the sub-unit treatments are applied in strips across an entire replication of main plot treatments.

Example 6

A_3	A_2	A_4	A_6	A_5	A_1
B_2	B_2	B_2	B_2	B_2	B_2
B_1	B_1	B_1	B_1	B_1	B_1

/...

What can be tested here?

(i) Effect of different fertilizer levels (A) and watering levels (B).

(ii) Effect of different feed regimes and hormone treatments on livestock.

Advantages of this design

(i) Facilitates physical operations on the sub-units.

(ii) Improves precision in comparing the AB interaction, especially in comparing B means for a given A treatment (Useful if this latter effect (A) is the primary effect in which you are interested).

Disadvantage of this design

(i) Sacrifices precision comparing the main effects of factor B.

CONCLUSION

Significant results arise from two things - large differences between yields from different treatments and a low experimental error. Design of an experiment is important because it affects the latter. Experimental designs, however, must be placed in proper perspective. They are a tool of the researcher. They are a means to an end and a small, though important, part of the total experiment. The importance of the statistical side of the experiment should not be overplayed. (Many useful enquiries can be made in which statistics may play a little or no part). The design utilized should, therefore, be the simplest that would answer the problem under consideration. A simple design

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is characterized by simple implementation (important when unskilled labour assists in conducting the experiment) and in most cases requires simple analysis. If problems require a large amount of experimentation and complex designs, it is probably best to tackle it in stages of increasing complexity and size as the researcher becomes familiar with the experimental materials and tools at his disposal. Finally, adhere to the three R's of experimentation - randomize, replicate and request help.

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ANNEX 1

DEFINITION OF TERMS

Accuracy - closeness with which a particular measuremen can be made.

Ceteris paribus - other things being equal.

Deductive reasoning - reasoning which proceeds from a general principle to a specific conclusion.

Degrees of freedom - number of independent variables (variables that can be chosen freely).

Experimental error - variation in the response due to the lack of precise control.

Experimental unit - a unit to which an individual treatment is applied.

Experimental material - experimental units.

Inductive reasoning - reasoning which arrives at a general principle from a specific conclusion.

Interaction - performance of one factor affected by the presence of other factors.

Observation - a measurement made on an experimental unit.

Precision - magnitude of difference between treatments an experiment is capable of detecting (design and replication critical here).

Randomization - use of an unbiased process to assign experimental units to treatments.

Replication - repitition of the same treatment on different experimental units.

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Treatment - any procedure (dosage, method) whose effect is being tested (measured and compared).

Variable - measurable characteristic of an experimental unit.

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ANNEX 2

SUGGESTED DISCUSSION PROBLEMS FOR GROUP SESSIONS

1. The object of the experiment is to compare two varieties. The known (A) and the new variety (B). Two equal sized plots are laid down side by side and sown with variety A and B.

   (i) Is it acceptable to argue that A is better than B if the yield is higher?

   (ii) When might the conclusion be sound?

   (iii) Identify at least five (5) sources of experimental error.

2. Suppose you want to evaluate the productivity of four different kinds of chemical fertilizer in growing MINICA I. The researcher designates the fertilizer F_1, F_2, F_3 and F_4. He/she selects four plots of land, L_1, L_2, L_3 and L_4 and assigns them at random to each of the F_j. (F_j represents the treatment variables and L_i the experimental material in the experiment.)

   Experimental data is collected from these plots in terms of pounds of cowpea produced.

   <u>Questions</u>:

   (i) Would the results of this experiment (as indicated above) be conclusive? Why not?

   (ii) If there are problems, how would you overcome them?

   (iii) What experimental design would you use and why?

3. The following data represents results from three fertilizer treatments on a cowpea crop. Four plots received each treatment. Are you able to conclude anything by observation of the data?

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Treatments	Yields			
1	47	52	62	51
2	50	54	67	57
3	57	53	69	57
4	54	65	74	59

/...

ANNEX 3

RANDOM NUMBERS

To randomize any set of ten (10) items or less, begin at a random point on the table and follow either rows, columns or diagonals in either direction. Write down the numbers in the order they appear, disregarding those that are higher than the number being randomized and those that have appeared before in the series. If you wish to randomize more than ten (10) numbers, pairs of columns or rows can be combined to form two-digit numbers and the same process followed as that described above.

8	2	0	3	1	4	5	8	2	1	7	2	7	3	8	5	5	2	9	0	6	3	1	6	4
0	8	7	3	3	1	9	7	5	2	5	7	6	9	8	0	3	6	2	5	1	2	7	5	2
2	3	3	8	6	1	4	2	4	0	2	6	1	8	9	5	2	6	9	8	3	4	0	1	0
4	7	5	5	6	3	0	7	7	1	9	1	6	1	7	4	1	7	1	3	7	9	3	3	7
1	9	3	9	5	3	4	9	5	5	2	7	5	8	0	3	4	8	8	1	2	7	5	3	4
2	8	7	8	1	4	1	4	9	4	2	4	1	5	2	9	4	6	2	1	5	2	8	1	9
8	4	8	5	1	3	9	6	6	0	7	2	1	9	0	2	0	6	7	0	6	0	1	3	0
0	3	8	8	4	7	5	1	5	1	7	3	4	5	2	0	7	4	7	9	6	6	7	7	4
3	5	3	1	9	3	7	4	9	5	0	2	0	1	4	6	2	5	4	5	8	5	0	9	2
3	4	5	9	5	2	7	9	8	9	0	5	5	8	5	1	7	7	3	5	5	4	7	7	2
4	1	5	3	0	9	1	3	7	2	5	8	7	7	1	3	6	3	9	7	8	7	9	1	7
7	2	9	5	6	7	8	5	4	5	3	4	5	4	1	9	8	6	7	5	7	9	3	1	8
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9	1	7	1	3	6	9	2	9	1	9	4	2	3	3	0	8	1	8	7	7	6	4	7	2
6	2	2	8	0	9	4	5	3	7	2	5	4	6	6	5	6	6	5	0	4	6	5	6	8
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9	4	9	1	2	2	0	1	3	2	4	8	7	9	1	8	8	2	9	8	3	2	8	2	9
7	2	5	1	4	4	9	6	5	2	8	5	5	1	0	8	2	6	2	0	6	9	2	2	3
9	9	2	5	7	4	3	1	2	3	6	4	1	5	2	4	0	4	2	2	8	7	1	8	2
2	0	9	1	8	9	4	4	6	1	4	8	6	7	9	2	5	0	6	9	3	3	0	1	2
6	5	2	6	1	2	1	7	7	1	4	7	8	1	4	2	7	3	7	4	0	0	1	2	9
1	2	9	9	6	4	2	5	3	2	7	4	3	2	3	3	8	5	3	3	6	5	5	3	2
3	2	8	3	7	9	6	0	4	8	6	0	5	4	1	1	4	9	0	5	0	9	4	4	1
0	9	3	4	1	1	9	5	8	3	2	4	6	7	3	4	4	9	2	3	7	2	5	7	8
6	7	5	3	4	2	1	5	5	0	1	2	4	7	5	5	2	6	8	7	8	2	8	0	3
9	6	0	1	3	0	5	3	6	6	2	9	6	0	3	4	7	6	1	1	9	1	6	5	3
4	6	9	9	6	7	8	5	8	1	2	9	2	6	2	4	4	9	0	5	5	4	5	2	0
9	7	7	1	9	2	6	5	6	3	3	6	3	6	8	3	9	9	8	7	7	2	7	9	7
7	5	3	3	3	3	7	3	7	6	7	3	9	1	1	2	3	9	0	9	5	9	6	5	7
2	8	1	3	1	3	4	2	1	0	3	1	2	3	2	0	2	3	9	7	7	5	0	6	9
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3	5	9	0	7	7	0	1	8	1	2	9	3	4	6	9	2	8	9	8	9	8	6	5	5
4	4	8	1	1	7	4	4	7	4	4	4	1	6	5	9	3	6	5	9	8	3	2	4	3
6	3	9	7	0	6	2	5	3	3	2	6	0	5	1	2	4	3	7	1	0	7	8	2	1

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CONDUCTING FIELD EXPERIMENTS: PRACTICAL ASPECTS

by

R.E. Pierre

In this paper, it is hoped to draw attention to a number of practical aspects in conducting field experiments. The paper is not exhaustive and certainly many of the points raised will not be unknown to you. But perhaps it may be surprising to learn that a large number of field experiments fail to yield meaningful results because one factor or another has been overlooked by the researcher.

For convenience, the paper is divided into three sections as follows:

- Preliminary work;
- Planning an experiment; and
- Executing an experiment.

PRELIMINARY WORK

Ideas for a particular experiment may emanate from several sources, e.g. the researcher, supervisor, extension officer, farmer, etc. Whatever the source, the primary obligation of the researcher is to study the available and relevant literature and to discuss the problem with colleagues and other persons who may be knowledgeable particularly of past work on the same or similar aspect of the study. This latter is of particular importance since much of the work done by Ministries of Agriculture in the region is not reported in the usual sources of information (journals and similar publications) but remains inaccessibly stored in files.

In reviewing relevant literature, the researcher has to use initiative and discretion. Review the literature which is closely related to the area of research to be carried out. For example, if one is interested in finding tomato varieties that are most suitable for production in Guyana it is not much point reviewing literature dealing with the performance of maize varieties in Guyana, but if one is interested in the fertilizer response of tomato on certain soil types and the available literature deals with the fertilizer response of maize on these soils, then it may be useful to study

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such data to obtain some indication of the fertility status of the soils in question.

In addition, a researcher needs to have a reasonably good basic knowledge of the subject on which the experiment is to be performed. For example, if the subject is a crop, one should be familiar with at least the following factors:

- basic botany of the crop including growth habit, types of cultivars and suitability for different purposes, growth cycle, photoperiod response, sensitivity to chemicals (pesticides, nutrient deficiency or toxicity);
- crop husbandry including most important diseases and pests to which the crop is susceptible and methods of control; and
- climatic (temperature mainly) and soil requirements of the crop.

The socio-economic importance of the subject, the likely impact of the proposed experiment and the overall linkage with a planned programme also need to be assessed before the experiment is performed. In short, the researcher should be convinced that some justifiable benefits are likely to accrue from the experiment.

Careful inspection of the field in which it is proposed to carry out the experiment is a very important prerequisite. Factors which should be considered include:

- size of area;
- slope;
- soil heterogeneity; and
- presence of obstacles, e.g. shade trees.

One should try to obtain as much information as possible regarding the history and present condition of the area in question including previous crops and/or experiments, abnormalities of the area, e.g. susceptibility to flooding, previous use, e.g. tethering of animals, dumping of crop refuse and other factors which are likely to increase the variability of the area.

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PLANNING AN EXPERIMENT

In planning an experiment the researcher should take a number of factors into consideration, most of which are related to the size and characteristics of the area available for the experiment, as determined by previous inspection of the field.

Both plot size and shape are influenced by the type of machinery and equipment (manual or mechanical) to be utilized. For machine operations, long relatively narrow plots of reasonably large size are preferred to facilitate tractor operations. Basically, the choice is mainly one of convenience but there are other factors which need to be considered.

In general, with plots up to 1,000 sq.ft., increasing plot size results in reduced error. Small plots are inherently more variable due to the fact that they contain fewer plants. Losses during harvest or growth period, and errors in measurement, have a greater impact on the accuracy of results. In addition, there is increased competition and border effects. But small plots sometimes may be necessary where either a large number of varieties are being evaluated, or planting material is limited or where there are budgetary restrictions.

Critical selection of the number, type and combination of treatments and the number of replications are essential, bearing in mind the main objectives of the experiment and the need to keep the trial down to manageable proportions together with economic and time-saving considerations.

In the case of the latter factor, it is necessary to choose the most appropriate epxeriment design (randomised block vs. split plot) and this is perhaps one of the main reasons underlying the need for early consultation with a biometrician or someone with adequate knowledge and experience of the subject.

A detailed plan of the experiment and field layout is an absolute necessity. Ensure that the plan is oriented in relation to some fixed

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reference point in the field, e.g. building, large tree, roadway, fence, etc., and that it contains all the treatments in the exact position relative to each other as they would be laid out in the field. A clear description of each treatment should accompany the plan.

In addition to being the guide for laying down the trial in the field, the plan provides insurance for certain unforeseen occurrences, e.g. removal of a marker before completion of the trial or obliteration of writing by the elements of the weather. The plan should contain sufficient information to enable the researcher to locate each treatment exactly, even if practically all the stakes and labels were removed from the field.

To complete the planning stage, it is necessary to list and collect early (to ensure availability when required) all materials and equipment (measuring tapes/chains, string, stakes, labels, markers, scales, containers, seeds, pesticides, fertilizers, etc.), that would be required to effectively execute the experiment.

EXECUTING AN EXPERIMENT

Field experiments generally require a considerable amount of time and labour and a researcher usually requires the assistance of one or more technicians to establish, maintain and harvest each trial. All participating technicians should be thoroughly briefed before-hand about the nature, objectives, plans and procedures of the trial and the type of data to be collected. Strive to ensure that technicians clearly understand not only the trial per se but also how it fits into the overall research and development programme.

One should virtually 'live' with one's experiment as there is no substitute for the watchful eye of the researcher.

Laying out a right angle: If the corners of plots are not laid out at

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exactly ninety degrees (90°), the plots will cover a different area from what is intended. One simple method of laying out a right angle in the field is based on the fact that a triangle with sides in a 3:4:5 ratio forms a perfect right angle.

The procedure is as follows (Fig. 1):

1. Lay out a base line at one side with a string and stakes. This should be as long as the width of the experimental area, i.e. the stakes (A, A1) should be two corner posts.
2. Place a third stake (B) along the base line at exactly 40 ft. from one of the corner stakes.
3. Have an assistant hold the end of the tape on corner stake A while you draw an arc on the soil surface with a 30 ft. radius in the approximate area in which the side boundary of the experiment is expected to fall.
4. Have the assistant hold the end of the tape at stake B and draw an arc on the soil surface with a 50 ft. radius in the area of the previous arc and place stake C where the two arcs cross. The angle CAB will be a right angle.
5. Repeat the process at A1.
6. Project the lines AC and A1C1 to the desired length of the trial and mark (D, D1). Check the line D-D1 to ensure that it is the same length as A-A1. Then measure and mark out plots, ensuring that the stakes are firmly driven in.

Labelling: Accurately label each plot using materials that are as resistant as possible to the elements of the weather or use means to adequately protect what is written, e.g. plastic cover, wax coating.

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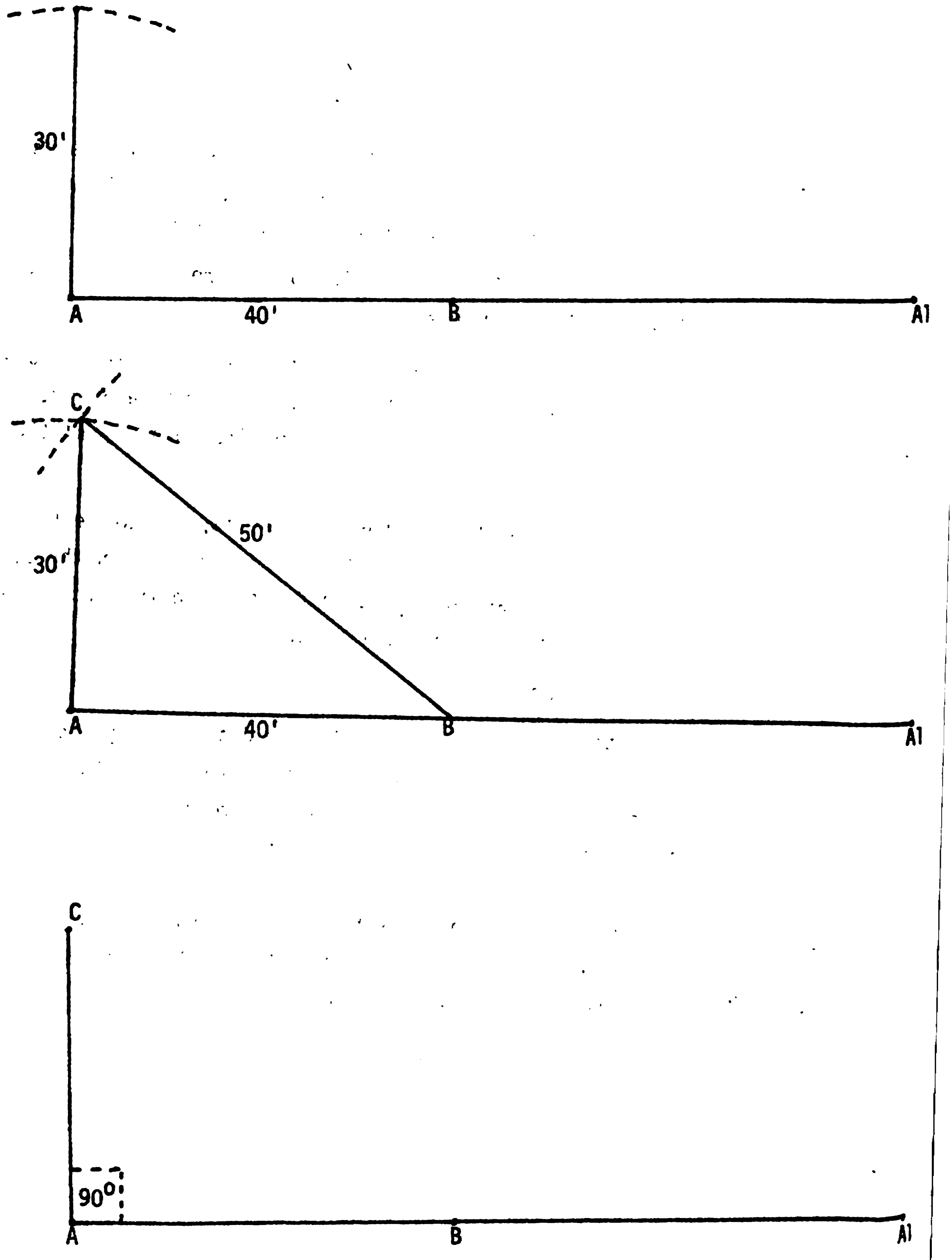

FIGURE 1: PROCEDURE IN LAYING OUT RIGHT ANGLE IN FIELD

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Applying treatments: Failure to apply treatments uniformly is an extremely common error which greatly decreases the value of an experiment. Extreme care should be taken to see that the fertilizers, pesticides, herbicides, etc. are applied exactly as specified and uniformly over the plot. If more than one person is applying the treatments it is preferable to have one person per replication rather than per treatment. Ensure that all basic cultural operations are applied to all plots including the control (check) plot. Avoid introducing unwanted variables, e.g. treatments involving soaking of seeds in different chemicals should be compared with seeds soaked in water; treatments involving the use of different foliar applications of pesticides should be compared with controls in which water has been applied to the foliage. Keep plots weed free.

Carefully weigh/measure all materials; calibrate spray equipment; thoroughly mix fertilizers containing different nutrient elements. Try to obtain a uniform stand. One solution is to plant at a greater density than required and thin to the desired stand. Make sure that seeds have a very high percentage viability.

Security: Inadequate security from man and animals is one of the most important contributory factors to unreliability of results of field experiments. Damage by domestic or wild animals may occur; workers may like the look of a particular cultivar and take a few pods here and there. Sometimes, dependent on the quantity removed, this goes undetected at harvest time, but shows up as unexplained variability and lack of consistency in results. Reliability of results decreases as the Coefficient of Variation (CV) increases. CV is the standard deviation per experimental unit expressed as a percentage of the overall mean of the experiment. A Coefficient of Variation of up to 20 percent is generally acceptable for field experiments. Above that, the reliability of the data becomes questionable.

Praedial larceny may result in the partial or total loss of a field experiment. If one or two plots/treatments are lost, it is still possible

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to analyse an experiment using the statistical concept of a *missing plot*. However, this becomes more complex and decreasingly useful as the number of missing plots increases.

In an effort to reduce and avoid such complications, around-the-clock security at the critical period (nearing harvest time) in the life of the experiment, may be essential.

Measuring and recording results: Improper measurement and recording of results are frequent causes of inaccuracy in field experiments. *When* and *what* to measure and the degree of accuracy in measuring are all very importan considerations. For example, different varieties mature at different times and over variable periods. It is important, therefore, to know not only the final yield, but the time to initial harvest, the frequency and duration of the harvest period in crops that require multiple harvests.

Consideration should be given to the possibility of obtaining information about important factors other than yield. In tomato, for exampl fertilizer treatments may affect fruit size, time to maturity, colour of fruits, disease susceptibility and nutrient content of fruits. Consumer requirements and marketability are also important. If these factors are taken into account before-hand, it should be possible, with appropriate linkage, to make maximum use of a single trial to obtain as much informatio as required.

With regard to degree of accuracy, the researcher should be *accurat but discreet*. Many qualitative attributes do not readily lend themselves to measurement in numerical terms. For example, in evaluating the incidence of disease, a frequently used classification is based on an assessment of whethe the disease is light, moderate or heavy. Such qualitative descriptions canno be analysed and it is better, therefore, to use some quantitative scale.

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In preparing and using such scales, the following guidelines are suggested:

1. Make as many steps in the scale as an experienced observer can distinguish and support each scale with photographs or sketches;
2. Try to design a scale so that observations are normally distributed, i.e. the middle number is the most frequently observed;
3. Where individual judgement is involved try to avoid more than one person making the observations. If this is not possible, restrict an individual to a block of treatments rather than to specific treatments.

Finally, all results should be clearly written. Get as much data as possible in the field to reduce the incidence of loss in subsequent handling. With products from which data will be required subsequently, be sure to label accurately and store the material safely.

CONDUCTING EXPERIMENTS: SOME SPECIFIC APPLICATIONS:
- FIELD AND VEGETABLE CROPS

by

A.M. Pinchinat

(Outline only)

INTRODUCTION

Farming System Concept

- Crop sequence over time unit (cycles)
- Spatial arrangements over farm unit (monocrop, multicrop systems)

Experiment Control

- Researcher (early stages)
- Farmer (advanced stages)

Gradual, iterative shift

RESEARCH PROBLEM

Is Research taken seriously?

Productivity

- Potential (seed quality, genetic value)
- Stability (environment and genetic interactions)

Management

- Soil environment
  1) Physical (tillage, drainage, structure change)
  2) Chemical (fertilization, liming, removing toxicity)

- Climate modification
  1) Water control (irrigation)
  2) Light control (plant density, distribution)
  3) Combined climatic factors (planting time, others)

- Crop protection
  1) Insect (chemical,biological)
  2) Disease (chemical, biological)
  3) Weed (manual, mechanical, chemical)

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- Harvesting (research/service)
  1) Time
  2) Means

MATERIALS AND METHOD

Treatment, Design and Replication

- Treatment
  1) Kind (according to identified problem)
  2) Number (as low as possible)

- Design (as simple as possible)

- Replication (as low as possible)

Inputs

- Seed (good quality, right variety)
- Fertilizer
- Pesticides
- Equipment
- Special (irrigation water, others)

Land Preparation

- Smooth
- Minimal use of energy

Plot Size and Shape

- Size
  1) Small, in more controlled environment
  2) Larger, under conditions closer to farm environment

- Shape
  1) Rectangular
  2) Non-rectangular

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Non-experimental Practices

- General
  1) Keep as realistic as possible
  2) With the exception of response variables, all others should be reasonably uniform (blocking advantages)

  Specific
  1) Crop rotation (diseases, insects, volunteer seeds)
  2) Field rotation (fertility interactions, soil borne insects/diseases, weeds and volunteer crops)
  3) Guard and border rows (isolation)

DATA COLLECTION

- Effective Plot Size

- Data Recording
  - Single harvest
  - Multiple reaping

DATA ANALYSIS

- Missing Plots
  - Accidental
  - Naturally caused

- Results Interpretation
  - Biophysical
  - Economic
  - Social

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CONCLUSION

Short cycle crops must be handled with great care as they are very susceptible to both field environment and management.

CASE STUDIES BY PARTICIPANTS

- Cowpea - Julius Ross
- Tomato - Chitra Singh

CONDUCTING EXPERIMENTS: SOME SPECIFIC APPLICATIONS

- TREE CROPS

by

C.S. Baichoo

INTRODUCTION

When planning an experiment in tree crops, the first thing that the experimenter does is make sure that his stated objectives are clear. The question to be answered must be properly stated. It must be established that the need exists for such research and the priorities must be in the right order. The experimenter must have full knowledge of the crop, i.e. the agronomy, the problems facing the farmers, the economics of growing the crop and the basic management practices of the crop.

A review of literature is necessary so that the efforts of other persons are not duplicated.

LAYOUT OF THE EXPERIMENT

In laying out an experiment there should be more than one plot having the same treatment . In field experimentation, the experimenter is always aiming at minimizing the experimental error, i.e. to keep the error between plots as small as possible. To do this, he has to arrange the blocks in such a way that there is minimum variation between the plots in a block and maximum variation between the blocks.

SITE SELECTION

Ideally, the site should have been uniformly cropped previously. Uniform management practices in previously history are also implied here. If management practices were uniform, then it is necessary to know the previous boundaries of the different management regimes in order that adequate measures of 'local control' can be incorporated into the experimental design. The exception here would be where residual treatment effects are being tested.

The site should reflect the average topography of the larger geographical area. Hopefully, by careful site selection, adequate 'local contr and adequate experimental technique, one should be able to eliminate much of

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the extraneous variation from experimental error even with the use of an average site. The results obtained from such sites should bear greater relevancy to in-field conditions on farmers' plots.

PREPARATION OF THE AREA

After careful consideration that a selected test area is suitable for its required purpose, it should be ensured, when planning the test, that all important test conditions are as uniform as possible.

Fertilization and cultural practices, including pruning of tree crops, should be carried out at the same time and in the same manner in order to avoid plants being brought to a state of abnormal predisposition.

CHOICE OF TREATMENTS

The experimenter should list all treatments which he thinks may produce the best or optimum results. This knowledge will come from an assessment of the crop, work done by other workers, and from discussion with farmers. He may also wish to introduce a control in the form of present farming practice, even though he knows this to be inferior, so that he may reject it in favour of an improved practice.

CHOICE OF DESIGN

Having decided on the treatment structure and having assessed the available resources, the experimenter is now ready to design his experiment. With a knowledge of his resources he should be able to decide how many plots are available for experimentation. Standard practice dictates that the design chosen fits into the number of plots available with the possibility of plots being wasted because the design chosen only allows a certain number of plots.

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BLOCKING

The experiment now has to be placed in blocks. The choice of size and number of suitable blocks will depend entirely upon the individual circumstances. The main purpose of blocking is to reduce to a minimum the heterogeneity among plots in a block. With proper blocking the differences among blocks are increased while differences within blocks are minimized. At this stage the main purpose for which an experimenter carries out an experiment is to detect treatment differences and to make statements about those differences thereafter. Treatment difference is considered to be fixed. If the true difference is very small it will be difficult to detect. If large, then it may be detected. If the experimental error is larger than the treatment difference, then the experimenter cannot detect the treatment difference. Since one cannot manipulate the treatment differences because they are fixed, then one must manipulate experimental error. Blocking is a tool with which an experimenter could manipulate and possibly reduce experimental error which is ever present and thus increase the chances of detecting treatment differences.

Gomez and Gomez (2) have set out some simple rules towards achieving proper blocking:

- When a unidirectional fertility gradient occurs, the blocks should be long and narrow and be oriented so that the length is perpendicular to the direction of the fertility gradient;
- When a fertility gradient occurs in two directions, with the directions perpendicular to each other or nearly so, a Latin Square design or covariance technique may be used; and
- When the fertility pattern is not known, or when fertile areas occur in unpredictable spots, then square blocks should be used.

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RANDOMISATION

The last stage in the design of any experiment is randomisation. Any experimental design can be analysed providing it is correctly randomised. If it is not properly randomised, then the experiment is worthless. The purpose of randomisation is to assign the treatments within each block to plots and this is usually done with the help of random number tables.

REPLICATION

Replication serves two purposes:

- It increases the precision of the experiment, since the mean of several replications provides a more accurate measure of varietal performance than does a single plot; and
- It permits the calculation of an estimate of error of the experiment. The number of replications will be determined by the variability of the soil, the variability of the material to be tested and the desired degree of precision.

According to Cochran and Cox (1), even a single replication of a factorial experiment is beyond the resources of the investigator, or it gives more precision in the estimates of the main effects than is needed. In a single replication of a 2^6 factorial, each main effect is an average over 32 combinations of the other factors, and hence in effect has 32-fold replications. In tree crops experiments perhaps 4- or 8-fold replications would suffice but this is for the consideration of the experimenter.

SHAPE OF PLOTS

In fertilization and variety tests, the shape of the plot has less influence upon the accuracy of test results if the test field is well balanced. In most cases, an unbalanced field should be anticipated. It has been established that long narrow plots give the best results in this case.

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The rectangular shape is also given preference over the square shape. Generally, the dimensions should be so selected that one is 5 to 10 times greater than the other.

It is not advisable to separate each plot by a small path because additional spacing between the peripheral plants can result in the development of other microclimatic conditions. The plots should adjoin each other in such a manner that the overall arrangement forms the pattern of a compact stand. If it is necessary, because of technical reasons, to make a path, then it is recommended to leave a separate strip along the edge of the path which is excluded from the test evaluation.

SIZE OF PLOTS

For perennial crops such as fruit trees, the plot size may be take as being equal to the number of trees or plants and this is determined chiefly by the type of experiment that is to be conducted, i.e. if it is insect infestation density. Generally, a minimum number of five trees shoul be chosen. In principle, the plots should be kept as small as possible because large plots cannot always be treated as uniformly as small ones. The evaluation is not so accurate either, when large plots are used. Added to this, an increase of the plot size involves more work, material and space, thus leading to the restriction of the whole test programme.

CHOICE OF EXPERIMENTAL MATERIAL

In conducting an experiment on tree crops, it is necessary that the planting material be of the same genetic makeup. With seedling plants, this is somewhat difficult, but by all means, careful selection must be done in the early stages. In the case of coconut seedlings, one should start by selecting mother palms of the same age, grown in the same block, and nuts of the same type/variety and same characteristics. The nuts should be subjected to the same seed treatment and rigid selection of the seedlings at the time of transplanting.

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In the case of fruit plants, it is best to work with plants that are vegetatively propagated because seedling plants exhibit varying genetic characteristics. In planning an experiment with avocado, mango and particularly citrus, it is important to standardise the root-stocks. If it is a trial on root-stocks then the scions have to be standardised. Much depends on what the experimenter sets out to achieve. When starting a new experiment on citrus, it is important that the seedlings are of the same age and size before the plants are budded, and that budded plants of the same size, age and conformation should be planted. It is also important that the varieties are not mixed up within the plot, e.g. the types of sweet orange (Valencia, Parson Brown, Hamlin, Washington-Navel, Pineapple, etc.).

SAMPLING

In agricultural experimentation, the main objective is the comparison of treatments in the face of uncertainty. This uncertainty arises because of the variability which is associated with the characteristics being measured for comparison. The variability is due to three main components:

- Environmental (soil, topogrpahy, cultural practices);
- Genetic (type of planting material); and
- Errors of observation (sampling and measuring error).

At the planning stage a decision will be made as to the sampling strategy, e.g. sample size.

The following steps may act as a guide in choosing the sample size:

- The experimenter will decide, in consultation with a Biometrician, on the size of error which is acceptable, for the character being measured;
- The experimenter may also have to give some information on the appropriate expected magnitude of the plot characteristic; and
- The formula for the standard error of the estimate of the plot

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characteristic may then be used to determine the minimum size of sample which would give the specific standard error.

These are only some of the principles governing sampling techniques useful in field experimentation.

A sample is a subset of plants in a plot or experimental unit. When there are limitations (labour, money, time) which do not permit the experimenter to measure all the plants in a plot, then sampling is employed. When sampling takes place then a sampling error which contributes to experimental error is introduced. Even without the limitations of labour, money and time, etc. it is not possible to take all the necessary measurements in a plot, and it is therefore possible to introduce non-sampling error due to human fatigue and other mistakes in recording.

Sometimes the non-sampling error is greater than the sampling error and in such cases a decision would be made to take a sample rather than measure all the plants in the plot with a view to reducing the experimental error.

Three methods of sampling which will be very useful in experimentation are:

- Simple random sampling;
- Stratified random sampling; and
- Systematic sampling.

The general purpose of sampling is to estimate the yield or other characteristics of a treatment from a subset of plants from the plot to which the treatment has been applied.

A simple random sample of plants/fruits from a plot is one in which a subset of the plants/fruits is chosen at random, so that each plant in the plot has an equal chance of being chosen. Random number tables may be used to select the sample.

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If the characteristic to be measured is not uniform over the whole tree, e.g root-stock or scion or the windward or leeward side of a tree, then stratified sampling is used. In such a case the plot is divided up into strata such that within a given stratum, the characteristic appears uniformly. A simple random sample is then taken within each stratum and the results aggregated to give a stratified random sample. This would lead to greater precision than to take a simple random sample from the plot, ignoring the presence of the strata.

Systematic sampling may be used instead of simple or stratified random sampling when there are field constraints which will impose greater error if simple or stratified random sampling is pursued.

PREPARATION OF A PROJECT SHEET

Before a project commences, a project sheet should be prepared so that anyone can take such a document and carry out the experiment. The following guidelines can be followed:

- Title of the investigation;
- Background information on the experiment;
- Objective and justification of the investigation;
- Names of the participants;
- Field plan of the project;
- Materials needed;
- Calendar of activities; and
- Format for data collection.

TRAINING OF SUPPORT STAFF

Personnel working with the experiment should be trained beforehand so that they understand what is expected of them. They should be able to handle simple machines and equipment and take care of these after use.

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In order to conduct tests accurately, it is necessary that all tasks be carefully planned and carried out. The possibility of committing errors when compounds are being weighed and measured should not be overlooked. Quantities of compounds stipulated for the different plots must be weighed or measured exactly and checked for correctness. The required machines and equipment to be used in the operations should be checked beforehand to ensure that they are in working condition.

RECORD KEEPING

Accurate records should be kept on the experiment, and it is essential that the experimenter carry a field note book at all times. The information collected should be later transferred to the relevant file where the information is kept. Sometimes it is necessary to keep records for individual trees; this enables the experimenter to observe any variations that may occur within the plot. In this case, a block that is abnormal can be eliminated.

Fruit trees have different fruiting seasons within the year, e.g. peak season, early season, mid season or late season. In some cases the yield data might only represent a small part of the treatment. On the other hand the increase in the height, girth or spread of the tree might have some correlation to the yield of the particular tree. Record keeping on individual trees can also give a true picture of the tree as to its general vigour, incidence of pests and diseases, or any abnormalities that may arise from time to time.

ANALYSIS AND INTERPRETATION

After the data is collected and grouped together, it is easy for the experimenter to carry out a full analysis.

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CONDUCTING EXPERIMENTS: SOME SPECIFIC APPLICATIONS:
- PLANT DISEASE CONTROL

by

R.E. Pierre

(Outline only)

1. Identify the Problem.

2. Diagnose the cause: Pathogenic or non-pathogenic disease. If pathogenic, which agents cause the disease:

   - fungi
   - bacteria
   - viruses and virus-like organisms
   - nematodes

3. Knowledge about the Disease. If it is fungal, what is known about the fungus disease. If one is knowledgeable about the disease, move on to the next step. If nothing is known:

   - Try to identify the fungus by isolation and laboratory examination. On the basis of frequency of isolation, make a preliminary diagnosis.

   It is necessary to confirm pathogenicity of organism isolated on the specific host.

   In laboratory testing one deals with small quantities, because of the need for a high degree of precision.

4. If the fungus is identifiable, classify it into one of the following:

   a) Phycomycetes
   b) Ascomycetes and Fungi Imperfecti
   c) Basidiomycetes

   as some fungicides are group specific. If you cannot classify the fungus, then you have a larger range of fungicides from which to choose. Do a bioassay in the laboratory. Move to the greenhouse possibly using single plant treatments to confirm effectiveness of fungicides.

5. Materials Required:

- 8 fungicides
- Sprayer
    - Ordinary knapsack sprayer
    - Low volume sprayer
    - Ultra low volume sprayer

Choice of sprayer depends on crop type:

- On sprayers, pressure regulator and pressure guage are needed as pressure determines output per minute twice.
- The uniformity of application is also important.

6. In a field experiment to control a pathogen:

- time the planting operation correctly to coincide with the season of the disease;
- put down innoculant rows ahead of time; and
- have guard rows/areas to buffer spray drift to other plots.

Drift may also be reduced by:

- spraying early in the morning or late in the afternoon when there is very little wind;
- using a large-nozzle orifice and a high-volume sprayer; and
- using screens.

Special sprayers for field experimentation do exist.

7. Plot Size: Plot size may be flexible, generally five (5) rows. However, try to use a plot size that will permit an easy calculable volume of spray materials.

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8. Equipment: It is desirable to have separate pieces of equipment for different treatments. If this is not possible, the same piece of equipment may be used to treat across replications.

   If this is done, equipment must be thoroughly washed with detergent and water after each use.

9. Frequency of Application:

   - 10-14 days is a reasonable period. May be even shorter under adverse weather conditions.
   - The interval between spraying and harvesting is important to avoid residues on the produce harvested.

10. Phototoxicity: Five to seven (5-7) days after treatment, check for any phototoxic reaction, e.g. foliar distortion, yellowing or browning, etc.

11. Disease Evaluation: All plants in the plot need not be evaluated. Sample randomly, at least five plants in the effective plot, and rate them for the disease.

    Rating introduces a qualitative measurement which introduces an element of bias. To avoid this bias, have one person do the evaluation throughout. If this is not possible, use one person per block.

12. Select and standardise leaves for rating. Use numerical ratings based on identifiable differences and compute disease index (DI):

$$DI = \frac{\text{Sum of ratings x 100}}{\text{No. of units x Maximum disease category}}$$

13. Yield Evaluation: After disease rating, do a yield evaluation.

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14. Analyse and conclude.

NOTES:

- If a tree crop is dealt with, a single tree or a portion of a tree can be used as a plot.
- The procedure is basically the same as above for weed control with regard to standardisation of equipment. It is important, however, to use high volume equipment with a fan nozzle.

CONDUCTING EXPERIMENTS: SOME SPECIFIC APPLICATIONS

- DISEASE CONTROL

by

F.D. McDonald

INTRODUCTION

Nature and Object of the Field Trial

The possibilities of effectively controlling diseases of plants are constantly being improved and widened by the development of new pesticides and methods. An integral part of this development is the testing of such new methods of disease control under practical conditions in the field. The results obtained indicate whether these new control methods carried out under field conditions, which forever vary from place to place and from year to year, meet with the requirements of farming, namely to give adequate suppression of plant diseases without producing any side-effects of a kind that will limit the treatment or even render it impossible. Furthermore, such control methods must not incur high costs.

The object of the field trial is thus established and its characteristics outlined. If the experiment is to fulfil its purpose, it must be carried out with absolute precision and the results must be valid for different soil, climatic and farming conditions over an average number of years. The implementation of such experiments aimed at yielding reliable and accurate results involves difficulties which usually are greatly underestimated because often there is no prior opportunity to become familiar with the prerequisites essential to an exact experiment. In this paper, the fundamentals of these prerequisites will be outlined and illustrated by a few selected examples. Through investigating all the aspects of the biological and technical problems, recommendations and standards will be worked out that are necessary for carrying on exact experiments.

An experiment is a means of obtaining information. In contrast to mere observations, effective factors are changed in the experiment according to the problem to be solved and the resultant reactions are usually register numerically or as estimates.

The result of an experiment must be conclusive. But the required measure of conclusiveness varies according to the object being studied and

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the task to be accomplished. For example, in studies of physical questions it is not the same as that required in investigations of biological questions which by nature involve greater variations.

Generally, the object of all efforts made to gain knowledge as anchored in the nature of the experiment is not just confined to acquiring that knowledge but from it to be able to predict and steer the course of events. Generally applicable rules should be derived which, in respect of practical crop protection, must read as follows:

> "When the investigated control methods are employed on a certain crop following occurrence of a particular pest, it may be expected that with great probability - the exact degree of probability being known - these methods will give successful control of the pest involved, that damage otherwise caused by this pest will be prevented and that the crop will not be harmed either directly or indirectly." (Unterstenhofer, 1963)

In order to derive such rules formulated on the basis of experiments, it is of the utmost importance to apply the suitable method according to a definite plan. This is essential if each test is to provide a maximum of information. Hence, the method is defined as well as the well planned procedure for solving a scientific problem.

For investigating and clarifying crop protection questions laboratory or greenhouse and field experiments are conducted. The laboratory or greenhouse is usually carried out under set conditions. Temperature and light and the elimination of rain and wind create artificial environmental conditions which, in addition, can be varied as required. In the field trial on the other hand, natural, complex conditions prevail which cannot be influenced by the investigator. Consequently, the methodical procedure for the field trial must be completely different from that adopted for the laboratory experiment. In the study of crop protection problems information provided by the laboratory experiment is supplemented by results obtained in the field trial.

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Due to the fact that numerous happenings in the field often cannot be explained, it is frequently necessary to return to the laboratory for analyzing and interpreting unknown phenomena. For it is in the laboratory that the effect of a certain factor or a toxic process can be exactly studied by keeping all other factors constant by using the technical aids available today, including air-conditioning chambers, stage thermostats, etc. Subsequently, several factors are combined, and their effect determined. In other words, simplified conditions are produced which permit recognition of the relationships between certain causes on the one hand, and observed effects on the other hand.

The exact field trial differs fundamentally from the so-called demonstration experiment in which usually two equal parts of a plant stand are treated differently with the differences between the two compared and sometimes recorded numerically by estimate. For an experiment to be exact, it is essential that it is carried out under similar infection conditions with several replications. In order to conduct such a test several preliminary requirements must be satisfied. These can be described and applied to the agricultural experiment as well as to the crop protection trial. They are:

- The personal interest of the investigator must be so keen that he supervises each operation himself;
- Trained personnel, fully reliable and familiar with the test problem;
- Efficient equipment, in particular, suitable types of sprayers and dusters. It is essential that the exact output of these machines is known; and
- A suitable test site.

Before a test is planned, it is essential to acquire an exact knowledge of the biology, etiology and epidemiology of the disease against which the treatments being examined are to be applied, because these factors

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in conjunction with the mechanism of action and the other properties of the biocide have a decisive bearing upon the test plan. They are also responsible for fundamental differences in the technique of test planning, implementation and evaluation existing between the crop protection experiment on the one hand, and the field trial conducted to clarify questions appertaining to varieties and fertilization, on the other hand. In view of this, the guiding principles for carrying out variety and fertilization experiments as derived from a wide range of experience can only be applied to the crop protection experiment with appreciable limitations.

It is therefore necessary in the crop protection experiment to submit the individual factors which may be influenced technically to a close study in order to ascertain whether and to what extent the guiding principles which have become established in the field trial may have to be amended, making particular allowance for special crop protection requirements. Furthermore, when making an exact determination of a reliable effectiveness in the crop protection trial, there are other factors to be considered, which are characteristic only of this type of experiment.

When drawing up a test plan, which is always the foundation of an experiment, first consideration must be given to the size, shape and layout of the plots. The decision on this question will be governed mainly by the marginal and the adjacent effects arising out of the active and passive distribution of the diseases. The marginal and the adjacent effects are two factors particularly characteristic of the crop protection experiment underlined by the drift of sprays and dusts. The general planning of tests also includes settlement of the question as to the number of replications to be made, allowance for failures and the spraying and dusting techniques to be employed.

If recommendations having a wide validity range are to be made on the basis of the test results, guarantee must be given that the results are reliable. To ensure this, the experiments must be carried out over a period of several crop seasons. During each season, particular importance must be attached to correct timing of the experiments and their evaluations. The correct data can be fixed by co-ordinating the mechanism of action of the

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pesticide with the "weak spot" in the life cycle of a pest population. Often it is reduced to very narrow limits. To determine such, use is made of widely varying methods some of which are employed in the so-called warning service. These include examination of plants for disease infestation and in case of insect pests, practices for capturing and sampling insects, such as the use of traps; observations of phenological occurrences; recording of meteorological conditions; and combinations of several investigation methods.

For the evaluation of the experiment it is very important to collect material for calculating the effectiveness. The selection of the right criterion and its application at the correct time, as well as appropriate sampling, have a decisive bearing upon this. Evaluation is carried out according to either degree of mortality or the extent of damage caused.

The values obtained in the evaluation of the experiment are calculated to give the effectiveness by applying action formulae. The effectiveness indicates by what percentage a control method is capable of reducing the severity of infestation or the measure of damage.

Apart from effectiveness, the nature and extent of side-effects upon the pest, the plant and living beings should be established in the field trial, because these factors also have a decisive bearing upon the value of a method or a compound.

PLANNING THE TRIAL AND TECHNIQUES OF CARRYING IT OUT

The statistical examination of test results shows how essential it is for every possible step to be taken into account from the technical aspect in order to keep the experimental error as small as possible, and thus increase the degree of accuracy. This automatically leads to another aspect of the field trial, i.e. to analyze it into the different factors that have a decisive bearing upon the accuracy and to examine what importance is attached to each factor, because in the evaluation the experimental error is always present. The magnitude of the error can merely be determined within

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units of computation, but not changed. Therefore, the greater importance must be attached to proper planning of the trial and to carry out all work with extreme care and thoroughness.

ORGANISATION OF THE TEST AREA

Size of Plot

In contrast to experiments on varieties and fertilization it is much more difficult to decide on the size of plots in the crop protection experiment. Fixed rules cannot be laid down here. Various circumstances arise from case to case, from year to year and from one locality to the next, which influence the choice of the plot size. General guiding principles resulting from the peculiarities of the crop protection experiment may be characterized as follows. In the evaluation of a crop protection experiment, the degree of effectiveness, which is determined according to the severity of the infestation or the extent of damage caused, is usually selected as the criterion for the effectiveness of a treatment, while it is only in a few exceptional cases, and then mostly to supplement the data, that the yield is chosen as this criterion. Therefore, the question may be formulated as follows: "To what extent is the severity of the infestation or the amount of damage influenced, under otherwise similar conditions, by the factor being investigated?". 'Under otherwise similar conditions' means, in this case, that in the plots, as the smallest units of an experiment in which the effectiveness is measured, all conditions influencing the severity of infestation - with the exception of the methods to be studied - are widely uniform and are free from fluctuations so that during the course of the test the widest possible causal relationship exists between the rate of infestation or the extent of damage and the control method to be tested. However, we know from experience that within the plots there are always differences in the rate of infestation. These are partly of a fortuitous and partly of a regular nature; they form the subject of the question on dispersion - the spatial distribution of the individuals of a species in the biotype.

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The chance factor plays a decisive part in migration and drift, and is all the more apparent the weaker the infestation potential, and as viewed from the aspect of the different plants or the different plant parts, the slighter the 'probability of control'.

The smaller plot size is of special interest for technical reasons when it is considered that:

a) it is possible to carry out the tests on a field scale; and

b) it is necessary to eliminate the influence of the individuality of the single pest and the single plant upon the total result, i.e. to obtain results representative of the population.

There is no difficulty in fixing the minimum plot size for testing eradicative treatments designed to control an infestation already present because then the differences in infestation can be recorded numerically and offset by suitable plot dimensions. The main difficulty lies in the testing of preventive methods for which the infestation density and fluctuations in this density cannot be predicted and consequently cannot be eliminated by means of a known optimum plot size. In this case, we merely have empirical values with corresponding insignificances.

The elimination of the individual variability of each pest and each plant is attained by carrying out the evaluation on an adequately large number of individuals. For this purpose a minimum rate of infestation is needed on a minimum number of plants or parts of plants and the pests parasitising on them. Whereas the number of plants per unit area depends upon the crop, no direct relationship exists between infestation density and the unit area; the severity of infestation is subject to the afore-mentioned fortuitous and regular conditions, as well as to the change in population density. The guiding principles that hold in agricultural research for breeding efficiency tests with respect to the size of plots, e.g. for cereals 15 to 20 m^2, for peas 20 to 25 m^2 and for root crops 25 to 30 m^2 can only be applied in the crop protection experiment for the elimination of the individual variability

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of the single plant.

If an adequate population density of soil pests is always present in a locality, e.g. nematodes, it will be possible for these principles to be largely observed.

For crop protection field tests, the minimum plot size is generally between 25 m^2 (5 x 5) and 100 m^2 (10 x 10).

If the possibility of an artificial infection exists, plot sizes smaller than those given above can be selected when it is intended only to determine the degree of infestation, provided the adjacent effect - to be discussed later - can be eliminated.

For perennial crops, too, such as fruit trees and grape vines, the plot size, which, in this case, may be taken as being equal to the number of trees or plants, is determined chiefly by the infestation density and the adjacent effect, if the effectiveness is selected as the criterion. Even though exact studies of this question are still lacking, past experience has shown that as a rule, a minimum number of five trees should be chosen. In principle, the plots should be kept as small as possible because large plots cannot be treated as uniformly as small ones. The evaluation is not so accurate, either, when large plots are used.

Furthermore, an increase of the plot size involves more work, material and space, leading to a restriction of the whole test programme.

Shape of plots

In variety and fertilization tests, the shape of the plot has less influence upon the accuracy of test results when the test field is well balanced. But if the field is very unbalanced - and this must always be anticipated - it has been established that long narrow plots give the best results.

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In the agricultural test, too, the long rectangular shape is given preference over the shorter square shape. Generally, dimensions should be so selected that one is 5 to 10 times greater than the other.

This experience, however, cannot be applied so readily to the crop protection experiment because the ground differences are less responsible than the infestation differences for the imbalance of the plots. There is no proof that in plots with an elongated shape, infestation differences will be more evenly distributed over the plots, which has proved to be the cause of ground differences; in fact, this cannot be assumed, at least not when consideration is given to the accidental causes of the differences. In crop protection experiments, the marginal effect, and to an even greater extent the adjacent effect, replaces the ground differences as to the factors determining the shape of the plots. When spraying and dusting, one is never fully successful in applying the chemical solely in the plots to be treated.

Only a very slight movement of air will cause the chemical to drift to the neighbouring plots. In elongated plots, this adjacent effect is particularly great.

Another adjacent effect with an equal, if not greater influence, is brought about by the active and passive movement of parasites from one plot to the next, which may result in such a marked reciprocal influence that the actual effectiveness becomes completely masked. In view of the marginal and adjacent effects the square shape should therefore be given preference over the oblong shape because then a nucleus for the test evaluation is obtained at least in each plot, which has a relatively small error due to the marginal and adjacent effects. But if the adjacent effect has slight influence it may be advisable to give preference to the oblong shape, e.g. for testing nematocides.

It is in principle a wrong practice to separate each plot by a small path because as a result of the bigger spacing between peripheral plants and due to changes brought about in the micro-climatic conditions, variations of unknown order of magnitude will be produced. Rather, the

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plots should adjoin each other in such a manner that their overall arrangement forms the pattern of a compact stand. But should it be necessary for technical reasons to make a path, it is recommended to leave a separate strip along the edge of the path, which is excluded from the test evaluation.

Marginal and adjacent effects

The marginal and adjacent effects have always been known as two factors which have a decisive influence on the magnitude of the test error in exact variety and fertilization tests. But in the crop protection experiment these two factors have even greater bearing, and may in fact be regarded as constituting the typical error of this experiment. Frequently, they decisively influence the planning, implementation and evaluation of the experiment as well as the interpretation of the recorded results.

Marginal effect

In variety and fertilization tests, a marginal effect is understood to mean that plants growing at the edges of fields or plots give yields differing from those produced inside the stand. The development of the plants at the periphery of the field does not conform with that in the centre of the stand. It is only natural that the influence of the marginal effect upon the total plot yield is greater, the higher the percentage of plants growing on the periphery. In order to establish differences in yield by conducting comparison tests it is essential that the percentage of plants growing at the periphery is equal in all the plots to be compared or that these plants in the periphery are removed shortly before the harvest, and excluded from the evaluation. As a rule, the latter course is taken because in comparison tests with varieties and fertilization not only the relative but also the absolute yields and yield differences should be determined.

The marginal effect in plant pathology concerns with the edge of the stand being infested far more severely than the interior of the stand especially if there is an occurrence of allochthenous pests. The marginal

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effect is less evident for fungal diseases, apparently because in this case the 'filted action' of the plants at the periphery of the stand is not so strong due to the small size of the propagative spores. At all events, there are no indications that the periphery of the stand is more severely infected than the interior. At the periphery, however, changes in the microclimate often lead to more unfavourable conditions for infection, e.g. for *Phytophtora infestans*.

This phenomenon of the marginal effect which occurs in crop protection experiments, in addition to variations in plant development due to local conditions, makes it necessary to exclude the peripheries of the stand from the experiment. The extent to which this must be done and the way in which the marginal effect should be rated must be decided from case to case on the basis of a careful check.

The adjacent effect

The adjacent effect is understood to mean the reciprocal influence between adjacent plots. In the variety and fertilization test, this effect is known to vary for the different cultivated plants. As a rule, it is all the greater the more the adjacent plots differ from each other. This effect can be eliminated by sowing covering seeds (protective strips). Generally, strips one metre in width will be found to be adequate.

Whereas in the variety and fertility investigations the marginal effect is always of greater importance than the adjacent effect, it is just the reverse in the crop protection experiment in which the adjacent effect is attributed to two causes:

a) the active and passive spread of disease pathogens and insect pests; and

b) the drift of sprays and dusts while carrying out the test as well as the long range effect, e.g. if volatile compounds, especially of herbicides.

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Number of Replications

Accuracy of the results can be improved by increasing the number of replications. But on the other hand, there is a limit to the number of replications, for the improvement of accuracy cannot be increased proportionally and becomes progressively smaller whereas there is a constant increase in the amount of work and capital expenditure involved. Allowance must be made for this when deciding on the number of replications to be carried out. In order to run field tests on sound economical lines, every effort should be made to keep the number of replications as low as possible.

It is not possible to give a generally valid ruling on the minimum number of replications. When planning the tests, the number of replications needed should be decided from case to case after careful deliberation, and in doing so, consideration should be given to the following points:

- The anticipated differences in effect;
- The criterion to be applied;
- Uniformity of the infestation and the soil; and
- Density of infestation.

A general idea of whether the anticipated differences in effect will be large or small will usually be given by laboratory experiments or exploratory field tests. The smaller the expected differences the greater will have to be the chosen number of replications: inversely when the differences are larger the number of replications can be proportionally smaller, irrespective of whether the yield or the effectiveness is taken as the criterion.

When the yield is exclusively used as the criterion, the variability of the crop on which the test is carried out will continue to determine the number of replications because, as proved, each crop differs in its reaction to changes in the fertility of the soil and in injury, e.g. Fusarium wilt of tomato in Guyana is influenced largely by environmental factors, hot, dry soil temperature; Late Blight of tomato is likewise influenced by cool, wet days and so on.

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Uniformity of the infestation and the soil likewise determines the number of replications, in fact to such an extent that this number may be all the smaller the more uniform the conditions.

Finally, the density of infestation also has a bearing upon the number of replications to be carried out. The weaker the infestation the greater this number must be, so that sampling can be made from a sufficiently large number of measurable entities, at the same time maintaining the random sampling. The question of the number of replications to be carried out shows that the practical possibilities, in the end, have a decisive influence upon this. Under very favourable conditions, three replications will do. Generally, four to five plots are sufficient. Should it be required to determine fine differences, as many as six to eight replications will be needed. It is only in exceptional cases that it will be possible, and necessary, to exceed this number.

Siting of plots

The modern test methods have been developed by R.A. Fischer and his school. These have now replaced the old methods. Several basic features are peculiar to all these plans. The plots are distributed at random within a block. In order to allow well-balanced influences to act on the different test plots, the blocks are replicated. In this it is assumed, with proven justification, that the probability of the same influences (disease infestation, growing conditions) acting on the different test plots is all the greater, the larger the number of replications carried out, because similar conditions repeatedly occur in the vicinity of the block. In the test field the blocks can be distributed at random in any of the experimental designs: Randomised Complete Block, Latin Square, Factorial Block, Factorial Plot in Latin Square, Factorial Plot in Latin Rectangle, and Split Plot and its derivatives.

Concentration levels

The effectiveness of new pesticides can, in principle, be

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assessed from the following two aspects:

1) Does a compound satisfy a minimum requirement, i.e. has it a potency equal to that of the average product recommended for this use?

2) Does the compound represent a genuine technical advance, i.e. is its performance better than that of the known active ingredients, in the sense that it has larger reserves of activity for exacting requirements?

As far as possible the experiments should aim at providing answers to both questions. To achieve this objective a method is available that is just as simple as it is dependable - the new active ingredient and the comparison substance are tested at different concentrations and dosages. A reliable practice is to test not only the dosage considered necessary for effective treatments, but also to test a half and a quarter of that dosage level in relation to the corresponding dosages of the standard products. This procedure can be regarded as a useful supplement to the replications. The results obtained will provide information on the potency of a compound and especially on its reserves which are an important property of all substances required to produce a residual action, e.g. protective fungicides and systemic insecticides, etc.

Failures

Failures have an influence upon the test result especially when the yield is selected as the criterion for the effectiveness of a compound. They make it necessary to correct the plot yields. For this purpose, several suggestions have been put forward. As the plants adjoining the failures produce yields above average because they grow in more favourable conditions, they should be removed before the harvest and the yields should be corrected with respect to the normal plants. Although this procedure is one of much controversy, it is nevertheless satisfactory for practical purposes. In agricultural research, it is adjudged possible for the covariant analysis to be corrected exactly.

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In crop protection research, cases in which plants are not attacked must be regarded as failures. The same applies, for example, when a fruit tree produces no fruit or if it loses the fruit prematurely so that no evaluations can be carried out as in studies on the effect of compounds used for controlling anthracnose in mango. When the effectiveness is taken as the criterion, the absence of objects on which the evaluation should have been made will, therefore, generally be regarded as a failure. Such failures can only be prevented by choosing sufficiently large dimensions for the plots. When the density of infestation is below a level whereby it is not possible to carry out at least 30 measurements, the result obtained will have to be regarded as much too fortuitous. Such results cannot be used to draw meaningful conclusions.

Preparation of the test area

Once careful studies have shown that a selected test area is suitabl for its required purpose, it should be ensured when planning the test that all important test conditions are as uniform as possible. Fertilization and cultural practices including pruning of fruit trees should be carried out at the same time and in the same manner in order to avoid plants being brought to a state of abnormal predisposition.

Spraying and dusting

In order to conduct tests quickly and faultlessly, it is essential that all tasks are carefully prepared and carried out exactly. The possibility of errors being made commences when the compounds are weighed and measured out. The quantities of compound stipulated for the different plots must be weighed out exactly. To avoid errors at this stage, the prepared quantities should be rechecked to ensure that they are correct.

In addition to having the required equipment and machines, these should be checked beforehand to make sure that they operate satisfactorily, and tools to make quick repairs and remedy minor faults such as clogged sprayer nozzles, etc., should be procured. Provision must be made for

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adequate supplies of water to be available in the test field. Facilities must also be provided for all personnel to wash themselves.

As a rule, sprays are first mixed with a little water. Once this has been done, a few litres of water are poured into the sprayer tank. Afterwards, the stock solution is poured in through a strainer, and the bulk of water is then added. Any remaining stock solution adhering to the vessel in which the spray is first mixed should be rinsed out with water and emptied into the sprayer tank. The diluted spray must be thoroughly stirred in the tank.

The next task is to distribute the preparation evenly in the plots and the efficiency with which it can be done depends largely upon the weather. Wind, sunshine, rain and relative humidity are all factors which have a bearing upon the distribution of active ingredients.

CONDITIONS GOVERNING THE TOXIC ACTION AND THE SIDE EFFECTS OF PESTICIDES

Among the phenomena associated with the actual test problem there are two combinations of factors that must be given special attention and carefully registered:

- The conditions governing the toxic action; and
- The side effects.

Conditions governing the toxic action of pesticides

The conditions governing the toxic action are the disposition of the organism and its stage-specific susceptibility, the environmental conditions, the time, the growth of the plants and the physical properties of the compound.

An analysis of the infestation symptoms, in which it is of great importance to determine the disposition of the population to poisons, should be made before the test is carried out in the case of therapeutic measures, and by observing the untreated check in the case of prophylactic measures.

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Reference has already been made to the importance of the weather conditions with respect to the application, even distribution and effect of sprays and dusts. Furthermore, they have a decisive bearing upon the reliability of the results. The weather conditions constitute an influential factor from two aspects, in that on the one hand, they determine the disposition of the causative agent and the plant host, and on the other hand, they influence the pesticidal potency of the compound. Heavy rainfall and wind reduce, to a lesser or greater degree, the action of the active ingredient by washing off or blowing away the deposits, whereby the extent of this reduction is largely determined by the quality of the physical properties of the compound. The exact determination of these properties of the compounds constitutes an important part of the field trial.

Detailed studies have revealed that the rubbing together of leaves and fruits and the brushing effect they produce on touching each other has a great bearing upon the decrease in the amount of active ingredient originally deposited on these parts, and that these effects (rubbing and brushing) often attach greater importance than rainfall.

The growth vigour of the plants as a factor influencing the effectiveness of pesticides is completely disregarded or else underrated. Full allowance must be given to the growth vigour of plants in fixing the intervals at which sprays are to be applied and in the interpretation of the results. An exact record must be kept of the state of the plants when the test commences and while it is being conducted.

Side effects

In order to make an assessment of the practical value of a pesticide, it is not enough simply to have a knowledge of the effectiveness and the conditions under which it is attained. On the contrary, it is also of the utmost importance to know the so-called side effects which are inseparably linked with the application of the compound. Side effects are understood to mean all effects which occur in addition to the actual purpose for which the compound is used, namely to afford the plants protection by killing the pests

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or disease agents, or expressed generally, by destroying the relation between parasite and host. As a rule, side effects are unintentional effects exerted on the pest/disease agent, the plant, other animals and human beings. They may be desirable, insignificant or harmful. Their exact registration is an essential part of the test evaluation.

Side effects on the pest

One hundred percent mortality of disease pathogens is very seldom obtained in field tests. The reasons for this may be of a technical nature associated with the methods of application or they may be due to the fact that the applied dosages were too low so that the most resistant members of the population were not killed. It is therefore of importance to establish which cause is responsible for the failure to obtain a 100% control or, in other words, for the survival of certain individuals. The development of resistant strains may be directly connected with this cause. Such development of resistance constitutes a phenomenon long since observed among numerous species.

An exact analysis of the infestation aspect may provide valuable indications as to whether the effectiveness of a compound is generally inadequate or whether, due to shortcomings in the spraying or dusting technique, it was only a case of insufficient quantities of the compound having been deposited in some parts of the crops, for it not to be effective enough. Generally, it may be assumed that the effect of the compound in the applied dosage is inadequate when disease-causing agents (fungi, bacteria, nematodes, etc.) and pests which have survived the control are to be found evenly distributed throughout the plot, in other words, when the conclusion is justified that mortality has not been caused despite contact between organism and poison. If, on the other hand, surviving disease agents are only to be found in small, isolated areas alongside which are large areas where effectiveness is adequate, then it can be concluded that the compound was not spread properly.

An exact description of the infestation aspect following application of the pesticide will provide valuable explanations of the effectiveness.

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Side effects on the plant

The growth of plants and the appearance of harvest produce, e.g. the finish of fruits, may be harmed or improved by the action of chemical pesticides. A positive influence is exerted when the productivity of the plants is increased, stimulation of growth is caused or when the chemical acts as a nutrient, such as described, for example, carbon disulphide and in several organophosphates. Such positive influence is manifested by a better growth of the plants. These side effects on the plant and the harvest produce attach still added significance as soon as major improvements of the pesticidal action cease to be attainable.

It is most important to keep an exact record of plant injuries caused by new active ingredients. Compounds not tolerated by plants are generally useless for crop protection.

Plant injuries may appear in different forms. One speaks of burns when tissue parts of leaves and shoots are killed (necrosis); they are identifiable as spots, discolourations and withering. The severity of the injuries is expressed in ratings (0 to 5). They may be species - specific or variety - specific, according to intensity and manifestation. Injuries do not always appear in the form of necrosis; they are also manifested by abnormal growth or poor formation of chlorophyll. The symptoms are then usually characteristic. They must be described exactly, and importance should be attached to recording details of the nature and extent of the injuries and their effect on yield.

Side effects on human beings and animals

Although it is not the duty of the phytopathologist but the task of a toxicologist to determine the effect of chemical pesticides on animals and especially on human beings, experience and information gained while carrying out the experiment may nevertheless prove to be of valuable assistance to the toxicologist. It must, however, be emphasized that the reproduction of such observations must be precise and to the point, and any views of a misleading

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and speculative nature must be avoided.

Investigators should make it a strict principle to obtain full details on the toxicity of the compound being tested before starting a field trial, in order to be able to take corresponding precautionary measures, and to inform physicians about the compound so that they will know what action to take if called upon to diagnose and treat cases of poisoning. After all, the investigator shoulders full responsibility for the consequences arising out of carelessness and negligence.

METHODS FOR FIXING THE DATE OF THE TRIAL

The time factor has very great bearing upon the reliability of results obtained in crop protection trials. Variations in results obtained with fungicides, nematocides and insecticides as well, are often due to the treatments being carried out at different times. A test conducted at the wrong time may nevertheless produce very accurate results but they will not be reliable. For this reason, the correct timing of a treatment is of fundamental importance.

Generally, the most favourable time for applying a pesticide is governed by the so-called "weak spot" in the life cycle of a pest or a pest population. The "weak spot" is understood to mean that stage in the development of a pest when it offers th least resistance to controls. It is not a stnading factor but is causally related to the behaviour of the parasite on the one hand, and to the stage specificity of the compound on the other hand. Very often narrow limits are set for the time when a test may be carried out, i.e. a control only gives the best possible effect when carried out within a definite period of time. It is essential that this period is established early and accurately by using certain methods. One such system applied today on a large scale is the so-called warning service, an organisation set up to forecast and warn growers of imminent outbreaks of plant diseases.

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These methods are based on:

- Results of biological research, namely
  - the knowledge of the biology of the causal organisms of plant disease;
  - the influence of environmental factors on the development of the disease pathogens; and
  - the susceptibility of plants in their different stages of growth to disease pathogens;
- Observation of disease occurrence by
  - establishing the first occurrence of disease;
  - establishing the main occurrence of disease; and
  - checking and determining the critical severity of disease;
- Comparisons and relations to other natural processes by
  - determining certain meteorological conditions; and
  - observing phenological occurrences.

The methods are, of course, only useful provided the values they give are representative of the test field.

Examination of plants for disease incidence

Regular examination of plants for disease incidence is a reliable method for fixing the dates of control. In fact, this method is employed with success for a number of plant diseases. The aim of this practice is to fix the date of control according to either a nimimum disease incidence (critical value) or the main occurrence of the disease-causing agents. The general procedure adopted is to plot the values obtained from the examination of the plant in a co-ordinate scheme with the time factor entered in the abscissa of the graphs and the disease incidence on the ordinate.

Late Blight of potatoes has well been studied and, based on meteorological data, the giving of warnings to farmers on late blight incidence is being done worldwide.

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METHODS FOR EVALUATING THE TRIAL

The problem involved in the evaluation of the trial is to collect material which will permit the effectiveness of a treatment or compound to be calculated accurately and reliably. To solve this problem allowance must be made for the following points:

- The choice of the right criterion for estimating the effect of a compound;
- The application of this criterion at the right time; and
- The availability of an adequate number of samples evaluated by this criterion.

The choice of a criterion which will allow the effect of a compound to be reliably estimated is of decisive importance for the success of an evaluation. Investigators will have to decide from case to case, on the grounds of careful studies, which criterion is the most suitable for the particular problem being investigated. It must also be taken into consideration whether the chosen criterion can be applied on a sufficiently broad basis. But, just as we established with respect to the timing of treatments, it will also be found here that an evaluation utilizing several methods, the values of which are critically compared, will permit the most reliable conclusions to be drawn.

The application of the suitable criterion at the right time is just as important as the choice of this criterion. The date of the test evaluation will depend, on the one hand, upon the properties of the test compound, especially its rapidity of action, and its residual action and on the other hand, upon the time when the criterion is most apparent and can best be registered. An evaluation carried out too early, just like one made too late, may produce very accurate values which are however not reliable in the technical sense.

Samples are taken and a certain number of plants or parts of plants

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are examined by the valid criterion. The problem of this procedure lies in taking samples for evaluation which will be representative of the effect of the compound in the whole plot. The reliability of a result given by a single sample is very slight. Generally, the reliability and accuracy of test results increase proportionally to the number of evaluated samples. The technique of sampling is also most important. It is by no means immaterial where and how sampling is done, especially when the spread of disease infestation and the distribution of the compound in the test are are not uniform. It is therefore essential that samples are taken which represent the average of the plots. Consequently, the more parts of a plot that are sampled, the greater will be the measure of success. Furthermore, all infested plant parts should be taken into account because the efficiency of a compound may vary from one part of a plant to another.

It is essential that the samples are taken at random. But on the other hand, it must be remembered that only similar plant parts may be compare with each other.

For technical reasons, it is desirable to evaluate as few samples as possible, which is quite understandable. The question thus arises: "What is the minimum number of samples that must be taken for the evaluation of a test?" Very many studies have been conducted to investigate this question, but so far it has not been possible to specify a number that has general validity. In principle, however, it may be said that this number can be reduced in proportion to the uniformity and density of the infestation and distribution of the compound.

The methods for evaluating the test can be divided into two groups according to whether the disease pathogen or insect pest or the disease aspect is taken as the basis:

- Determination of the number of living and/or dead pests; and
- Determination of the number of infested plants or parts of plants.

Occasionally the yield is also used as a criterion, but only as a supplement to the data on disease evaluation.

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EXAMINATION OF PLANTS FOR DISEASE INFESTATION

Determining severity and density of infestations and infections

The injury caused to the plant is always used as the criterion for evaluating plant tolerance tests. It is sometimes also used in insecticidal tests, and frequently in fungicidal and nematocidal tests. It must, however, be considered that the disease symptoms need not be specific so that it cannot be unconditionally concluded from the injury that it has been inflicted by a particular pathogen or by the action of a compound unless proved beyond all doubt.

Nevertheless, it is possible in the case of a number of fungal diseases to conclude with reasonable certainty from the nature of the injury which causal organism is responsible for the damage. Side effects of pesticides may be manifested in many different ways so that their cause is often difficult to interpret. When the injury is used as the criterion for estimating the effect of a compound it is always decisively important to have an exact knowledge of the symptoms if the results are to be reliable. The special advantage of this criterion lies in the fact that it permits conclusions to be drawn, within limits, regarding the economic importance of a pest.

In addition to counting methods, estimation methods are usually chiefly employed in evaluations by the injury criterion. These estimations are based on ratings usually divided into five or six classifications either according to the severity of infestation or according to the effectiveness A few examples are given below.

Late Blight of potatoes (Phytophthora infestans)

The following ratings for estimating incidence of Late Blight in the field:

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Late Blight in %

0.0	No Late Blight;
0.1	Odd plants infected; up to 1 or 2 spots in an area with a radius of 10 m;
1.0	Up to 10 spots per plant, or evenly distributed, slight incidence of spots;
5.0	Approximately 50 spots per plant, or one spot on about every tenth leaf;
25.0	Lesions on practically every leaf, but plants still growing normally. Field smells of Late Blight but still appears green although each plant is infected;
50.0	Each plant infected and approximately half of leaf green destroyed;
75.0	Approximately 75% of leaf green destroyed. Field appears neither predominantly green nor brown; and
95.0	Very few green leaves; stalks still green.

Root knot nematodes (Meloidogyne spp.)

The following ratings have proved to be useful for evaluating trial controls of root knot nematodes:

0 = No roots infested;
1 = Root with a few small galls;
2 = Root with many small galls;
3 = Root with a few large galls;
4 = Root with many large galls; and
5 = Root with knotted growth.

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Soil fungi (*Fusarium*, *Rhizoctonia*)

Recommended ratings:

0 = Plant not infected;
1 = Plant showing slight injury;
2 = Plant showing moderate injury; and
3 = Plant completely withered.

Powell *et al* (1971) introduced the following classification system for rating root necrosis:

0 = No necrosis;
1 = Less than 10% of root system necrotic;
2 = 11-25% necrotic;
3 = 26-50% necrotic;
4 = 51-75% necrotic; and
5 = 76-100% necrotic.

Each root system is assigned one of the classes, and a disease index for each treatment is calculated using the following formula:

$$\text{Disease index} = \frac{\boxed{\begin{array}{l}\text{No. of plants}\\ \text{in Class 1X1}\end{array}} + \boxed{\begin{array}{l}\text{No. of plants}\\ \text{in Class 2X2}\end{array}} + \dots \boxed{\begin{array}{l}\text{No. of plants}\\ \text{in Class 5X5}\end{array}}}{\text{Total no. of plants in treatment X5}} \times 100$$

This disease index is used in data presentation to describe relative necrosis development in the various treatments. Data are subjected to statistical analysis.

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CONDUCTING EXPERIMENTS: SOME SPECIFIC APPLICATIONS:

- PEST CONTROL

by

A.K. Sinha

INTRODUCTION

More than one million species of insects have been described, and it is estimated that insects constitute 75% of all the species in the animal kingdom (Borror et al, 1976). Fortunately, only a small percentage of these are agricultural pests. Despite this, the farmer is faced with insect pests on every crop he grows. The extent of damage varies from year to year, and from one crop to another. In most instances, the most practical way to combat pest species is through discretionary use of insecticides.

All insecticides are toxicant to a greater or lesser extent. There are, however, wide variations in organisms in terms of their susceptibility to a given insecticide, and it is these differences in susceptibility that determine the role a product plays in our economy. Thus an insecticide is said to be "selective" in toxicity if it is highly toxic to only a few related organisms or "broad spectrum" in toxicity if it has high toxicity to a wide range of organisms.

The test of any plant protection chemical is its performance under practical conditions, and field trial is the ultimate criterion. Comparisons by the method of field trial are expensive, laborious and lengthy. It is expensive because of the need to provide adequate biological materials, laborious, because of the work involved in obtaining quantitative results, lengthy, because repetition is necessary to obtain a sufficient variation in environmental factors to justify a generalization applicable to average conditions. The influence of one or more of the variable factors is eliminated and, by the combination of the results of a series of trials in which different variables have been held constant, an attempt is made to synthesize which will hold good under field conditions. This analytical procedure is the principle of the method of laboratory trial.

In this paper the principles and methods used in laboratory and field screening techniques will be outlined and illustrated by a few selected examples.

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It often happens that an insecticide must be selected for use against a particular pest. In these circumstances, the important question is the ultimate efficacy in the field under conditions where results will depend, not only on the inherent toxicity of a substance, but on its chemical and physical stability, its solubility and physical state. In choosing a test method, physical factors affecting field results should be considered. From such laboratory tests, the next step is the small field trial and finally the best criterion is a full scale field trial. As stated earlier, field trials are expensive, slow, etc., therefore they should be reserved until laboratory tests have narrowed the choice down to three to five chemicals.

LABORATORY SCREENING TECHNIQUES

A great deal of research on insecticides involves either comparisons of the potency of different compounds or comparisons of the susceptibility of different species of insects. In either case the most useful method of comparison is on the basis of equitoxic doses. As Finney (1963) points out, there are three general ways of assaying poisons to find these critical doses:

i) by direct assay; or by indirect assay, based on
ii) quantitative response, or
iii) quantal response.

<u>Direct assay</u> involves measuring the exact doses necessary to kill individual animals. This generally involves the gradual increase in dose up to the critical point.

<u>Indirect assay</u> involves giving standard doses to batches of individuals and recording the responses obtained.

Tests based on <u>quantitative response</u> require the effects of the various standard doses to be reflected in continuous change, e.g. the magnitude of some property of the subject, such as its survival time. Technical

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difficulties in the exact determination of survival times, however, limit the usefulness of this method of testing insecticides.

In tests based on quantal response, the data required are the proportions of each batch reacting in particular ways. Although the statistical treatment of the data approximates to that with the quantitative reaction, the quantal response conception is logically more closely allied to direct assay. Indeed, the object of the method is to estimate the magnitude of the dose which is just sufficient to produce death (or a particular level of intoxication) within a given proportion of a population of insects. Comparisons may then be made on the basis of this critical dose.

For statistical reasons, it is easiest to estimate the medium (50%) response level of a population rather than the most susceptible or tolerant.

Selection of test insects

Basically, it is necessary to expose batches of insects to a range of doses of poison. The insects chosen for testing should be as homogeneous as possible; in other words, they should be standardised to exclude variations in resistance due to age, stage, sex, condition of nutrition, etc.

Having restricted the choice to standard individuals, as far as possible, it is necessary to decide on the numbers required for each batch. This will be governed largely by practical considerations. The larger the number per batch, the greater is the accuracy in the test; but there is generally little advantage in exceeding 30 to 50 per batch, unless the population is very heterogeneous. With precise experimental conditions and using insects that are difficult to rear, batches as small as fifteen or twenty individuals may be used. It is seldom worth testing numbers lower than these and even with such figures it is very desirable to repeat the test when more insects become available.

In allocating insects to batches, apportion them in such a way that the insects selected are randomised among the batches. If done

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otherwise, the insects chosen first (or from a single culture) may all occur in the same batch and if their susceptibility is slightly abnormal, it will bias the dose/mortality relationship.

Selection of Insecticides

The insecticides obtained may be technically pure material or a commercial formulation.

In selecting the doses or concentrations for testing, it is desirable to space them as evenly as possible over the mortality range. Since toxic effect is more conveniently related to the logarithm of the dose than to the dose itself, the doses chosen should be in a geometric series, as:

- 1, 2, 4, 8; or
- 1, 3, 9, 27.

There are many advantages of this technique. These include:

- the high degree of precision and replicability which can be attained;
- the large number of tests which can be made in a relatively short time;
- the small number of insects, say 10-20 required per replication for relatively uniform results;
- the very small amounts of chemicals required for testing; and
- the fact that LD 50 values obtained for any species are reasonably constant and reproducible from laboratory to laboratory providing identical conditions are observed.

The successful utilisation of this technique is absolutely dependent on a means of accurately and rapidly producing small droplets of fluid ranging in volume from 0.1 to 10 microlitres with a precision of the order of five percent.

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The choice of a solvent for the toxicant to be administered depends on the route of administration, i.e. topical, oral or injection, and on the properties of the material to be dissolved. Most topical and injection studies have been made using acetone or ethyl alcohol, or kerosene.

Suitable anatomical sites for topical application or injection are dependent on the insect species, its size and its life stage. Most topical applications are made on relatively broad, flat areas such as the dorsum of the prothorax, the sternum between the legs, or the abdominal segments in the case of immature stages.

The topical application method has been widely used and also recommended by FAO for measurement of pest resistance to pesticides for Plutella xylostella larvae, chilo suppressalis larvae, spodoptera littoralis larvae (Busvine, 1980), for Cosmopolites sordidus adults (Swaine and Corcoran, 1973).

Exposure to treated surface

The so-called "residual" contact insecticides normally act by contaminating insects which crawl over deposits on various surfaces, e.g. vegetations or materials. Naturally, therefore, in many experiments intended to study the performance of such insecticides, batches of insects are confined on prepared residues, for varying periods. Superficially, the method seems to be an easy way of dosing insects, so that it has frequently been used for bioassay work and for screening tests to evaluate chemicals as possible insecticides and even test for insecticide resistance.

Investigations of insecticide films are generally of two types:

- experiments concerned with the performance in the field, therefore demanding some approximation to practical conditions; and
- experiments using rather artificial media, either for simplicity or precision.

For experiments of the first type, residues are sometimes produced by

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dipping, spraying or painting the substrate. Residues for the second type of test are often prepared by application using a pipette or Potter Tower or atomiser.

Dipping

In a considerable number of investigations of residues on plants the insecticide is simply applied by dipping either the whole plant or part of it in a formulation of the type to be used in practice.

Spraying

Probably the majority of investigations concerned with performance of residues in practice involve application of insecticides by spraying. The spraying apparatus to be used is the Potter Tower or atomiser.

Sometimes in a test, the insects are restricted to part of one surface of a single leaf. This is done by confining the insects in a glass ring, or in various types of plastic cells or cages. These methods have been used with mites, aphids and beetles.

The method of exposing insects to sprayed leaves in cages can be used to assess residual potency of foliage of plants weathered, in the field.

A test, similar in principle, has been used for this purpose with flea beetle on egg plant, sweet potato weevil on sweet potato.

Tests with artificial substrates

Several workers have employed a simple method of applying residual insecticides, by dissolving them in a volatile solvent (usually acetone) and spreading a measured quantity, as evenly as possible, over a test surface. The glass vessels treated ranged from petri dishes to conical flasks.

Volatile solvents may also be applied to treat paper. Thus.

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FIG. 1

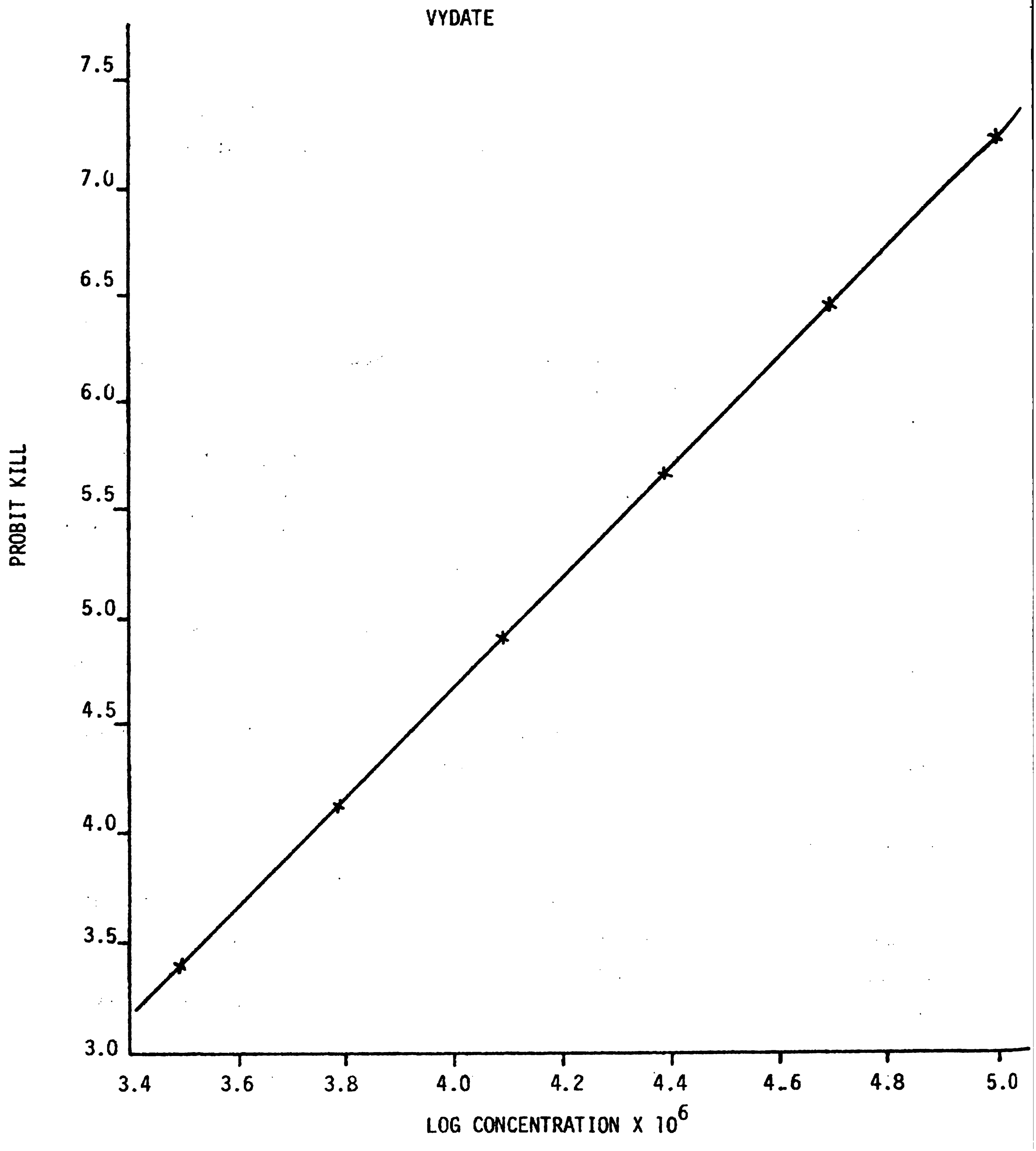
VYDATE
PROBIT KILL
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
3.4
3.6
3.8
4.0
4.2
4.4
4.6
4.8
5.0
LOG CONCENTRATION X 10^6

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TABLE 1: EXAMPLE OF CALCULATING PROBIT AND LD 50

Insect: Banana Root Weevil (Cosmopolites Sordidus) **Insecticide:** Vydate

Concn % (L)	Log. Concn (X)	No. of Insect Tested (n)	No. of Insect Killed (r)	% Kill (P)	Empirical Probit (From Table) ∝	Expected Probit (From Graph)	nw	Working Probit (From Table)	nwx	nwx^2	nwy	nwy^2	nwxy
0.1	5.000	30	30	100.00		7.40	1.850	7.786	9.25	46.25	14.367	111.575	71.836
0.05	4.699	29	28	96.55	6.825	6.40	8.756	6.739	41.144	193.338	59.007	397.646	277.289
0.025	4.398	30	19	63.33	5.340	5.61	15.948	5.290	70.139	308.473	84.365	446.290	371.035
0.0125	4.097	30	13	43.33	4.832	4.90	19.029	4.824	77.962	319.409	91.796	442.823	376.089
0.00625	3.796	29	5	17.24	4.054	4.20	15.416	4.070	58.519	222.139	62.743	255.364	238.172
0.00312	3.494	30	2	6.67	3.501	3.40	7.126	3.537	24.898	86.994	25.205	89.149	88.064
Control		30	0	0.00									
							68.125		281.912	1176.603	337.483	1742.847	1422.465

$b = \frac{Sxy}{Sxx} = 2.58897 \quad b^2 = 6.70276$

$1/b^2 = 0.14919$

$y = \bar{y} + b\,(x - \bar{x}) = 4.95388 + 2.58897\,(X - 4.13816)$

$= 4.95388 + 2.58897X - 10.71357 = 2.58897X - 5.75969$

$m = \bar{x} \pm 5 - \bar{y}$

Log LC50 = 4.15597

Anti Log LC50 = 14320.89

LC50 = 0.014

Place the following in place of Y in the equation:

5.0000	----	LD50	LC50
6.2816	----	LD90	LC90
7.3263	----	LD99	LC99
8.0902	----	LD99.9	LC99.9
8.7190	----	LD99.99	LC99.99

$$V(m) = \frac{1}{(b)}2\left[\left(\frac{1}{Snw}\right) + \frac{(m - \bar{x})^2}{Sxx}\right]$$

$$= 0.14919\left[0.01468 + \frac{(4.15597 - 4.13816)^2}{10.0067}\right]$$

$$= 0.14919\,(0.01468 + 0.000316) = 0.00219$$

$$\text{St. error } m = \sqrt{V(m)} = \pm 0.046$$

If value is less than unity.

$1/Snw = 0.01468 \quad \bar{x} = \frac{Snwx}{Snw} = 4.13816 \quad \bar{y} = \frac{Snwy}{Snw} = 4.95388$

$Sxx = \left(\frac{Snwx}{Snw}\right)^2$

$= 1176.603 - \frac{(281.912)^2}{68.125}$

$= 1176.603 - 1166.5963$

$Sxx = 10.0067$

$Sxy = Snwy - \frac{Snwx \times Snwy}{Snw}$

$= 1422.465 - 1396.5579$

$Sxy = 25.9071$

$Syy = Snwy^2 - \left(\frac{Snwy}{Snw}\right)^2$

$= 1742.847 - \frac{(337.483)^2}{68.125}$

$= 1742.847 - 1671.8498$

$Syy = 70.9972$

$(Sxy)^2/Sxx = 67.0728$

$X^2 \text{ (calculated)} = Syy - \left(\frac{Sxy}{Sxx}\right)^2$

$= 70.9972 - 67.0728$

$= 3.9244$

X^2 (tabulated) at d.f. 4 = 9.6

If calculated value of X^2 is less than tabulated value at d.f. 0.05%, the data is homozygous regression.

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Admixture to food

Insecticides can be mixed with the food material which serves the purpose of attracting the insects to accepting the food material along with the poison (baits). Various types of poisoned baits have been used, e.g. grasshopper baits, cockroach baits, housefly baits and various ant baits. Ant baits are generally tested in the field by using the single mound/nest method.

Statistical evaluation

Insects treated with different amounts of poison may exhibit various degrees of intoxication, ranging from trivial temporary effects to complete prostration and death. Since insecticides are intended for killing insects, the response usually chosen is death.

Within a population there is a variation of susceptibility towards a poison. Different concentrations result in different mortalities. A percentage calculation is often sufficient. A useful transformation of the percentage is the so-called Probit transformation.

The use of Probit/log. dosage transformation

The use of probits and log. doses to obtain estimates of critical dosage levels and their limits of accuracy can be done in several ways to different degrees of precision. These are the:

i) simple graphical method;
ii) standard method of computation; and
iii) possibility of using a computer programme.

Graphical method

For some experiments, the critical doses or susceptibility can be estimated with sufficient accuracy from a probit/log-concentration

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filter paper may be treated by applying a small volume, spirally, using a pipette.

It is difficult to ensure that dry residues from volatile solvents are uniform and repeatable. Therefore, some workers have used them to deposit films of non-volatile oil or water.

Treatment of soils

Various contact insecticides have been applied to soil to kill pests living in it, such as wireworms, crickets and cutworms.

In a few investigations, the insecticides were applied to soil samples in the form used in practice, generally dilute emulsions or suspensions. Moderately large soil samples were used in trays, about 45 to 60 cm^2 or boxes 22 x 10 cm. Generally, samples of various types of soil are dried (at about 50 ^{o}C), treated with insecticide, and thoroughly stirred. Small quantities are then transferred to waxed paper cups, small glass jars, tins, clay pots or petri dishes.

Harris and Svec (1968) put batches of twenty half-grown cutworms into their soil trays and made mortality counts after forty-eight hours.

First instar nymphs of cricket are kept in treated soil waxed cups for twenty hours at 25 ^{o}C.

Test using Banana root weevil

Soil from an unsprayed area is slightly moistened and then placed in 2 kg specimen jars at a depth of 5 cm. In test, insecticides are applied to the soil surface only in each jar by means of a fine pipette at a rate of 1 ml/4700 mm^2 = 500 ml stool of radius one metre. One adult weevil is placed in each jar together with a large chunk of fresh banana/plantain pseudostem as food. Mortality is recorded on specified days after treatment. The criterion of death is inability to fully extend and flex all six legs.

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graph. The two transformed variables are plotted on plain paper, or the original data (percentage kill and dose) can be plotted on logarithmic probability paper. A straight line is fitted by eye and critical doses determined by inspection. Values determined graphically are often remarkably close to calculated results but they give no precise information on limits of accuracy.

Calculation of the regression line relating probits and log. dose (Probit Analysis)

The method of analysis of quantal response data has been thoroughly discussed in the book on probit analysis by Finney (1971). The various steps in the computations are as follows: (See Table 1)

1. In the column headed L, enter, in suitable units, the doses tested, arranging them in descending order from the highest to the control or zero concentration;
2. In the column headed x, enter the logarithms of L, to base 10, correct to two decimal places;
3. In the columns headed n and r, enter for each dose the number of insects tested and the number badly affected, moribund, or dead;
4. Calculate the percentage kill, $p^1 = 100\ r/n$, to the nearest whole number. If n exceeds 200 for many of the doses, give the percentages to one decimal place;
5. Correction for control mortality: It happens quite often that a proportion of insects die during an experiment from natural causes or from causes not connected with the insecticide used. The magnitude of this mortality may be estimated from "control" batches, treated in exactly the same way as the test insects except for the exposure to toxicant. This "control mortality", if it is appreciable, will affect the

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precision of the results and a correction is usually applied in the following form:

$$Pt = \frac{Po - Pc}{100 - Pc} \times 100, \text{ where}$$

- Pt = corrected mortality;
- Po = observed mortality; and
- Pc = control mortality;

and all are percentages. This is commonly known as Abbott's formula;

6. Enter the empirical probits of p in the "empirical probit" column corresponding to the corrected percentage kill (Table I, in Finney, 1971);
7. Plot the empirical probits against x (on graph); draw a provisional straight line to fit the points, placing the line by eye (Fig. 1);
8. For each of the dosages used in the experiment read the value of the ordinate to the provisional line. These are the expected probits, Y, correct to one decimal place;
9. Read the weighting coefficient for each Y (Table II, in Finney, 1971), multiply by the corresponding n, and enter to one place of decimals in the column nw;
10. Enter the working probit, Y, corresponding to each p (not p^1) and Y (Table IV, in Finney, 1971); and
11. Multiply nw by the corresponding x and enter the product in the column nwx. Multiply nw by y and enter the product in the column nwy.

Follow further calculations as done on the solved problem (Table I).

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FIELD SCREENING TECHNIQUES

Comparative field trials are a vital component of agricultural progress. It is certain that no new plant variety, agronomic technique or plant protection product will take its place in agriculture without first having to pass through a series of comparative trials. Whilst scientists and technicians all over the world are involved in this struggle to make progress, their methods and successes still vary greatly and depend on experience, training and luck.

Any problem can be successfully solved only if each step is carried through in conformity with the problem and without error. In order to achieve this aim as rationally as possible, trials should be planned beforehand. The objective of the trial determines this work, since the planning and evaluation of trials consist not only in setting up and fulfilling statistical rules but rather in the statement of problems in the form of precise questions and finding of precise answers to these questions.

Plot Size

Plot size can be defined in different ways. A plot may be defined as a number of trees, plants per square metre, etc. Plot size should be such that:

- the spray drift does not affect neighbouring plots;
- the plant/pest material to enable sampling and assessments according to the objective; and
- the pest population is not able to move to neighbouring plots within the period between application and assessment.

In most trials the untreated control plots are bordered by treated plots on at least two sides and more commonly on three or four sides. In these trials the movement of mobile pests, into and out of the control plots, may be restricted by the sprayed plots. This may lead to heavier or lighter pest attack in the control plots than would occur in isolated untreated

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control plots.

When all plants are untreated, the infestation is relatively uniform. When an untreated plot is surrounded by treated plots, the insects may migrate from the untreated plot and be killed. Therefore infestation in the untreated plot will be estimated at lower than is actually the case. On the other hand, the insects may be repelled by the treated plot and migrate to the untreated plot, thus producing an artificially high infestation in the untreated plot.

Such influences caused by treated plots may be reduced by enlarging the plot size and assessing only the central area of the plot. For crop protection field tests, the minimum plot size is generally between 25 m^2 and 100 m^2.

Number of replications

Accuracy of results can be improved by increasing the number of replications. But on the other hand, there is a limit to the number of replications because increasing the number beyond a certain level does not necessarily lead to further accuracy.

It is not possible to give a general valid minimum number of replications. When planning the test, the number of replications required should be decided from one test to another after viewing the type of crop, type of pest and its population.

Application

Methods of Application

The methods of application vary according to the stage of development of the product type and damaging stage of pest, location of pest on crop and crop itself. In the early stage trials use equipment specially designed to evenly distribute the insecticide where the insect is found.

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In later stage trials use commercial equipment or apparatus specially designed for use on a smaller scale but which has similar performance.

Time of application

Timing should be related to the economic thresholds for infestation and damage.

In early stage trials use arbitrary timing, chosen on the basis of previous experience with products having similar chemistry and standard products. In later stage trials use the experience gained earlier with the new product, in particular, its duration of effect, to establish the most favourable time of application in terms of yield and quality improvement.

Data collection

The right data represent the true situation in each plot. The response criteria are defined in the objectives and are valid for the data collection. If, for example, the response criteria are defined as percentage infestation, it is not the damage but the infestation which should be measured. Moreover it is often necessary to determine the location where the response criteria are to be measured (e.g. on the upper part of plants, on the underside of leaves, etc.). The timing of the evaluation is dependent upon whether an initial or a residual effect is to be measured (e.g. 5 days after application; 50 days after sowing, etc.). The main response criteria in plant protection trials are degree of infestation, damage level and yield.

Sampling

The data are usually collected from samples. In insecticide trials the choice of the most suitable sampling method will depend on:

- the conditions of the insect and plants;
- knowledge of their biology; and
- previous experience with sampling in a similar situation.

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In order to establish the type, extent and frequency of sampling, we must know the time and site of the appearance of the pests and have some idea about the further development of natural population, especially its duration.

Since during their various development states, insects often give preference to certain locations, not all parts of the plant have the same probability of being infested. For this reason the greatest saving can be made by selecting only those plant parts for sampling which, on the basis of experience, are most heavily infested.

If we have insufficient knowledge or experience to plan deliberate sampling of this kind in advance, it is essential to allow sufficient time to precisely investigate the behaviour and distribution of the insect and the conditions in the crop before establishing the type of sampling.

Sampling should be done in such a manner as to disturb the insects as little as possible and if possible, without damaging or destroying the plants. Removal of parts of plants changes the conditions for the remaining parts.

Removal of entire plants affects the growth of the neighbouring plants. Changes of this kind can affect both the distribution of the infestation and the yield.

Two different kinds of measurement can be employed:

i) Counting the insects, the affected plant parts, etc. This is used in most cases; and

ii) Estimating the infestation according to various classes. This procedure is useful if great numbers of individuals (e.g. Spider mites, scales, insects, aphids) are present. The differences between the various classes should be appreciable and clearly discernible.

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Since conditions change constantly during the trial, we must, before each assessment, determine changes in the type, degree and distribution or infestation, and on the basis of these data, establish the method and the extent of sampling.

Evaluation of trial: Data analysis/calculation of efficacy

In field trials, it is not enough just to collect data. It is important to decide what is to be done with the data. If there are several samples in a trial concerning the same characteristics, i.e. biological efficacy of various insecticides against a certain pest, then we are interested to know whether the different treatments can be distinguished from one another in their effectiveness. An investigation is necessary to define which treatments are significantly different from the others. The "Turkey-Test" or "Duncan's Multiple Range Test" is one of the statistical tests which deals with this problem.

The "Turkey-Test" calculates a 'Least Significant Difference' (LSD). When two treatments do not differ by at least this amount, they cannot be said to be significantly different.

One method used to express the effect of a treatment is to calculate the % efficacy. Different formulae are available to calculate the efficacy under different trial conditions. It is very important to use the correct formula.

Collected data	Trial Conditions	Correct formula to calculate % efficacy
Live individuals or infestation	Non-uniform infestation before application	Henderson-Tilton
	Uniform infestation before application	Abbott
Dead individuals or mortality	Non-uniform infestation before application	Sun-Shepard
	Uniform infestation before application	Schneider-Orelli

/...

Henderson-Tilton

$$\% \text{ efficacy} = \left(1 - \frac{TA}{Ca} \times \frac{Cb}{Tb} \right) \times 100$$

Collected data:

Infestation in the treatment plot before application = Tb
Infestation in the treated plot after application = Ta
Infestation in the control plot before application = Cb
Infestation in the control plot after application = Ca

Sun-Shepard

$$\% \text{ efficacy} = \frac{(Pt \pm Pck)}{100 \pm Pck} \times 100$$

Collected data:

% mortality in the treated plot = Pt
% change in population in the control plot = Pck
x calculated on the basis of live individuals before and after application

$$Pt = \frac{Tb - Ta}{Tb} \times 100; \text{ and}$$

$$Pck = \frac{Ca - Cb}{Cb} \times 100$$

The formula is a slightly altered version of Henderson-Tilton's equation. It does not use survivors (infestation) but % mortality as a criterion.

/...

Schneider-Orelli - Same as Abbott's formula

$$\% \text{ efficacy} = \frac{b - k}{100 - k} \text{ X } 100$$

Collected data:

	Test Treatments	Control
Live individuals before application	Tb = 300	Cb - 500
Live individuals after application	Ta = 30	Ca = 600
% mortality in treated plot = 300 - 30 = 270	Pt = 90%	
% change in population in control plot = 600 - 500 = 100		Pck = 20%

$$\% \text{ efficacy (Henderson-Tilton)} = \left(1 - \frac{Ta}{Tb} \text{ X } \frac{Cb}{Ca}\right) \text{ X } 100$$

$$= \left(1 - \frac{30 \text{ X } 500}{300 \text{ X } 600}\right) \text{ X } 100$$

$$= \left(1 - \frac{\overset{5}{\cancel{15000}}}{\underset{\underset{12}{\cancel{60}}}{\cancel{180000}}}\right) \text{ X } 100$$

$$= \frac{12 - 1}{12} \text{ X } 100$$

$$= \frac{11}{12} \text{ X } 100$$

$$= 91.67\%$$

/...

$$\text{\% efficacy (Sun-Shepard)} = \left(\frac{Pt \pm Pck}{100 \pm Pck}\right) \times 100$$

$$= \left(\frac{90 + 20}{100 + 20}\right) \times 100$$

$$= \frac{110}{120} \times 100$$

$$= 91.67\%$$

In cases where the degree of infestation is estimated in categories, the % infestation may be calculated by using the Townsend-Henberger equation:

$$\text{\% infestation} = \left(\frac{\Sigma nV}{iN}\right) \times 100$$

Collected data:

Value of category = V
Highest category value = i
Number of plants (plant parts) in each category = n
Total number of investigated plants (plant parts) = N

Example

Collected data:

Category (V)	Infestation	n	nV
0	0	2	0
1	0.1-3%	1	1
2	4-9%	1	2
3	10-22%	1	3
4	23-48%	1	4
5	49-100%	24	120
		N = 30	ΣnV = 130

/...

$$\% \text{ infestation} = \frac{130 \times 100}{5 \times 30}$$

$$= \frac{13000}{150}$$

$$= 86.7\%$$

<u>Examples for Evaluation of Field Trials</u>

Crop	Pest	Plant parts affected and damaging stage	Evaluation techniques
Cabbage	Plutella xylostella (Diamond back moth)	Leaves and head Larvae	- Record the number of live larvae on at least ten plants per replicate before and after treatment at various time intervals. - In the event of a full season spray programme, grade each plant before harvesting on a 1-6 scale. 1 = no damage 2 - 3 = light to moderate damage to outer leaves. 4 - 6 = light to severe damage to head.
	Bud Worm	Growing point	- Calculate the marketable heads which fall under < 3 score.
		Larvae	- Count the number of plants infested after treatment at various time intervals.

/...

Crop	Pest	Plant parts affected and damaging stage	Evaluation techniques
Tomatoes	*Keiferia lycopersicella*	Leaves Larvae	- Record the number of larvae on at least 10 plants per replicate before treatment and at 1, 3, 5, 7, 10, 14, 21, 27 days after treatment.
Corn	*Spodoptera frugipeda* (Fall armyworm)	Leaves Larvae	- Count the number of live and dead caterpillars on 25 plants at each 4 points in a plot before treatment and 3, 6, 14, 21 days after treatment.
Egg Plant	*Epitrix pilosa* (Flea beetle)	Leaves Adult	- Estimation of adult population on at least 10 plants per replicate before and after treatment at various time intervals.
Legumes	*Liriomyza frifolii* (Leaf miner)	Leaves Larvae	- Count the number of live miners on leaves on 10 plants before treatment and 1, 3, 5, 7, 10, 14, 21 days after treatment.
Paddy	*Spodoptera frugipeda* (Fall armyworm)	Leaves Larvae	- Count the number of armyworms in the area of $0.36m^2$ in 25 places before and 2, 4, 10, 14, 21 days after treatment.
		Panicles and grains Nymphs and adults	- Collect the bugs by sweeping hard over panicles five times while walking and count the number of nymphs and adults. Ten to fifteen such units should be recorded from each plot before treatment and 1, 3, 4, 6, 9, 14, 21 days after treatment.

/...

Crop	Pest	Plant parts affected and damaging stage	Evaluation techniques
Plantain/ Banana	*Cosmopolites sordidus* (Banana root weevil)	Corm Larvae and adults	- By placing split 'pseudostem' trap at the rate 62 traps/ hectare before treatment and 15,30,45,60, 90,120 days after treatment. - By using percent coefficient index (P.C.I.) at the time of harvesting.
All crops	Aphids	Leaves and stem All stages	- Assess the population before and at 1,7,14 days after application. In case of light infestation inspect all the plants in plot. In case of heavier infestation it is sufficient to pick 25-50 leaves at random per plot. Estimate or count aphids using 0-4 scale: 0 = no aphids 1 = 1-5 aphids 2 = 6-20 aphids 3 = 21-100 aphids 4 = >100 aphids
All crops	Mites	Leaves and buds All stages	- Before the application and 2,7,14 and 21 days after the application. - Pick 20 randomly chosen leaves or buds of medium age and if necessary with the use of a good hand lens estimate the degree of infestation using a 0-4 scale: 0 = no infestation 1 = 1-5 individuals 2 = 6-20 individuals 3 = 21-100 individuals 4 = > 100 individuals

/...

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SIMPLE PROCEDURES OF ESTIMATING HERITABILITY

by

M.A. Rahman

Heritability of a character is one of the important factors in designing a breeding programme as well as to formulate an effective selection programme. Heritability can be estimated only when the components of variances due to genotype and environment are known. Therefore, in most breeding experiments, the breeder is interested in estimating the components of variances. The components of variances can be obtained by writing the Expectations of Mean Squares (EMS) due to different factors. There are various statistical procedures available which are suitable for estimating variances in plants and animals due to genotype, environment and genotype-environment interaction.

The procedures employed in plants sometimes vary considerably from animals because of the difference in mode of reproduction. Therefore, procedures employed in plants and animals will be discussed in separate sections.

A. PLANTS

Most plant characters of economic importance are quantitative in nature and are controlled by many independent genes. The effect of these genes is cumulative, each gene contributes a small effect on the character. The expression of these genes is also influenced by the environmental factors to a great extent. Therefore, it is difficult to judge whether the observed variation is heritable (genetic) or due to environment (non-genetic). With suitable statistical procedures, it is possible to partition the total variance into genotypic and environmental variances and these are utilized in estimating heritability.

Let us consider an experiment conducted in Randomized Block Design with 'g' genotypes (genetically pure) with 'b' blocks to test the yielding ability of the genotypes. The total variance can be partitioned due to block, genotype, and error variation. The analysis of variance is presented in Table 1 and the first two columns are completed.

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The correction term (CT) is calculated before the sum of squares and mean squares due to various source are calculated. The correction term may be calculated as follows:

$$CT = \frac{(\sum_{i=1}^{N} Xi)^2}{gb} \simeq \frac{(\text{Grand Total})^2}{gb}$$

where, g = Number of genotypes; and
b = Number of blocks in the experiment.

SUM OF SQUARES

Total:

$$SS = \sum_{i=1}^{N} (Xi^2) - CT$$

$$= (X_1)^2 + (X_2)^2 + \ldots . + (X_N)^2 - CT$$

Table 1. Analysis of variance in a Randomized Block Design

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F Calculated	F Tabular
Block	(b-1)					
Genotype	(g-1)					
Error	(b-1)(g-1)					
Total	(gb-1)					

Table 2. Analysis of variance in a Randomized Block Design

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F Calculated	F Tabular
Block	(b-1)	SSB	MSB		$\frac{MSB}{MSE}$	
Genotype	(g-1)	SSG	MSG	$\sigma_E^2 + b\sigma_G^2$	$\frac{MSG}{MSE}$	
Error	(b-1)(g-1)	SSE	MSE	σ_E^2		
Total	(gb-1)	SS				

/...

Block:

$$SSB = \frac{\sum_{i=1}^{J} (Bi^2)}{g} - CT$$

$$= \frac{(B_1)^2 + (B_2)^2 + \ldots . (B_J)^2}{g} - CT$$

where, $B_1, B_2 \ldots . B_J$ = Total of Block 1, Block 2, ... Block J; and g = Number of genotypes.

Genotypes:

$$SSG = \frac{\sum_{i=1}^{K} (Gi^2)}{b} - CT$$

$$= \frac{(G_1)^2 + (G_2)^2 + \ldots . + (G_K)^2}{} - CT$$

where, $G_1, G_2 \ldots . G_K$ = Total of Genotype 1, Genotype 2, ... Genotype K; and b = Number of blocks.

Error:

$$SSE = SS - SSB - SSG$$

MEAN SQUARES

Block:

$$MSB = \frac{SSB}{D.f \text{ for block}} = \frac{SSB}{b-1}$$

Genotype:

$$MSG = \frac{SSG}{D.f \text{ for genotype}} = \frac{SSG}{g-1}$$

Error:

$$MSE = \frac{SSE}{D.f \text{ for error}} = \frac{SSE}{(b-1)(g-1)}$$

/...

Now, all the sum of squares and mean squares are entered in the analysis of variance table (Table 2).

The calculated F ratio for genotype with (g-1) and (b-1)(g-1) degrees of freedom is compared with the tabular F ratio at a desired level of significance. When the calculated F ratio for genotype is significant, we conclude that the genotypes are different in their yielding ability.

We know that all the genotypes tested are uniform genetically, therefore the expected mean square for error (EMSE) will be purely a random environmental variance. The mean squares between genotypes will consist of variances attributable to genotypic differences and due to environmental variation among individuals of each genotype (Table 2). Thus the expected mean square for genotype (EMSG) will consist of the following variances:

$$EMSG = \sigma_E^2 + b\sigma_G^2$$ where,

σ_G^2 = Genotypic variance;
σ_E^2 = Environmental variance; and
b = Number of blocks.

Similarly, the expected mean square for error (EMSE) will consist of environmental variance as shown below:

$$EMSE = \sigma_E^2$$ where, σ_E^2 = Environmental variance.

Therefore the genotypic variance (σ_G^2) can be estimated as follows:

$$\sigma_G^2 = \frac{MSG - MSE}{b}$$ where,

MSG = Mean square for genotype;
MSE = Mean square for error; and
b = Number of blocks.

The environmental variance (σ_E^2) can be estimated as shown below:

$$\sigma_E^2 = MSE$$ where, MSE = Mean square for error.

Thus the phenotypic variance (σ_P^2) will be equal to $\sigma_G^2 + \sigma_E^2$.

Once the genotypic and the phenotypic variances for a particular character are known, heritability in the broad sense (h^2) can be estimated for that character.

/...

Heritability in the broad sense (h^2) is estimated as follows:

$$h^2 = \frac{\sigma^2_G}{\sigma^2_G + \sigma^2_E}$$

$$= \frac{\sigma^2_G}{\sigma^2_P}$$

Heritability is a property not only of a character but also of the population and of the environmental condition to which the individuals are subjected. Since heritability estimate depends on the magnitude of all the components of variance, a variation in any one of these components will affect it considerably. The genetic variances are influenced by the gene frequencies and therefore may differ from one population to another.

Worked Example

Six genotypes of rice were tested in a Randomized Block Design with 3 blocks. Observations were recorded on grain yield per plant and are presented below:

Data on grain yield (g)/plant

Genotypes	Block 1	Block 2	Block 3
1	104.9	84.3	77.0
2	88.0	106.5	89.8
3	80.0	71.3	77.5
4	80.8	106.5	83.3
5	60.0	52.5	53.0
6	96.4	98.8	99.1

Analyse the data and calculate heritability in the broad sense.

/...

Solution:

Genotypes	Block 1	Block 2	Block 3	Total
1	104.9	84.3	77.0	266.2
2	88.0	106.5	89.8	284.3
3	80.0	71.3	77.5	228.8
4	80.8	106.5	83.3	270.6
5	60.0	52.5	53.0	165.5
6	96.4	98.8	99.1	294.3
Total	510.1	519.9	479.7	1509.7

$$\begin{aligned} CT &= \frac{(\sum_{i=1}^{N} X_i)^2}{gb} \\ &= \frac{(\text{Grand total})^2}{gb} \\ &= \frac{(1509.7)^2}{6 \times 3} \\ &= 126621.89 \end{aligned}$$

SUM OF SQUARES

Total:

$$\begin{aligned} SS &= \sum_{i=1}^{N} (X_i 2) - CT \\ &= (X_1)^2 + (X_2)^2 + \dots + (X_N)^2 - CT \\ &= (104.9)^2 + (88.0)^2 \dots + (99.1)^2 - 126621.89 \\ &= 4908.08 \end{aligned}$$

/...

Block:

$$SSB = \frac{\sum_{i=1}^{J}(Bi^2)}{g} - CT$$

$$= \frac{(B_1)^2 + (B_2)^2 + \ldots. + (B_j)^2}{g} - CT$$

$$= \frac{(510.1)^2 + (519.9)^2 + (479.7)^2}{6} - CT$$

$$= \frac{760610.11}{6} - 126621.89$$

$$= 126768.35 - 126621.89$$

$$= 146.46$$

Genotype:

$$SSG = \frac{\sum_{i=1}^{K}(Gi^2)}{b} - CT$$

$$= \frac{(G_1)^2 + (G_2)^2 + \ldots. + (G_K)^2}{b} - CT$$

$$= \frac{(266.2)^2 + (284.3)^2 + \ldots. + (294.3)^2}{3} - CT$$

$$= 130421.82 - 126621.89$$

$$= 3799.93$$

Error:

$$SSE = SS - SSB - SSG$$

$$= 4908.08 - 3946.39$$

$$= 961.69$$

/...

MEAN SQUARES

Block:

$$MSB = \frac{SSB}{b-1} = \frac{146.46}{3-1} = \frac{146.46}{2} = 73.23$$

Genotype:

$$MSG = \frac{SSG}{g-1} = \frac{3799.93}{6-1} = \frac{3799.93}{5} = 759.99$$

Error:

$$MSE = \frac{SSE}{(b-1)(g-1)} = \frac{961.69}{(3-1)(6-1)} = \frac{961.69}{2 \times 5} = 96.17$$

Table 3 below shows the analysis of variance for the grain yield example:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square	F Calculated	F Tabular
Block	(3-1) = 2	146.46	73.23		0.76 NS	4.10 7.56 14.91
Genotype	(6-1) = 5	3799.93	759.99	$\sigma^2_E + b\sigma^2_G$	7.90**	3.33 5.64 10.48
Error	(3-1)(6-1) = 10	961.69	96.17	σ^2_E		
Total	(3 x 6 - 1) = 17	4908.08				

NS = Not significant; ** = $p < 0.01$

We know, $EMSG = \sigma^2_E + b\sigma^2_G$ and

$EMSE = \sigma^2_E$

Therefore,

$$\sigma^2_G = \frac{MSG - MSE}{b}$$

$$= \frac{759.99 - 96.17}{3}$$

$$= \frac{663.82}{3}$$

$$= 221.27$$

and $\sigma^2_E = 96.17$

Now the phenotypic variance can be calculated as follows:

$$\sigma^2_P = \sigma^2_G + \sigma^2_E$$

$$= 221.27 + 96.17$$

$$= 317.44$$

/...

Heritability in the broad sense for grain yield can be estimated as follows:

$$h^2 = \frac{\sigma^2_G}{\sigma^2 P}$$

$$= \frac{221.27}{317.44}$$

$$= 0.69$$

The estimated heritability for grain yield in rice is 69 percent which is a high value. A high value of heritability of grain yield would enable the breeder to base his selection on the phenotypic performance.

B. ANIMALS

Heritability of characters of economic importance of animals can be estimated by several statistical procedures. However, here only the Hierarchical Design will be discussed. The hierarchical design is also known as Nested Design, and can be employed for both plants and animals.

Let us consider that in a breeding experiment there are four sires A,B,C and D. If sire A is mated to a set of 4 dams, say dam 1, dam 2, dam 3 and dam 4; another set of 4 dams, say dam 5, dam 6, dam 7 and dam 8 are mated to sire B, producing 'p' progeny per dam and so on the design is known as hierarchical or nested design (Fig. 1). Both sires and dams are chosen at random and the dams are randomized to sires at mating.

In this design, the sources of variation are due to between sire, between dams within sires, and progenies within dams. The analysis of variance is shown in Table 4 and the first two columns are completed.

/...

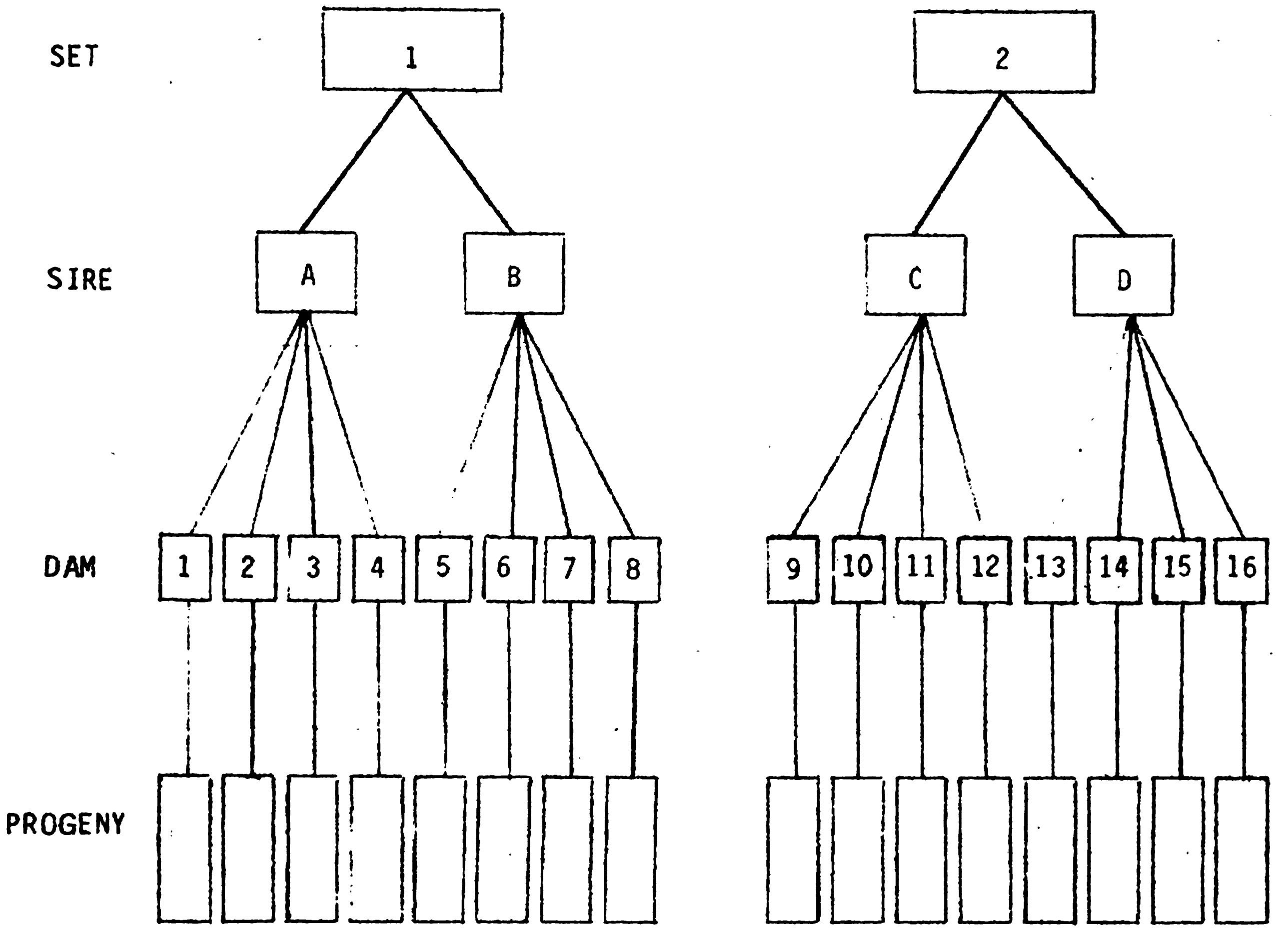

FIG 1: PLAN FOR HIERARCHICAL DESIGN

/...

Table 4: Analysis of variance in a Hierarchical Design

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square
Between Sires	(s* - 1)			
Between Dams	(m** - 1)			
Progeny within Dams	(N*** - 1)			

*s = Number of sires;
**m = Number of dams; and
***N = Number of progeny in the experiment.

Table 5: Analysis of variance in a Hierarchical Design

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square
Between Sires	(s - 1)	SSS	MSS	$\sigma^2_W + p\sigma^2_D + pd\sigma^2_S$
Between Dams	(m - 1)	SSD	MSD	$\sigma^2_W + p\sigma^2_D$
Progeny within Dams	(N - m)	SSW	MSW	σ^2_W

/...

The correction term (CT) is calculated before the sum of squares and mean squares due to various sources are calculated. The correction term may be calculated as follows:

$$CT = \frac{(\sum_{i=1}^{N} Xi)^2}{N}$$ where, N = Number of progeny in the experiment.

$$= \frac{(\text{Grand total})^2}{N}$$

SUM OF SQUARES

Between Sires:

$$SSS = \frac{\sum_{i=1}^{h}(Si)^2}{dp} - CT$$

$$= \frac{(S_1)^2 + (S_2)^2 + \ldots + (S_h)^2}{dp} - CT$$

where, S_1, S_2 .... S_h = Total of Sire 1, Sire 2 and Sire h;

d = Dams per sire; and

p = Progeny per dam.

Between Dams:

$$SSD = \frac{\sum_{i=1}^{j}(Di)^2}{p} - \frac{\sum_{i=1}^{h}(Si)^2}{dp}$$

$$= \frac{(D_1)^2 + (D_2)^2 + \ldots + (D_j)^2}{p} - \frac{\sum_{i=1}^{h}(Si)^2}{dp}$$ where, D_1, D_2 .... D_j = Total of Dam 1, Dam 2, ... Dam j; and p = Progeny per dam.

/...

Progeny within Dams:

$$SSW = \sum_{i=1}^{N} (Xi^2) - \frac{\sum_{i=1}^{j}(Di)^2}{p}$$

$$= (X_1)^2 + (X_2)^2 + \ldots. + (X_N)^2 - \frac{\sum_{i=1}^{j}(Di)^2}{p}$$

MEAN SQUARES

Between Sires:

$$MSS = \frac{SSS}{D.f \text{ for sire}}$$

$$= \frac{SSS}{s-1}$$

Between Dams:

$$MSD = \frac{SSD}{D.f \text{ for dams}}$$

$$= \frac{SSD}{m-s}$$

Progeny within Dams:

$$MSW = \frac{SSW}{D.f \text{ for progeny within dams}}$$

$$= \frac{SSW}{N-m}$$

Now all the sum of squares and mean squares are entered in the analysis of variance table (Table 5).

/...

ESTIMATING THE VARIANCE COMPONENTS

$\sigma^2_W = MSW$ where, MSW = Mean square for progeny within dams.

$\sigma^2_D = \frac{MSD - MSW}{p}$ where,
MSD = Mean square for dams;
MSW = Mean square for progeny within dams; and
p = Progeny per dam.

$\sigma^2_S = \frac{MSS - MSD}{pd}$ where,
MSS = Mean square for sires;
MSD = Mean square for dams;
p = Progeny per dam; and
d = Dams per sire.

HERITABILITY ESTIMATES

<u>Sire-component</u>:

$$h^2_S = \frac{4\sigma^2_S}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

<u>Dam-component</u>:

$$h^2_D = \frac{4\sigma^2_D}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

<u>Sire and Dam</u>:

$$h^2_{(S + D)} = \frac{2(\sigma^2_S + \sigma^2_D)}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

This estimate is based upon full-sibs and contains twice the maternal effects and one-half the dominance variance.

/...

Worked Example

From a large non-inbred population of White Rock poultry birds, five sires and fifteen dams were chosen at random and mated, one sire to three dams. Each dam produced three female progeny. The 8-week body weights of these progeny were recorded to the nearest gram. What are estimates of heritability for this population?

Sires	Dams	Progeny Weight		
A	1	965	813	765
	2	803	640	714
	3	644	753	705
B	4	740	798	941
	5	701	847	909
	6	909	800	853
C	7	696	807	800
	8	752	863	739
	9	686	832	796
D	10	979	798	788
	11	905	880	770
	12	797	721	765
E	13	809	756	775
	14	887	935	937
	15	872	811	925

/...

Solution:

Sires	Dams	Progeny Weight			Totals	
					(D)	(S)
A	1	965	813	765	2543	
	2	803	640	714	2157	
	3	644	753	705	2102	6802
B	4	740	798	941	2479	
	5	701	847	909	2457	
	6	909	800	853	2562	7498
C	7	696	807	800	2303	
	8	752	863	739	2354	
	9	686	832	796	2314	6971
D	10	979	798	788	2565	
	11	905	880	770	2555	
	12	797	721	765	2283	7403
E	13	809	756	775	2340	
	14	887	935	937	2759	
	15	872	811	925	2608	7707

TOTAL = 36381

N = Number of progeny = 45;
P = Progeny per dam = 3;
d = Dams per sire = 3;
s = Number of sires = 5; and
m = Number of dams = 15

/...

$$CT = \frac{(\sum_{i=1}^{N} Xi)^2}{N}$$ where, N = Number of progeny in the experiment.

$$= \frac{(\text{Grand total})^2}{N}$$

$$= \frac{(36381)^2}{45}$$

$$= 29{,}412{,}825$$

SUM OF SQUARES

Between Sires:

$$SSS = \frac{\sum_{i=1}^{h} (Si)^2}{dp} - CT$$

$$= \frac{(S_1)^2 + (S_2)^2 + \ldots + (S_h)^2}{dp} - CT$$

$$= \frac{(6802)^2 + (7498)^2 + \ldots + (7707)^2}{9} - CT$$

$$= 29{,}476{,}034 - 29{,}412{,}825$$

$$= 63{,}209$$

Between Dams:

$$SSD = \frac{\sum_{i=1}^{j} (Di)^2}{p} - \frac{\sum_{i=1}^{h} (Si)^2}{dp}$$

$$= \frac{(D_1)^2 + (D_2)^2 + \ldots + (D_j)^2}{p} - \frac{\sum_{i=1}^{h}(Si)^2}{dp}$$

$$= \frac{(2543)^2 + (2157)^2 + \ldots + (2608)^2}{3} - 29{,}476{,}034$$

$$= 29{,}546{,}147 - 29{,}476{,}034$$

$$= 88{,}113$$

/...

Progeny within Dams:

$$SSW = \sum_{i=1}^{N}(Xi)^2 - \frac{\sum_{i=1}^{j}(Di)^2}{p}$$

$$= (X_1)^2 + (X_2)^2 + \ldots. + (X_N)^2 - \frac{\sum_{i=1}^{j}(Di)^2}{p}$$

$$= (965)^2 + (803)^2 + \ldots. + (925)^2 - 29{,}546{,}147$$

$$= 165{,}732$$

MEAN SQUARES

Between Sires:

$$MSS = \frac{SSS}{D.f \text{ for sires}}$$

$$= \frac{SSS}{s-1}$$

$$= \frac{63{,}209}{5-1}$$

$$= 15{,}802$$

Between Dams:

$$MSD = \frac{SSD}{D.f \text{ for dams}}$$

$$= \frac{SSD}{m-s}$$

$$= \frac{88{,}113}{15-5}$$

$$= 8{,}811$$

/...

Progeny within Dams:

$$MSW = \frac{SSW}{\text{D.f for progeny within dams}}$$

$$= \frac{SSW}{N-m}$$

$$= \frac{165,632}{45 - 15}$$

$$= 5,524$$

Table 6 below shows the ANOVA table for the poultry bird example:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Expected Mean Square
Between Sires	5-1 = 4	63,209	15,802	$\sigma_W^2 + p\sigma_D^2 + pd\sigma_S^2$
Between Dams	15-5 = 10	88,113	8,811	$\sigma_W^2 + p\sigma_D^2$
Progeny within Dams	45-15 = 30	165,632	5,524	σ_W^2

ESTIMATING THE VARIANCE COMPONENTS

We know: $\sigma_W^2 = MSW$

$$= 5,524$$

$$\sigma_D^2 = \frac{MSD - MSW}{p}$$

$$= \frac{8,811 - 5,524}{3}$$

$$= 1,095$$

/...

$$\text{And} \quad \sigma^2_S = \frac{MSS - MSD}{pd}$$

$$= \frac{15,802 - 8,811}{9}$$

$$= 776$$

HERITABILITY ESTIMATES

Sire-component:

$$h^2_S = \frac{4\sigma^2_S}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

$$= \frac{4(776)}{776 + 1,095 + 5,524}$$

$$= 0.42$$

Dam-component:

$$h^2_D = \frac{4\sigma^2_D}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

$$= \frac{4(1,095)}{776 + 1,095 + 5,524}$$

$$= 0.59$$

Sire and Dam:

$$h^2_{(S+D)} = \frac{2(\sigma^2_S + \sigma^2_D)}{\sigma^2_S + \sigma^2_D + \sigma^2_W}$$

$$= \frac{2(776 + 1,095)}{776 + 1,095 + 5,524}$$

$$= 0.51$$

/...

The estimate of heritability from dam-component (h^2_D) is larger than the heritability estimate from sire-component (h^2_S). The estimate of heritability from dam-component (h^2_D) is large possibly because of presence of maternal effect.

However, the heritability estimate from combination of sire and dam based on the resemblance between full sibs may be considered as the best estimate.

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EXPERIMENTAL DESIGNS II

TABULATING DATA, DATA ANALYSIS AND INTERPRETATION OF RESULTS

by

J.R.D. Ford

INTRODUCTION

Statistical techniques are designed to measure, to reduce problems to reliable figures on the basis of which answers can be generated and decisions made. It is important at the outset to again place some limitations on results observed from agricultural experiments. A quote from Wishart and Sanders[6] does this effectively:

> "The outstanding agricultural limitation of an experiment lies in the fact that its result is only strictly applicable to the particular field in that particular year. When the variation that exists between different fields - in soil type, in fertility, in cleanliness, in drainage - is considered, together with the vagaries of climate and the diverse methods of management used for the crop concerned, the greatest hesitancy must be felt in predicting similar results in other situations. Neverthelss, experimental results must be applied widely. It follows that a single experiment can be of little agricultural value and that practical recommendations can be safely based only on an extensive series of experiments. It should be a rigid rule to continue one enquiry for at least three years before drawing definite conclusions."

The agricultural researcher who is aware of these limitations tends to be more careful and sensitive in the data handling stages of the experiment. It should always be borne in mind that the aim of the experiment is to establish new facts and if this can be done without reliance on statistics, so much the better. The question may therefore arise, suggesting that statistics are needed only where changes in the response resulting from the treatment are so small that they do not really matter. The argument for the use of statistics would have to rest upon the fact that the methods would detect not only the small differences but will show the larger differences with more certainty. Further, statistics are important because of the imprecision of eye judgement. Some studies show that yield differences of 20 percent and more are often missed by experienced practical men. Thus, we must often get to the counting and analysis stages.

/...

DATA TABULATION

In this section we will look briefly at two aspects of data tabulation, what to count and how to count, respectively. Obviously, what to count depends on the goals of the experiment as well as the nature of the experimental material. However, a few comments can still be made. The establishment of an experiment and disappearance of the researcher until time of completion of the experiment is unforgivable. Information available throughout the duration of the experiment is equally as important as the final yield data even if the final data is the comparison yardstick being utilized. Only if observations are made and records kept throughout the experimental period can insights with regard to the action of treatments be made. In other words, counts or measurements made during growth may be extremely valuable in explaining subsequent differences in yield (flowers produced by particular plots, leaf damage on particular plots). A full analysis indicates the complexity of yield and shows that the end result only tells a little of the whole story.

After deciding what to count the researcher faces the decision of how to count. This latter decision has several aspects. Firstly, it is usually not possible to count all the experimental units, therefore a sample has to be taken. Obviously, it is necessary that this sample be representative of the total experiment. To ensure this the sample (sampling units) should be scattered over the entire plot and done in a random manner. The sampling units must not be too small and the total sample should be at least 10 percent of the total experiment. Certain restrictions may have to be laid down to ensure adequate dispersion throughout the experimental area. One method is to divide the plot into sections and ensure that a definite number of units fall into each section. All the time a random process for selection should be utilized. Once a plot has been harvested and the produce weighed, it is too late to reject it as part of the analysis. Records should be entered directly into their final position (avoid recopying). The data should be examined for out of line figures at the time of collection and rechecked immediately if necessary.

/...

Another aspect of counting involves accuracy. Accuracy differs from precision in statistics in that the latter refers to how effectively the experimental design detects differences between treatments while the former refers to the closeness with which a particular measurement can be made. Generally, the rounding rule followed indicates that measurements on experimental units should not be recorded to a number place less than one-fourth the standard deviation per unit. Certainly, in reporting final results, superfluous digits should be dropped.

Finally, data is most commonly tabulated using a frequency table. Data is drawn from a large sample and variates are tallied in several class intervals. Most biological data, when plotted in a frequency curve, closely fit a mathematically defined curve referred to as a normal curve. Normal distributions vary from one another only in terms of their means and standard deviations. It is on the basis of data tabulated in this way that analysis of results is carried out.

DATA ANALYSIS

The easiest and most effective method of analysing results from an experiment is by means of the technique of analysis of variance. The short and simple calculations which characterise this method will be carried out on the same data for two of the designs treated in the first section on experimental designs. This serves to demonstrate the method of analysis as well as to bring out differences in precision that may characterise particular designs.

The experimental results being analysed are from an experiment intended to evaluate how weight gain is affected by three different hormones when applied to bulls. Sixteen bulls were chosen, ear tags were assigned and the hormones were administered randomly. (Four bulls received each treatment.) The results collected were as follows:

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Treatments	Weight Gain			
1	47	52	62	51
2	50	54	67	57
3	57	53	69	57
4	54	65	74	59

The analysis varies only slightly for the two designs.

Analysis 1: Using a Completely Randomized Design

The first step is to work out two sums of squares, the total corrected sum of squares and the corrected treatment sum of squares. The heart of the analysis of an experimental design is the partitioning process, specifically partitioning the total sum of squares into meaningful and distinct portions.

The total sum of squares (SS) is calculated by squaring each observation and summing the squares.

$$SS = \sum_{i=1}^{k} \sum_{j=1}^{m} X_{ij}^2$$

In our example this is: $47^2 + 52^2 \;\ldots\ldots + 59^2 = 54678$.

The correction factor (C) to yield the corrected sum of squares is calculated by summing all the observations, squaring the sum and dividing by the number of observations.

$$C = \frac{1}{n} \left(\sum_{i=1}^{k} \sum_{j=1}^{m} X_{ij} \right)^2$$

In our example this is: $(47 + 52 + \ldots\ldots 59)^2 / 16 = 53824$

The corrected total sum of squares is therefore:

$$CSS = SS - C = 854$$

/...

The second sum of squares to be worked out is the treatment sum of squares. The uncorrected treatment sum of squares (TSS) is found by adding observations in each treatment (T), squaring each total, adding them, and dividing by the number of observations making up each total.

$$\therefore\ T_i = \sum_{j=1}^{m} X_{ij} \quad \text{and} \quad TSS = \frac{1}{j}\left(\sum_{i=1}^{k} T_i^2\right)$$

In our example this is:

$$\begin{array}{lllrr} T_1 & = & 47 + 52 + 62 + 51 & = 212 & 44944 \\ T_2 & = & 50 + 54 + 67 + 57 & = 228 & 51984 \\ T_3 & = & & = 236 & 55696 \\ T_4 & = & & = 252 & 63504 \\ \hline & & & & 216128 \\ \hline TSS & = & 216128/4 & = & 54032 \end{array}$$

To obtain the corrected treatment sum of squares (CTSS) subtract the same correction factor C:

$$CTSS = 54032 - 53824 = 208$$

The major part of the calculations is now complete and the familiar ANOVA table can be assembled:

ANOVA Table 1

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Observed F	Required F	
Total	15	854	-	-	5%	1%
Treatments	3	208	69.3	1.29	3.49	5.95
Error	12	646	53.8	-	-	-

There are two sources of variation in this experiment. Firstly, variation among experimental units within a treatment. These are chance variations

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(uncontrolled variation) and are classified as experimental error. The second source of variation is among treatment means and reflects differences in treatments. Together, these sum to the total source of variation in the experiment. The total degrees of freedom is one less than the number of observations. Similarly, the treatment degrees of freedom is equal to the number of treatments minus one. In this case the error degrees of freedom is derived by subtraction of the treatments from the total. Degrees of freedom are also normally partitioned according to the experimental design. The sum of squares for treatments reflects the variation between treatments (hormones). The error sum of squares represents the uncontrolled variation. In order to compare these two sources of variation they are transformed into mean squares (by dividing by the corresponding degrees of freedom). The mean squares are compared by dividing the treatment mean square by the error mean square. This ratio between the two variances is referred to as the F statistic and is used to test the equality of means. The F value generated here is 1.29. Before interpreting this result let us complete the analysis using the same data but under a different experimental design.

Analysis 2: Using a Randomized Complete Block Design

The same experiment is being carried out here but instead of assuming that all sixteen bulls are similar and having four replications it is assumed that there is variability between them and that it occurs in blocks. Each replication is assumed to be a ranch which is different in some way (either animal or management characteristics). Uniformity, however, characterizes the blocks. The hormone treatments are now imposed on the four blocks. The same data is obtained:

Treatments	Weight Gain (Blocks)			
	1	2	3	4
1	47	52	62	51
2	50	54	67	57
3	57	53	69	57
4	54	65	74	59
Block Totals	208	224	272	224

/...

The analysis is slightly different here as there is an additional source of variation to be separated out. The sum of squares for the blocks is calculated similarly to the sum of squares for treatments. The block totals are calculated, each total is squared, the squares are added and divided by the number of observations making up each total. This yields the uncorrected block sum of squares. The same correction factor is subtracted and the corrected block sum of squares is obtained. On completion of the calculation you will find it to be 576. We can now fill in our ANOVA table for this design.

ANOVA Table 2

Sources of Variation	Degrees of Freedom	Sum of Squares	Mean Squares	Observed F	Required F	
Total	15	854	-	-	5%	1%
Blocks	3	576	192	24.69	3.86	6.99
Treatments	3	208	69.3	8.91	-	-
Error	9	70	7.78	-	-	-

With the experimental data when analysed under a different design, completely different results are obtained. The interpretation of results in general and these in particular form the discussion of the next section.

INTERPRETATION OF RESULTS

This paper started out by indicating the limitations of agricultural results in terms of their general applicability. This limitation arises from the location specific nature of these results. When we speak of interpretation of results in this section we speak within the context or location of the experiment. It is common to refer to results as 'significant' or 'highly significant'. 'Significant' indicates that a statistical test evaluates the 'sample' result as compared with the assumption contained in the null hypothesis. The 'highly significant' results correspond with a risk level of 1% that the sample results could be expected to cause rejection of the true null hypothesis.

/...

In other words, 99% of the time the sample results are expected to reject (or accept) the null hypothesis correctly. Significant results do the same for a 5% level of risk. Thus, when a researcher says 'the treatments are significantly different', he is saying that the null hypothesis is false and that the significant result was due to a real treatment effect.

Let us now interpret the results of the analyses carried out. In the first instance the observed F statistic is much lower than the required F statistic for significance at both the 5% and 1% level of significance. Thus the null hypothesis is not rejected and it is concluded that there are no significant differences among the means and hence the treatments had no effects. This does not prove that the treatments had no effects and it is important for the researcher to understand this. There is always the chance that there are real effects but the experiment was not sensitive enough to detect the differences. The second analysis utilizes a different experimental design and the same data demonstrates this.

In the second analysis we have an observed F statistic that is greater than the required F at both the 5% and 1% level of significance. Thus, analysis of the same data but using a different design, which was able to isolate variation due to blocks, leads to rejection of the null hypothesis and to the conclusion that real block and treatment differences do exist. Thus, because block differences were removed, treatment differences which were not detected under the completely randomized design were now evident.

It should be always borne in mind, however, that the conclusions drawn from an experiment are the researcher's own and he should bear responsibility for them. The conclusions should be based on more than the statistical evidence and certainly more than the final (yield) analysis. The conclusions must be logical and make sense in terms of the researcher's general knowledge of the experimental material. Before recommendations are made the consequences of being wrong should be taken into consideration. If the consequences are not serious, you may even make the recommendation while you go on testing. The

/...

judgement of the researcher, based on his knowledge of the experiment and experimental material, is the critical variable in the interpretation of results.

CONCLUSIONS

The agricultural researcher has to deal with data, he has to analyse it, interpret and report results. If this is to be done successfully, we said that the agricultural researcher must be a 'theoretical thinker' and a 'dirty fingernails' person. In other words, he must be willing to spend the time in the field to understand the variables with which he is working and must be disciplined enough to want to learn more than just the 'recipes' for analysis of data. He must have a working knowledge of the methods he is utilizing. He should understand that statistical knowledge is important for designing experiments, for conducting them properly and are not reserved for working out results. Finally, interpretation is the last and most important step in the analysis of data. At this stage the researcher must bring to bear on his findings all his knowledge of the crop, the treatments, the environment and the methods of analysis utilized. After incorporating these sources of influence and information he will undoubtedly be in a better position to interpret his findings.

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PRESENTING RESEARCH RESULTS

by

A.M. Pinchinat

(Outline only)

INTRODUCTION

Product of Applied Research

Results that can be readily adopted by farmers to improve their farming system and thereby attain desired goals (more food, higher income, more stable production, less hard work, lower costs for same or higher output)

Means Towards Achieving That Objective

- Direct mass communication: radio, meeting, visits, demonstrations
- Written materials: usually the one means more directly available to the applied research worker

In all cases, the messages must be clear, progressive, readable

CONTENTS OF APPLIED RESEARCH PAPERS

Title (concise, precise)

Abstract/Summary (problems, objectives, materials, methods, results, conclusions)

Introduction

- Problem focused on in the paper
- Hypothesis (scientific/technical base)
- Objective of the research work carried out
- Objective of the paper

/...

Materials and Methods

- Resources/Inputs
- Tools/Equipment/Other means
- Strategy/Procedures
- Special management

Results

- Conditioning factors (normal, abnormal)
- Response variables (corresponding to the specific objectives of the research activity)
- Use tables, graphs, figures instead of lengthy writing

Discussion

- Interpretation of results according to set objectives
- Relation with previous research results, observations or experiences (references)
- Uncovering (or discovering) of new or unexpected research leads or hints

Conclusion

- Responding concisely to the research problem and objectives
- Assessing materials and methods used
- Suggesting next step

Acknowledgements

Literature Cited

- Complete and precise references
- Include informal references
- Avoid use of footnotes (except standard paper identification)

/...

RESEARCH PAPER LEVELS

According to the nature of the problem, research objective, sophistication of methods used and intended audience or potential users of results

Scientific (Highly Technical)

- Support research (cytogenetic, physiology)
- Usually from on-station/controlled condition research and uni-disciplinary
- By-product of on-farm research
- Reporting basic knowledge/techniques
- For scientific/technical journals (for peers)

Technical

- Off-station research or farm simulated on-station multi-disciplinary research
- Majority of applied research activities
- Reporting and explaining new technology
- For technical/professional journals (peers and extension workers)

Semi-Technical

- Wider scope, combining scientific, technical and professional experiences or views, or several research activities and levels
- May involve biophysical, economic and socio-political considerations
- Suggesting/recommending technology or proven sets of techniques

/...

- For general miscellaneous media directed to farmers, directly or through extension agents, administrative levels, policy makers or general public

PAPER PRESENTATION

Varies according to the paper level

Scientific (Highly Technical)

- Limited problem scope, mostly discipline oriented
- Detailed methodology/description
- Accent on precise measurements
- Complex mathematical/statistical treatment of results or elaborate description of observations
- Rigid, almost impersonal discussion of results and ample or exhaustive reference to literature
- Scientific jargon, mostly confined to the discipline
- Strict format and style
- Example: Papers in "Crop Science" (male sterile mutant in a cultivar)

Technical

- Broader problem scope, production oriented
- Simplified/concise methodology description
- Practical measurements stressing relevant farming variables
- Simplified statistical treatment of results and emphasis on observations of more practical relevance
- Influence of professional experience or judgement on bare experimental results

/...

- Simple straightforward language
- More flexible format and style
- Example: Papers in "Agronomy Journal"

Semi-Technical

- Broad problem scope, oriented to practical recommendations about farming improvement
- General methodology description
- Practical measurements or reasoned assessment of farming variables
- Minimized statistical treatment and maximised broad-scope (biophysical and socio-economic) analysis of experimental results or selected observations of practical significance
- Combining scientific knowledge, technical findings and multi-disciplinary professional experience in dealing with a problem focused on in paper
- Brisk, straightforward and almost relaxed (ordinary) language
- Varied formats and styles
- Example: Papers in "Crops and Soils"

CONCLUSION

Be Precise

Be Clear

Adjust format and style to research level and intended audience

REFERENCES

APPENDICES

APPENDIX 1

PROBLEMS FOR PRACTICAL SESSION II

1. You have just returned from a visit to a major food production region in your country and you have found that a weevil is destroying one of the major crops. Identify the steps you would go through (including the discussions, actions and decisions expected at each step) leading to the eventual resolution of the problem (eradication of the pest in the area).

2. You have just been transferred to a new unit at the agricultural experimental station and you have been given the task of analysing the following data:

	1	2	3	4	5
1	10	13	9	14	11
2	5	10	5	10	6
3	6	12	5	10	6
4	4	8	4	11	5

From the notes left you found out that your predecessor was investigating the effect of 5 fertilizer levels on cowpea yield. Do the following:

1) Indicate how you would go about the job assigned.

2) Analyse the data.

3) Report briefly on your completed work to the Minister of Agriculture.

APPENDIX 2

EVALUATION OF SEMINAR/WORKSHOP

1. In your opinion the seminar/workshop was
    1.1 Unnecessary
    1.2 Useful
    1.3 Very useful
2. Rank the following in order of usefulness:
    a. Identifying agricultural research priorities
    b. Basic concepts in applied agricultural research
    c. Experimental designs I: Essential principles of experimental design theory
    d. Conducting field experiments: Practical aspects
    e. Conducting experiments: Some specific applications
        i) Field and vegetable crops
        ii) Tree crops
        iii) Livestock
        iv) Disease control
        v) Pest control
        vi) Breeding
    f. Experimental designs II: Tabulating data, data analysis and interpretation of results
    g. Presenting research results
    h. Practical exercise
        i) Research planning and designing
        ii) Statistical data analysis
3. Was any of the presentations
    3.1 Too rudimentary?
    3.2 Too technical?

<u>Note</u>: Identify the presentations by code as listed in No. 2 above.

/...

4. List any topic from the above or other relevant areas in which you feel that additional guidance will be beneficial·

   4.1
   4.2
   4.3
   4.4
   4.5

5. Identify any weaknesses in the research system in Guyana which you would like removed.

   5.1
   5.2
   5.3
   5.4
   5.5

6. List some specific recommendations to correct the identified weaknesses.

   6.1
   6.2
   6.3
   6.4
   6.5

7. Indicate

   7.1 Your area of work

      a. Research
      b. Extension
      c. Other (Specify)

/...

7.2 Your specific functions

a.

b.

c.

APPENDIX 3

ANALYSIS OF THE EVALUATION EXERCISE

1. In evaluating the usefulness of the workshop, 81% of the participants considered it very useful and the remainder useful. No participant felt that the workshop was unnecessary.

2. Topics dealt with at the workshop were ranked in their order of usefulness. The system of ranking used was 1 = highest and 5 = lowest. Table 1 shows topics, ranks and the number of responses for a particular rank.

Table 1

Topics	Ranks				
	1	2	3	4	5
Identifying agricultural research priorities	4	3	2	2	2
Basic concepts in applied agricultural research	13	6	-	2	2
Experimental designs	1	6	8	4	2
Conducting field experiments: Practical aspects	2	3	4	7	3
Conducting experiments: Specific applications	2	2	2	3	5
Tabulating data, data analysis and interpretation of results	2	1	3	7	4
Practical exercise	1	4	6	-	7

Using ranks 1 and 2, the result was:

- "Basic concepts in applied agricultural research" was the most highly rated topic. Rated as second most important were "Identifying agricultural research priorities" and "Experimental designs". Rated third were "Conducting field experiments: Practical aspects" and the "Practical exercise".

/...

3. Among the presentations, some were identified as too rudimentary while others were considered too technical.

   Those identified as too rudimentary were:

   - Identifying agricultural research priorities; and
   - Conducting experiments - Specific applications (Tree Crops).

   The too technical presentations were:

   - Conducting experiments: Specific applications (Breeding); and
   - Tabulating data, data analysis and interpretation of results.

4. The areas cited for additional guidance were as follows:

   - Identifying agricultural research priorities;
   - Experimental designs;
   - Conducting field experiments: Practical aspects;
   - Conducting experiments: Specific applications:
     - Field and vegetable crops;
     - Tree crops; and
     - Breeding;
   - Tabulating data, data analysis and interpretation of results;
   - Practical exercise:
     - Research planning and designing; and
     - Statistical data analysis;
   - Research techniques as applied to agricultural economics;
   - Building multidisciplinary teams;
   - Aquaculture; and
   - How to make allowances for political interference and have long-term, meaningful research.

/...

5. The areas of weakness of the research system as identified by participants of the workshop are summarised as follows:

   - Lack of a policy statement/document outlining a planned programme, detailing what is to be done and how it should be done;
   - Shortage of trained/experienced staff, support staff, finance and materials to conduct and complete research projects/programmes;
   - Absence of a system of analysing data;
   - Lack of a proper method of documenting data;
   - Poor dissemination of information;
   - Lack of co-ordination within the research framework;
   - Lack of collaboration among research agencies, both locally and internationally, resulting in a duplication of research efforts;
   - Little emphasis is placed on agricultural research by policitians;
   - Lack of proper orientation and guidance of young researchers into the system;
   - Weak link between research, extension and farmers;
   - Poor remuneration of research staff;
   - Unidisciplinary approach to research;
   - Research is not "Applied" enough;
   - Absence of follow-up research; and
   - Lack of evaluation of research projects.

6. The recommendations identified to correct weaknesses are summarised as follows:

   - Formulation of a well planned policy document;
   - Provision of adequate, well trained support staff, finance and materials to conduct and complete research work.

/...

- Establishment of a proper method of documenting, storing and disseminating data;
- More collaboration of research efforts among organisations and co-ordination of research through infrastructural and institutional changes;
- Conducting seminars on the importance of research;
- Proper orientation and guidance/training of young researchers into the system by senior staff and trained personnel;
- Provision of incentives to research workers;
- Adoption of a multidisciplinary approach to research;
- Conducting more off-station work;
- Continuity of research work; withdrawal of funds when research projects are not complete; and
- Establishment of a Board to censure research work; establishment of a pecific time frame and evaluation period for projects.

7. Areas of work of the participants were:
   - research;
   - extension;
   - research/extension;
   - research/planning;
   - planning; and
   - teaching (Guyana School of Agriculture).

   The majority of participants, however, worked in the area of research.

8. The functions of the participants generally suffered from lack of breadth. Few researchers had extension responsibilities and few extensionists had research responsibilities. Both groups, however, claimed to have administrative and management responsibilities.

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11. Mr. Roger Cromwell
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13. Miss Audrey Trotman
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14. Mr. Leslie Munroe
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15. Dr. Anil Sinha
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16. Mr. Reginald Thompson
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17. Mr. Frederick Jones
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18. Miss Janice Gittens
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19. Dr. B.K. Sharma
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20. Mr. Errol Luke
Veterinary & Livestock Officer
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21. Miss Carmen Francis
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22. Mr. Tapeshwar Singh
Senior Agricultural Officer (ag.)
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23. Mr. Kelvin Craig
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24. Mrs. Patricia Bender
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26. Mr. Wesrick Stephen
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27. Mr Raymond Trotz
Agricultural Officer
Region 7
Bartica
ESSEQUIBO

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28. Mr. Abdool Annief
Agricultural Officer
Region 1
Hosororo Agricultural Station
NORTH WEST DISTRICT

29. Mr. Clifton Paul
Principal Lecturer (Technical)
Guyana School of Agriculture
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APPENDIX 5

PROGRAMME

WEDNESDAY, SEPTEMBER 29, 1982:

OPENING SESSION

CHAIRMAN: Dr. R.E. Pierre

09:00 - 09:10 hrs:	Chairman's Welcome	
09:10 - 09:40 hrs:	Opening Address	: Mr. E. Hubbard
09:40 - 10:00 hrs:	COFFEE BREAK	

TECHNICAL SESSION I

10:00 - 11:00 hrs:	Identifying Agricultural Research Priorities	: Dr. A.V. Downer
11:00 - 12:00 hrs:	Some Basic Concepts in Applied Agricultural Research	: Dr. A.M. Pinchinat
12:00 - 14:00 hrs:	LUNCH	

TECHNICAL SESSION II

CHAIRMAN: Dr. J.R.D. Ford

14:00 - 15:30 hrs:	Experimental Designs I:	: Dr. J.R.D. Ford
	Essential Principles of Experimental Design Theory	: Dr. J.R.D. Ford
15:30 - 16:30 hrs:	General Discussion of Participants' Problems	

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THURSDAY, SEPTEMBER 30, 1982:

TECHNICAL SESSION III

CHAIRMAN: Dr. A.M. Pinchinat

09:00 - 10:00 hrs: Conducting Field Experiments:
Practical Aspects : Dr. R.E. Pierre

10:00 - 10:30 hrs: COFFEE BREAK

10:30 - 12:00 hrs: Conducting Experiments:
Some Specific Applications

- Field and Vegetable Crops : Dr. A.M. Pinchinat

- Tree Crops : Mr. C.S. Baichoo

12:00 - 14:00 hrs: LUNCH

TECHNICAL SESSION IV

CHAIRMAN: Mr. Tapeshwar Singh

14:00 - 16:00 hrs: Conducting Experiments: Some
Specific Applications (cont'd)

- Disease Control : Mr. F. McDonald (Presented by Dr. R.E. Pierre)

- Pest Control : Dr. A.K. Sinha

- Heritability : Dr. M.A. Rahman

16:00 - 16:30 hrs: General Discussion with Panel

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FRIDAY, OCTOBER 1, 1982:

TECHNICAL SESSION V

CHAIRMAN: Mr. C.S. Baichoo

09:00 - 10:00 hrs: Experimental Designs II: Tabulating Data, Data Analysis and Interpretation of Results : Dr. J.R.D. Ford

10:00 - 10:30 hrs: COFFEE BREAK

10:30 - 12:00 hrs: Presenting Research Results : Dr. A.M. Pinchinat

12:00 - 14:00 hrs: LUNCH

TECHNICAL SESSION VI

14:00 - 16:00 hrs: Practical Session

FECHA DE DEVOLUCION

Autor

Título Proceedings of Seminar/Workshop on Applied Agricultura ...

Fecha Devolución	Nombre del solicitante

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