STRATEGIES FOR CROP RESEARCH

Henry A. Nix

CSIRO Division of Land use Research
Canberra City
Australia

ABSTRACT

Some basic concepts and methods of crop research are critically examined and their implications for crop research strategy discussed. Definition of the objective function of crop research is seen as a necessary foundation for useful discussion of alternative crop research strategies. Development of dynamic interactive systems of environmental data banks and crop production models offers best prospects of general solutions and location – specific prescriptions. Concepts of minimum data sets, optimisation of experimental networks and the 'omnibus' experiment are defined and discussed in relation to development of new crop research strategies.

INTRODUCTION

What is a crop? If we accept the broadest definition then a crop is the desired product from a managed parcel of land. Grain, meat, wool, sugar, fruit, milk, sawlogs, woodchips, water and maintenance of viable populations of native flora and fauna — all of these are crops. The logic and method espoused in this paper apply equally to research strategies for any of these end products of land use. However further discussion will be restricted to the more conventional definition of crop in the strict agricultural sense.

What then are our objectives in crop research? Logically we might expect differences in these objectives at national, regional and farm scales. At the national level the primary objective should be the efficient management of the land and water resource base. This demands answers to three basic questions:

(1) For any given **crop** which areas offer greatest biophysical and socio-economic advantages?
(2) For any given **area** which crops offer greatest biophysical and socio-economic advantages?
(3) For any given **crop** or **area** how can productivity be raised and sustained?

In Australia and, I suspect, in New Zealand, answers to these questions are sought by a tangled web of institutions, each claiming special responsibility for one or more of them. Fragmentation of responsibility obscures the thread that binds these questions together. Simply, the general problem is one of prediction. If it were possible to predict the performance of any crop at any location given a specified set of soil, crop, weather and management data then we could answer all three questions.

At farm level, the primary objective is to prescribe a technology that is relevant to the land, labour, capital and management resources of the individual. Since every farmer and every farm is unique the prospect is daunting. Available evidence suggests that current research and extension strategies are not satisfying the need for farmer and farm specific prescriptions. But, once again, if it were possible to predict the performance of any crop at any location given a specified set of soil, crop, weather and management data then it would be possible to prescribe appropriate technologies.

I have argued elsewhere (Nix, 1968; 1976) that prediction of crop performance is an attainable objective and that it can be identified as an ultimate goal of crop research. However, unless there are major changes in the prevailing logic and method of crop research this objective is unlikely to be achieved.

LOGIC AND METHOD IN CROP RESEARCH

Progress towards this ultimate goal of prediction of probable outcomes (ecological and economic) of any crop production system at any location has followed an evolutionary path from simple trial and error, transfer by analogy, correlation and regression/analysis of variance (statistical agronomy), multivariate analysis to systems analysis and simulation techniques (Nix, 1968). These methods are not mutually exclusive and each has a role to play in crop research strategy.

Trial and error

Given enough time, stable and successful crop production systems can be evolved through generations of trial and error experiment. Farmer innovation has been and still remains a major source of new technology. However, the social cost is considerable, since for each success there may be thousands of failures. A major task of crop research is to reduce the social cost of such trial and error experiments. Despite development of increasingly sophisticated approaches the simple observational trial retains a place in the armoury of regional research and extension techniques. A modest additional effort in monitoring a minimum set of soil, crop, weather and management parameters could transform the value of such trials. However, this prospect will be canvassed in more detail later in this paper.

Transfer by analogy

Underlying most agricultural research strategy is the concept of transfer of information by analogy. Since it is physically impossible to replicate every experiment on every farm in every season, a 'representative' site is chosen and results extrapolated to other sites and seasons that are classed as having similar properties. The central hypothesis is that all occurrences of a defined class should respond in a similar way to management. Vegetation, soil and climatic classifications, provide the usual basis for selection of a 'representative' site, but social and economic factors and, even more importantly, political factors often have as much or more influence on the location of major research centres and experimental stations. Understandably, the analogue approach fosters proliferation of research stations and experimental sites since successful extrapolation of results is seen to hinge on proximity. For any individual farm, the ideal location is as close as possible. Although other and newer methodologies offer prospects of freedom from the shackles of the analogue approach much can be done to improve it in the interim.

Given that present crop research strategy is very firmly based upon the transfer of information by analogy, a network of experimental sites is an obvious necessity. In my judgement, most developed countries and many developing countries have overdeveloped networks. Field experimentation is expensive, but essential. Any rationalisation and upgrading of such networks could have tremendous benefits, both in terms of research efficiency and cost effectiveness. Is it possible to define an optimum network (or networks, accepting that different crops have different requirements)? Tentative steps in this direction have been taken at national and international levels. Thus, for instance, the International Centres of Agricultural Research, whether regional or commodity based, are keenly interested in optimising their various networks of outreach sites on a global basis.

Modern techniques of numerical taxonomy or pattern analysis offer prospects of more objective classification of regions. One example of this approach is provided by an analysis and classification of dryland wheat environments in Australia (Nix, 1975). A generalised simulation model of wheat was used in deriving measures of the radiation, thermal and water-balance regimes **during** each of the vegetative, reproductive and grain-filling phases for a standard cultivar seeded at or near the optimum time. Numerical classification of these attributes resulted in delineation of distinct wheat environmental regions. Good agreement between these regions and those used in recommending cultivars and management practices was obtained. However, when distribution of research centres in relation to these regions was examined it became obvious that these research centres were inequitably distributed. Where State boundaries set limits to institutional responsibility, research centres were duplicated and triplicated. This analysis suggested that some rationalisation and streamlining of the research network for dryland wheat should indeed be possible and desirable. It also suggested a much more radical alternative; that by serial seeding over the autumn-winter-early spring period at a defined nodal location in central-western N.S.W. practically all of the environments occurring in the Australian wheat belt could be duplicated.

Correlation/regression

The techniques of regression analysis brought some rigour into studies of environmental and management factors and their relationships to yield. In environments where one or two factors dominate crop performance simple correlations can have useful predictive value. Generally, if raw climatic and/or soil data can be transformed into more relevant indices and a phenological rather than calendar time scale used, such predictive equations can have greater generality. Usually, however, the deficiences in this approach are due to explicit assumptions of linearity of responses, implicit assumptions that correlation implies causation and the location, season, cultivar and management specific nature of the relationship. Desipite these criticisms, correlation and regression techniques remain valuable in fitting functions and as components of more complex modes of analysis.

Analysis of variance

The prevailing, conventional, 'white-peg' agronomy is a deeply entrenched component of crop research strategy. But these solidly established techniques of statistical agronomy will never provide solutions to the global question of prediction. The inadequacies of conventional agronomic experiments were well documented more than two decades ago (Collis-George and Davy, 1960). Statistical differentiation of treatment effects in situations where site x season interactions may account for the major share of total variance, is not conducive to understanding nor to development of general functional relationships. What is not so well appreciated (Nix 1976) is that results from laboratory, glass house and controlled environment facilities are commonly just as limited by this approach as is the maligned field experiment.

Accepting that any rapid change in agronomic research is unlikely, how can the conventional white-peg randomised and replicated block be upgraded to yield more useful data? As in the simple observation trial, much could be achieved if a standardised **minimum** set of soil-crop-weather and management data were collected. The whole emphasis must be on a **minimum** data set rather than some notional **optimum** set and it is essential that **balanced** sets of soil-crop-weather-management data be the goal. Very few experiments meet this criterion. Commonly, very detailed measurements are made on one or other components or processes of the crop system, while others, equally important are totally neglected. While collection of standardised minimum data sets from conventional agronomic experiments would be a notable improvement, it makes more sense within the context of systems analysis and simulation techniques.

Systems analysis and simulation

A need for a holistic approach to problems of crop production has long been recognised, but progress was slow until the advent of computers and the development of systems analysis and simulation techniques. Following World War II, rapid progress in the general conceptual area of systems analysis and operations research was made by military scientists tackling problems of rapid analysis of all the implications of possible alternative strategies. Today, in most developed; countries, the systems aproach to agricultural research is decidely fashionable. However, having access to sophisticated computers and the active development of simulation models, in themselves are not sufficient evidence of adoption of a systems approach. In my experience, few, if any, existing crop research strategies are truly systems based.

Adoption of a systems approach immediately emphasizes the need for interdisciplinary teamwork, since knowledge and insights gained from biological, physical, social and economic disciplines are required. However, such an organisation transgresses the normal arrangement of discipline and subject-matter research groups and competes for funds and facilities with reductionist type research. At this point it is necessary to stress that both systems based on synthetic research and the more traditional reductionist research are necessary components of a balanced research strategy. Maintaining an appropriate balance is a major challenge for any research administration.

A systems approach formalises what is already known about the crop and the crop production system. It aims at identifying the more important components and processes and in quantifying their interactions. Most significantly, it helps to identify significant bottlenecks to improved crop performance.

A research strategy based on the systems approach would centre around the development of working models of crop production systems. Such models need to be structured so that they remain operational yet capable of continuous improvement in logical structure and function. Ideally, it would be useful to have a hierarchy of models capable of application at a range of scales and offering some choice in the level of precision and accuracy.

It is only through the development of such crop models that it becomes feasible to identify **minimum data sets** that are needed as input data for adequate analysis, synthesis and extrapolation of experimental results. Field, laboratory and controlled-environment experiments are the major sources of data for development of crop response functions, process models and whole crop models. It is essential that data sets be collected that adequately define at least the major radiation, temperature, moisture, and nutrient regimes in addition to the data that describe crop response. The need for **balanced** crop-soil-weather-management data and the need for co-operative efforts to acquire it should not need emphasis. But what is balance and what is a minimum data set?

MINIMUM DATA SETS FOR AGRONOMIC EXPERIMENTS

Initially, the concept is extended only to existing field trials and experiments. Thus, it must be stressed that we are not concerned with entirely new types of experiments, but simply with upgrading existing experiments through additional observations and measurements. The concept of standardised minimum data sets arose out of the need for balanced data and recognition that definition of a minimum was a more practical objective than definition of an optimum data set. In the development and implementation of any such standardised system of data collection it is essential that all relevant staff be involved from the beginning. In addition to field agronomists and experimental staff we should expect contributions from crop physiologists, plant breeders, pathologists, entomologists, soil-scientists, agrometeorologists and other subject specialists.

Recognising the differing objectives of field experiments and the differences in facilities available, my own group has proposed a hierarchy of minimum data sets. Successive levels maintain a balanced monitoring of the whole crop system, but precision, accuracy and frequency of measurement are upgraded. The three level system developed is presented here briefly, but only as an example. It is important that the parameters chosen for inclusion in the minimum data set be chosen by research workers experienced in their own environment. The most important parameters are those that represent factors responsible for significant variation in yields or other measures of crop performance, from site to site and year to year.

Level O: Applicable to simple observational trials or experiments distant from laboratory facilities and meteorological stations.

Data collected are the absolute minimum required for simple analysis of crop/environment interaction and comparative analysis of crop performance at widely spaced sites and/or seasons. Weather data regarded as essential inputs are total solar radiation, maximum and minimum temperature, relative humidity, precipitation and potential evaporation. At this level, weekly time steps are judged to be adquate and all weather data, except for precipitation can be obtained from a weather station within the general region, providing climatic gradients are subdued. Step one then is to locate such experiments with respect to existing weather stations that meet these requirements or that can be upgraded by installation of additional equipment for the duration of the experiment. No weather data no experiment!

Soil data are limited to initial and final samples for soil water status and, where indicated, nutrient status. The actual techniques used will vary with the crop and location. Crop data are limited to phenological observations of date of seeding, emergence, flowering and harvest (where possible, in our own work at this level, we attempt to add floral initiation and physiological maturity dates) and yield components and dry matter partitioning at harvest. This data set is just sufficient for calculation of empirical biophysical indices, for initialising and verifying runs of the simplest crop models and for development and testing of empirical yield prediction equations.

Level 1: Applicable to field experiments conducted at or closely adjacent to major regional research centres.

Emphasis remains on collection of a balanced set of weather, crop and soil data, but more comprehensive and more frequent observation and measurement permits analysis of crop performance on a physiological or process basis. The same stepof weather data is monitored, but the time step is daily and the experimental site must be closely adjacent to the meteorological installation. Greater precision is required in defining phenological events. Floral initiation is regarded as a vital point in the crop's developmental strategy, but is rarely measured in field experiments because it requires regular sampling and subsequent dissection under a binocular microscope. The whole process can be streamlined by using long-term and/or real time weather data to predict expected date and then bracketing this date with more frequent sampling. Also, stem samples can be taken and stored in an appropriate solution (e.g. F.A.A.) and bulked for later determination in the laboratory. A further limitation is that, for many crops, reference charts are not yet available that depict development of the floral primordium. Mr M. Moncur, of my program, is completing an atlas of floral initiation for more than fifty field crops, using scanning electron microscopy at moderate magnification to produce high quality images.

Crop data required are partitioned dry matter and leaf area sampling at or close to key phenological events e.g. floral initiation, terminal spikelet, ear emergence, last flower, physiological maturity. Chemical analysis for nutrient uptake of target elements may be added. Soil data is restricted to sampling for water and nutrient status at each of the times of crop sampling as well as at seeding and at or just after harvest. The data collected at this level provide a sounder basis for development and testing of process-based models of growth, development and yield.

Level 2: Applicable only where major data-logging and data-processing facilities available.

At this level the primary objective of data acquisition is directed at the understanding of component processes. Some may equate this level with the boom period of micrometeorological experimentation during the sixties. However, very few, if any of such studies maintained the necessary balance in monitoring all major components of the crop system. Often, incredibly detailed monitoring of particular processes such as CO_2 gas exchange or transpiration took place while other components of the system were totally ignored. Such experimentation did contribute substantially to our understanding of particular processes, but only marginally to our understanding of whole system function.

Observation and measurement at this level use a time frame of minutes to hours. Data processing and storage facilities are essential. Specialised monitoring instruments are mandatory since non-destructive sampling is indicated e.g. soil water status would be monitored using neutron moderation techniques rather than simple gravimetric sampling as in the previous two levels. Very careful planning of such experiments is indicated and explicit statement of objectives essential, otherwise they very quickly become a sink for scarce research funds.

Since it is neither necessary nor practical to model a crop system or subsystem at a level of detail greater than is necessary for useful prediction, it should be obvious that agronomic experiments will be restricted to levels 0 and 1 in the hierarchy of minimum data sets. Even at these levels it soon becomes apparent that adoption will lead to fewer, but better monitored experiments. Futher thought and examination inevitably leads to a recasting of existing research strategies. As one example only of possible alternative strategies I shall refer to a combinatorial, non-randomised, non-replicated design that I have dubbed an 'omnibus' experiment.

OMNIBUS EXPERIMENTS

The objective function is to generate a comprehensive set of data that covers the widest possible range of cultivar/environment/treatment interactions in the shortest possible time and with most economical use of land and labour resources. Every effort is made to identify the major sources of potential variation in crop performance and treatments designed to exploit the widest possible response and not simply identify an optimum. Thus, serial seeding at monthly intervals may be used to expose the system to a wide range of climatic conditions. Trickle irrigation or line-source sprinklers together with rain-out shelters may be used to engineer a wide gradient in water regimes. Population and geometry together with fertiliser application present no particular problems in relation to engineering treatment gradients. For a given crop, cultivars are selected that span a wide range of developmental patterns and yield responses.

For any given crop under study it will be obvious that such a strategy very quickly gives rise to hundreds of individual treatments. However, treatments are **not** randomised or replicated. Each treatment is unique and is monitored in terms of minimum data sets. Within-treatment sampling is, however, randomised and replicated. Some saving in labour requirement can be affected through monitoring designated modal or average treatments more intensively (e.g. Level 1) and the remainder less intensively (e.g. Level O). The data generated provide a basis for exploration of functional responses to a wide range of treatments and treatment combinations, and for development and validation of crop models that can be expected to have wider generality. When such models are coupled to an appropriate environmental data base they can be used to make predictions of performance, to explore potential alternative management strategies and to explore the consequences of differing growth and development strategies in the target crop. Some examples of the application of this type of logic are presented in the recent group of papers relating to potato production in the Australian environment (Sands, *et al.,* 1979; Hackett *et al.,* 1979 a,b)

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