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# ADAPTING FARMING SYSTEMS RESEARCH CONCEPTS TO AUSTRALIAN RESEARCH NEEDS

R.L. McCown
CSIRO - Tropical Crops and Pastures
Davies Laboratory
Townsville Queensland 4814

## INTRODUCTION

One of the greatest technological achievements of history is the efficiency with which modern societies feed their populations. While the overall cost-effectiveness of the agricultural research and development that has provided the basis for modern agriculture is beyond question, the goals and organization of agricultural research of recent decades are increasingly coming under question.

Modern agricultural technology has required detailed knowledge on a great many fronts, hence a high degree of research specialization. This compartmentalization of agricultural research and training has unfortunately resulted in an often less-than-adequate capacity to deal with issues cutting across a number of compartments, i.e. issues unique to the larger system. The problem created by this has become apparent, belatedly, on two fronts.

The first is that of the developing country with a predominantly traditional peasant agriculture. Here, in spite of the presence of research organizations conducting "modern" research it was widely observed that farmers rarely adopted the recommendations for changes in technology. The search for explanations revealed that the well-known conservatism of farmers was not the main problem. Rather, agricultural scientists too often ignored or misunderstood the needs and constraints of the farming system and in conseqeuence conducted inappropriate research. This realization and the enormous importance of the problem has resulted in the development of a philosophy and a procedure for making research more efficient in terms of benefitting producers. This methodology is most commonly referred to as Farming Systems Research (FSR).

The second front of belated recognition of the need to view research in the context of the farming system is in developed countries. Here, the "systems approach" to agricultural research which emerged in the early 1970s has had only a modest impact on the way the main body of agricultural research is conducted. Instead, with its major emphasis on simulation modelling, it has become a new area of research specialization. During the 1980s, however, crises of two types have created an environment for agricultural research institutions which gives reason for a fresh look at a systems framework for research. Firstly, economic pressures have brought about scrutiny of the current cost-effectiveness of research and a new demand for relevance and accountability to producer clients. Secondly, serious land degradation problems, some exaccerbated by previous yield-improving technologies, has resulted in a new need to view farming in terms of managing a fragile ecosystem. Some sort of systems approach is essential for efficiently targetting research within complex production systems using both productivity and sustainability criteria.

The aim of this paper is to consider a systems approach to agricultural research in a developed-country context which draws on several well-developed schemes and to illustrate such an approach using a study of the feasibility of dryland cropping in northern Australia.

## A SYSTEMS PHILOSOPHY FOR AGRICULTURAL RESEARCH

The notion of a systems approach to agricultural research was an outgrowth of the development of general systems theory and its applications in industry in the 1960s. The basic philosophical tenet that "the whole is more than the sum of its parts" implies that combining the outcome of (even excellent) disciplinary research does not guarantee a realistic understanding of system phenomena; organisms or phenomena must be seen and studied in their complex relationships.

This philosophy is common to several schema for agricultural research in a systems context but which differ in their specific aims and in methodologies. Farming Systems Research (1) is characterized by its focus on efficient improvement of the welfare of a target group of farmers in a region by improved technology/management. Conway's Agroecosystem Analysis and Development methodology (2) aims to improve the management of the agricultural production resources of a physical region, identified as being relatively homogeneous. A third approach, the Systems Approach (3) is characterized less by its goals than by its methods, methods in which mathematical models mimic important aspects of agricultural systems.

### Farming Systems Research

Figure 1 is a diagram of FSR which originates from Collinson (4), was modified by Dillon and Virmani (5) and further modified here. Collinson's scheme, in keeping with the basic tenet of FSR, begins and ends with the farmer in (i). Emphasis is on identification of research needs on the farm and conduct of research on the farm in association with the farmer, supported by appropriate research on stations.

While in principle, this on-farm focus maximizes the prospect of research adoption (if innovations are simple adaptations), concerns about the economics of this concentration of research resources on such specific targets have been expressed (6). In Australia, unless the issues are clearly general, the targetting of major research effort on specific groups of farmers is probably not generally affordable. Since the concept of targetted research expressed in the diagram seems applicable and equally helpful at larger scales, possible targets in Fig. 1 have been broadened to include an agroecosystem or an industry (Fig. 1, i).

The first research stage (Fig. 1, ii) is diagnosis of problems and/or development opportunities in the production system. An important contribution here is the priorities expressed by producers. In the next stage, (iii), decisions must be made about whether research is needed and, if so, what research. If sufficient understanding can be gained from the existing body of knowledge (vii), then steps can be taken to formulate possible solutions to be tested, first in (iii) and then in (iv). Any new research of the sort conducted using research stations and/or intensive scientific input arises from (v) and when conducted in (vi) contributes further knowledge and material to (vii) which is evaluated in terms of its impact on the system, first in (iii) and then (conditionally) in (iv).

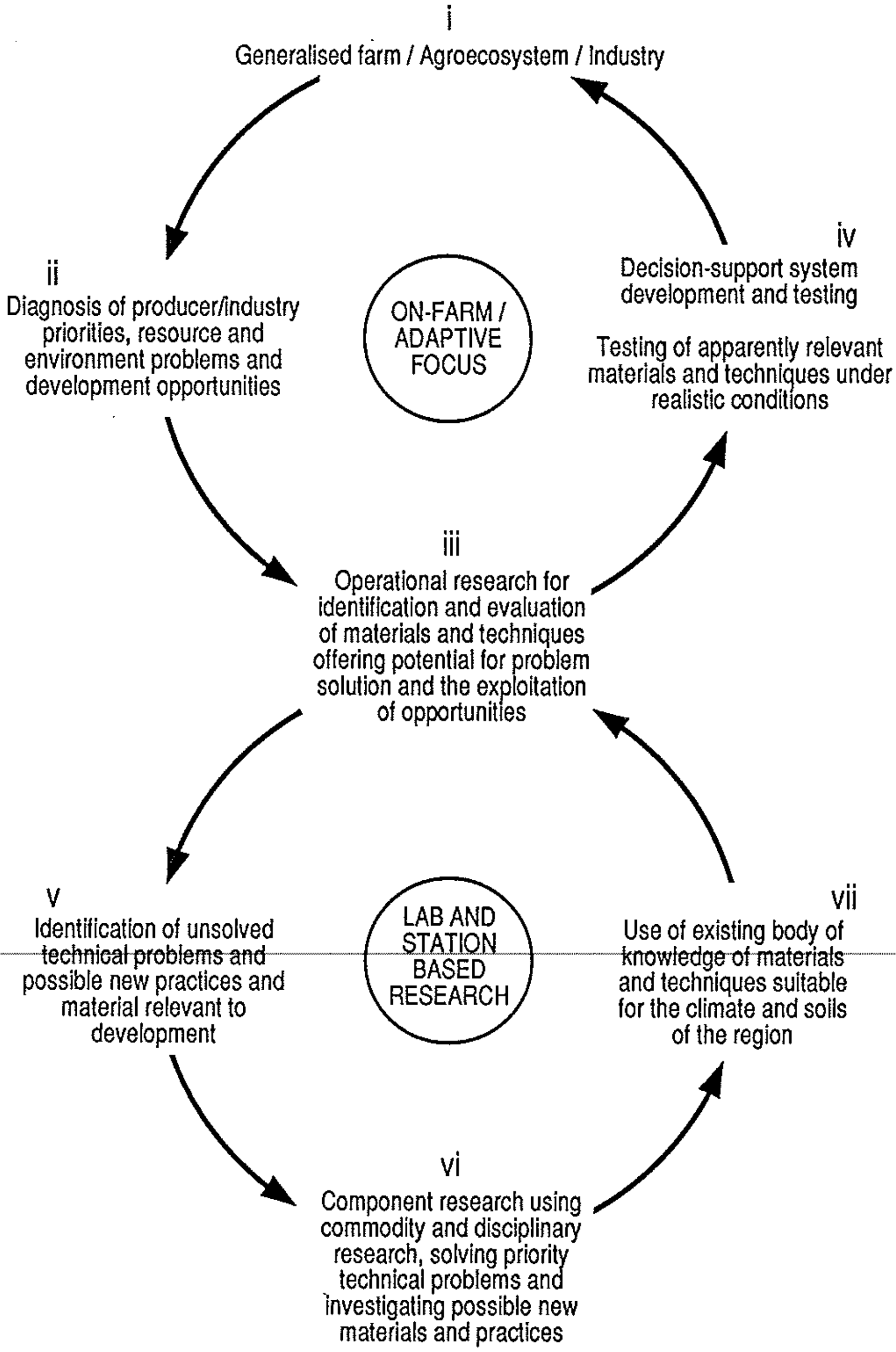

Figure 1. A schematic view of a systems methodology for targetted agricultural research.

When the target is an agricultural production system in an area in which the land and biological resources are relatively homogeneous, and the central purpose for research is improvement of the system's performance, the broad conceptual relationships between the production system and agricultural research in FSR merge with those of Agroecosystem Analysis and Development Agroecosystem Analysis (2).

The relationships in Figure 1 are not unfamiliar to Australian agriculturalists and agricultural scientists; in a general sense this is how research and extension already works. The important issue here is whether a more explicit systems approach can substantially improve the efficiency of this process.

## The Systems Approach - Systems Analysis and Simulation

This is a methodology for dealing objectively, and, as often as practicable, scientifically, with the complexity of systems (3). A mathematical model of the system is constructed which mimics the behaviour of the real system, allowing studies of the response of the system to various factors to be made using the model.

Computer-based experimentation using a model which can simulate crop or animal response to management inputs or environment has certain important advantages over field experimentation. The high cost of field experiments means that they can be conducted in only a few places and in only a few years at any location. However, once an adequate model exists, simulation experiments can be conducted cheaply at any location for which there is data on weather and soil and in as many years for which there are weather records or for as many years as is needed for estimates of year-to-year variability. (Requirements for long sequences of historical weather data are declining with the development of weather simulators). Two of the most important attributes of agroecosystems are (a) the variability and unpredictability of yields among growing seasons and (b) sustainability of average yields in the long term. Models provide the most practical way for research to efficiently explore the range of possible management strategies for addressing these for different climates, soils, and farmer goals and socioeconomic circumstances.

Since models of relevant components of farming systems have been around for over 15 years, the question might well be asked as to why we haven't seen more achievement from research involving models. Firstly, adequate simulation of yield response over a sufficiently wide range of conditions has been found to be more difficult to achieve than expected. Secondly, only a minority of modelling efforts had the improvement of a farming system as a concrete objective. The interests of research groups with the required skills for biological modelling most often has been in model building. Less often this interest extends to model evaluation, and even less frequently does it include model application. Furthermore, systems simulation does not share the explicit utilitarian orientation of FSR and Agroecosystems Research, and even when the expressed purpose is improvement of farming systems, as Dent and Blackie (7) point out, there is no intrinsic means to consider important socio-economic factors.

In spite of past shortfalls and limitations, the potential of these methods in agricultural research remains high, and a resurgence of interest in them appears to be in progress (8). One reason for this is that substantial progress has been made in modelling strategies and in the development of models of key land and crop processes; a large portion of the development costs of useful production system models has been paid.

Secondly, as a result of the personal computing revolution, there is a new degree of receptivity to this computing-intensive methodology. Thirdly, deficiencies in considering socio-economic factors can be overcome by the merging of these methods with the philosophy of FSR.

## OPERATIONAL RESEARCH IN FSR

The notion of integrating the science of using models of systems with Farming Systems Research is not novel (5, 8), yet there is little evidence of it happening. In proposing this integration of methods, Dillon and Virmani (5) introduced the term <u>operational research</u> into component (iii) of the Collinson diagram of FSR (Fig. 1). Operational research can be defined as the application of the methods of science to complex problems which arise in directing and managing large systems of men, machines, materials, and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcomes of alternative decisions, strategies and controls. The purpose is to help management determine its policy and actions scientifically (adapted from (9)). In general, the term "operational research" (or "operations research") is not used much in agricultural circles, where "systems approach" has effectively substituted (3). However, as a component activity of Farming Systems Research, "operational research" is a more distinctive term.

The key to improved efficiency of research in FSR is in (Fig. 1, iii). This is where decisions are made regarding research priorities. Collinson (2) refers to this as the planning stage. Two interrelated objectives can be distinguished. The first is identification of those possible changes to the system that might be relevant and feasible. The second is the evaluation of selected potential innovations in terms of efficacy and feasibility prior to either testing them on farms or committing research resources to them.

Effective operational research in this context requires (a) a perspective of agriculture systems that is in keeping with FSR focus on relevance, together with a scientific systems approach to research (3); and (b) a good understanding of the existing farming system or agroecosystem. While the breadth of understanding needed may require a multidisciplinary team it is essential that the team include generalists - individuals with special talent in evaluating and integrating information and interpreting outcomes in terms of overall system performance. In most FSR to date, the quality of decisions in (Fig. 1, iii) has depended on the experience and good judgement of the scientists involved. While it is hard to imagine the value of these human ingredients declining, the decision process can be greatly aided by computer-based tools. The combination of a biological simulation model of a relevant system or enterprise and a compatible method for economic analysis (11) provides a powerful aid to evaluate system performance and the effects of possible changes or innovations in terms of both short- and long-term ecology and economics.

The operational research activity is not exclusive to the planning stage of FSR (Fig. 1, iii). Field research needed for developing and testing models, and testing the operational feasibility of complex technical strategies overlaps with field research on components (Fig. 1, vi). Adequate description of certain problems such as climatic risk require the use of models in conjunction with (Fig. 1, ii). Development of decision support systems for producers in variable climates (part of Fig. 1, iv) requires use of models to generate relevant probability distributions of outcomes. On-farm testing can be conducted in only a few places and years, and generalization of results depend heavily on use of the simulation models driven by weather from other years and locations and specified for other soils.

What criteria are used to judge performance in this research which uses simulated system function to gain insight to the function of real-world grain production systems? For some purposes the farming system is helpfully viewed as an agroecosystem and performance viewed in terms of productivity, stability, and sustainability (2). Ultimately, however, performance must be in terms of economic returns to producers both now and in the future. This approach offers a means to assist producer decisions-makers over a range of physical and economic environments by providing strategies for (a) risk efficient grain production and (b) maintenance of soil productivity. A superior strategy for the former does not simply increase average production and profit; it is preferred to other strategies by "risk-averse" farmers. A superior strategy for (b) must result in slower decline in production as a result of practices that maintain a more favourable soil state as regards organic matter, erosion, acidity, salinity, etc.

## THE APPLICATION OF A FARMING SYSTEMS APPROACH IN RESEARCH IN NORTHERN AUSTRALIA

A project to assess the feasibility of dryland cropping in the semi-arid tropics (SAT) provides an example of certain aspects of this approach to research. In 1978 self-government for the N.T. gave rise to reconsideration of the development of dryland cropping to complement the existing extensive beef industry. Land resource surveys had indicated sizeable areas of land with apparently favourable climate and soils in the Daly Basin; considerable cropping experience had accrued from previous local research and commercial (failed) cropping schemes. In 1978 CSIRO initiated a project to reassess the feasibility of cropping with the benefit of hindsight of past problems and mistakes and the availability of new technology not available in the previous cropping era.

It had become clear that water erosion of cultivated croplands was a particularly serious problem in this rainfall environment. Recent research in similar environments in Nigeria had demonstrated the benefits of no-tillage/mulch retention in conserving soil and water. This same research had shown benefits of mulch in reducing high soil temperatures, thus aiding crop establishment at these latitudes. The fact that severe soil surface conditions had been shown to be a serious problem at Katherine added to the case for an evaluation of no-tillage/mulch retention in any new research on cropping.

The ley farming system of southern and western Australia had long been viewed as a possible model for the tropics where there was a well-established grazing industry and where supply of soil nitrogen was a substantial cost of crop production. Recent research in tropical Australia had produced several well-adapted, productive, pasture legumes. However in the more extensive grazing systems of the Northern Territory, the economics of oversowing pasture legumes was considered marginal. Could sown pasture be profitable if it provided nitrogen for crops in a ley system in addition to improved forage? A research program was undertaken to answer the question " Could cropping in a no-till, legume ley system be profitable and ecologically sustainable in the semi-arid tropics of northern Australia?

This hypothetical system was viewed by the researchers as in Fig. 2. In addition to legume ley pasture and the grain crop, there is an intercrop of pasture legumes that results from legume seed germinating after pasture kill and crop planting. The main features of the system are: (a) legume pastures of 1-3 years duration in rotation with maize or grain sorghum, (b) cattle graze native grass pastures during the green season and leguminous pasture and crop residues in the dry season, (c) crops are planted directly into chemically killed pasture, and (d) an understory of volunteer legume is allowed to form in the grain crop.

The first question we faced was that of how a small team could evaluate this complex system in a reasonable time. Our first step was to identify four compartments which we considered sub-systems: (a) the effect of the legume ley on crop production, (b) the effect of no-tillage/mulch on crop production, (c) the effects of the presence of a forage legume intercrop on crop production and dry season feed supply, and (d) the effects of cattle-ley pasture relations on animal and crop production.

Our ultimate goal was (and remains) to be able to assess the feasibility of dry-land grain cropping at any given site in northern Australia taking into account local climate and soil factors. It was clear from the outset that most research must be conducted at Katherine, N.T., and that extrapolations of findings to other (relatively similar) locations would depend heavily on crop-climate-soil models and existing data bases of soil and climatic information.

The initial phase of the research was to evaluate the first three sub-systems - the effects of leys, no-till/mulch, and forage legume intercrops on crop production. In each of these, a hierarchy of questions was constructed. Are legume leys and no-till technically feasible in the SAT? What is the nutritional contribution to grazing cattle of croplands consisting of maize stover and swards of dry legume? Each question logically raises several others subsidiary to it. For example, with regard to the feasibility of legume leys, what is the effect of duration of ley on grass invasion and crop N supply? How much do legume species differ in these?

The organizing of perceived problems as systems of ordered questions for research is a key step in the Agroecosystem Analysis and Development methodology of Conway (2) and in the planning stage of FSR (11). The value is, of course, in directing resources to those matters most pertinent to the goal of improved system performances and avoiding tendencies to fill information deficits in accord with a different agenda, e.g. originality in practice of a scientific discipline.

Using on-stations experiments, over a period of six years, we obtained answers to the main technical questions. Crop production was as high or higher with no-tillage as long as there is adequate mulch. One year of productive pasture legume can provide the equivalent benefit of as much as 70 kg fertilizer N. A legume intercrop competes for both water and N, but the magnitude varies widely among seasons. The biggest problem in the grazed system was grass invasion, even in leys of only two years duration.

In most cases, answers were conditional on seasonal characteristics and soil type. In some years there was little response to N fertilizer or previous legume ley history. In years when the rains started late there was little production of pasture/weeds prior to planting resulting in insufficient mulch at planting. In some years there was evidence of large

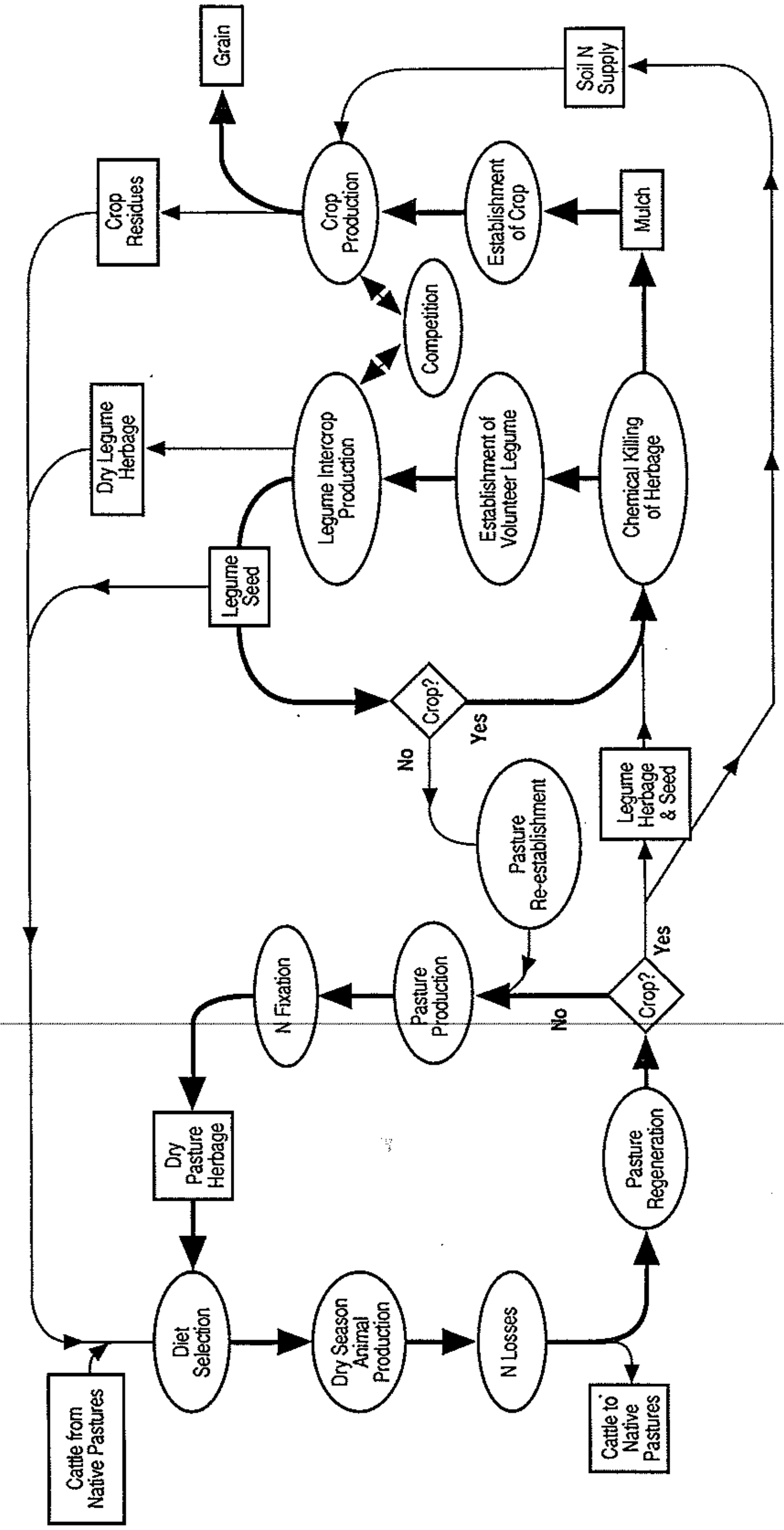

Figure 2. The hypothetical farming system being evaluated at Katherine showing flow of inputs among sub systems (boxes) and important processes being researched (ovals).

nitrate leaching losses on the sandy soil. The remaining question in these cases, and many others like them, is "How often can this be expected? In terms of our project goal of establishing the feasibility of various dryland cropping practices, this dimension of temporal variability is crucial. Since we could not conduct experiments in sufficient years (nor in enough places to deal with the geographic dimension), the use of simulation models was required.

Up to this point, in terms of Fig. 1 (i), the project had identified an agroecosystem characterized as arable red earth soils in the SAT, identified key resource limitations (ii), identified possible solutions in (iii) and proceeded to research various components via (v) and (vi).

A new phase of the project began with a focus on developing a capability for simulating yields of crops of interest in this climatic region. To do so would enable problem definition in Fig. 1, (ii) to consider climatic risk, to make first approximations of the implications of risk on the various components of the hypothetical system under evaluation, and to be able to do replicate this exercise for other places in this zone on similar soils. The strategy adopted was (a) to minimize our investment by identifying and adopting the most appropriate existing models; (b) to test and adapt models using data initially from Katherine; and (c) to further test the model using data from other locations.

We began by acquiring CERES-Maize (12), one of a family of cereal models developed at Temple, Texas under the leadership of Joe Ritchie. This model and software package was highly developed - the product of many man-years of research and development. The level of explicit treatment of processes seemed appropriate to facilitate re-specification for a new site or genotype using information that was of practical types and amounts. Most importantly, CERES included a nitrogen sub-model.

We are now engaged in developing a family of models of the CERES type for the tropics. Maize has been adapted (13) and a tropical sorghum model developed from the tropical maize model (14). Field data sets have been collected for Carribean stylo pasture, kenaf, soybean, mung bean and cowpea, and models are being developed for these crops, utilizing the structure and format of CERES-Maize as far as is practicable. Special attention has been given to testing and adapting the N sub-model for predicting mineral N supply following pasture leys of legumes or grass, and on soils differing in rates of mineralization and leaching.

The high priority of evaluation of no-tillage and mulch retention in this project places a high premium on a capability to model water and energy flux at the soil surface. Models of the effects of mulch (15) and improved models of water entry with more explicit treatment of roughness and conductivity factors have been developed (16).

Even with these changes and new developments, what we have are improved models of various crops and their environment, while what we need is a model of a cropping system which incorporates these. Although there are a few models of cropping systems, none can readily utilize the modules which we now have.

To meet this need we have developed AUSIM as a generic model of a field (13). It consists of a core program and a library of crop and pasture growth submodels. The core program simulates changes in a specified soil in response to weather and management. It includes submodels of the processes that influence the status of water, N, and P, organic matter and mulch cover. Soil changes are simulated continuously whether under a crop, pasture, or a weedy or bare fallow. Crops and cultivars are selected from an open-ended list of crop-specific routines and genetic parameter files. Although this component of the model incorporates our existing validated crop and soil models, one change of great importance to the new model is the shift of all plant variables from the soil to the crop routines.

Relevant sequences of crops/pastures may be simulated in response to either assigned rotations or assigned decision rules. Mixtures of crops may be simulated using combinations of sole-crop growth routines; one application is the simulation of a crop with an associated weed component that competes for resources.

Surface residue dynamics are simulated, and output influences soil evaporation, water entry, and N and P supply.

In the next few years this model will be used to address several complex issues pertaining to cropping feasibility in northern Australia. Firstly, the relative risks due to high temperature and water stress of growing maize, sorghum, soybean, mungbean, and peanuts will be quantified. Yield probability distributions for various sites and soils will be generated by simulating production using historical weather records. This provides a quantitative description of the instability of production that producers face, or would face, when growing each of the main crops considered suitable for the region. For certain of these crops, a second task is to explore the opportunities for reducing risk by varying planting time and by changing phenology by breeding.

A third task is that of quantifying nitrogen fertilizer needs for coarse grain crops. Because the model simulates mechanistically and dynamically the effect of weather on N mineralization, leaching, and crop response, computer experiments can be conducted on the efficacy of pasture leys in replacing N fertilizer.

A variable having a major influence on the success of no-till planting in this climatic zone is the amount of mulch at planting, which is related to cumulative growing conditions prior to planting. A fourth task is to quantify the risk of inadequate mulch for the same set of stations, years, and soils as for crop yields.

A fifth task is to estimate the effects of various cropping sequences on long term organic matter trends (18).

All five of these tasks are activities in (ii) and (iii) in Figure 1. They all pertain to the ecological limitations and the degree to which technology and management might alleviate these limitations. Since we have no economist on the team, we are are presently exploring collaborative arrangements to provide the complementary economic assessment needed to evaluate the feasibility of a tropical dryland cropping industry.

Anderson _et al_. (10) examined the role of socioeconomic modelling in FSR and identified its place as being in (ii) and (iii) in Figure 1. Of the various types of economic models, they conclude that budgeting and mathematical programming (MP) are the most useful, the former because of simplicity and flexibility and the latter as a powerful approach to optimizing whole-farm systems. The investment required to develop an MP is unlikely to be warranted in the case of our assessment of the feasibiltiy of a non-existent farming system. However, where the aim is the improvement of an existing farming system, the development of an MP appears to be a very rewarding. This is exemplified by experience in Western Australia with MIDAS (Model of an Integrated Dryland Agricultural System), developed to assist a farming systems approach to research and extension (19).

## FARMING SYSTEMS RESEARCH IN THE HEARTLAND OF AUSTRALIAN AGRICULTURE

Much of Australia's agricultural income comes from production of wheat and wool in the Mediterranean zone. In the main, economic success of this agriculture has been more in spite of than because of the quality of the natural resource base. Success can be attributed instead to technological innovations for which Australian farmers and scientists are deservedly renowned. With this history, it is not surprising that our research and development philosophy has featured (a) a rather adversarial attitude toward the environment and (b) a belief that technology will conquer. However there is increasing evidence that we have entered an era in which the opportunities for dramatic technical advances have been largely exhausted and the priority need is to improve the management of our resources.

Agricultural management in Australia's Mediterranean zone has become increasingly complex. The mixing of crop and grazing enterprises is an important means of coping with the uncertainties of the climate and the marketplace, but brings a high managerial requirement. Bare fallow has been a means of compensating for low quality of land in times and places where land is an abundant factor of production. However, fallow areas decrease as production pressure on land increases, with the net outcome of increased output, costs, and risks dependant largely on proficiency of management. In an earlier period, ley pastures largely replaced fallow in better watered regions. Today, as a result of continuing cost/price pressures, fallow in the drier regions is being progressively replaced by drought-tolerant grain legumes (20). The economic future of this large region depends on the management of a dynamic mosaic of practices including fallow, legume leys, lupin, and N fertilization (21) against a backdrop of high season-to-season variation in rainfall.

The complexity increases with the increased recognition of the need to manage to avoid problems of soil erosion, acidification, and salinity. One of the most promising innovations for a more sustainable agriculture is conservation tillage. However, here again a major cost for successful adoption is an increased management proficiency.

The potential value of having both an appropriate philosophy and methods for efficiently researching complex systems in order to improve their management is obviously high. Although it cannot be said that either are major features of current research in southern Australia generally, one can identify a number of important efforts where one or both is.

MIDAS has already been mentioned. This economic model has been used effectively as an operational research tool to indentify the optimal percentage of cropping vs. livestock (22), to identify the optimum time for lambing (23), to identify the potential role of lupin as a new crop (24),and to assess the economic feasibility of deep ripping as a means of increasing cereal yields (25). But the impact of MIDAS is limited, not only by its nature as an OP (mentioned earlier), but as yet it has been specified only for a limited number of sites in Western Australia.

A number of wheat models have been developed and tested (26, 27). A systematic program for development of models of the effects of tillage on soil properties important to crop growth is being conducted at Melbourne University (28).

While the quality of these efforts is high, it is somewhat ironical that there is such a paucity of agricultural systems research in Australia, when Australian scientists played such an important pioneering role in crop simulation modelling and in contributing to the development of currently important models internationally. There is a widespread attitude that systems research was a fad of the 1960s which flopped. That such a dated viewpoint is held so widely is the less surprising in light of the traumatic reductions in Australian research capabilities of recent years. Such "dark ages" do not foster interest in new possibilities as much as in survival. However, I think that the reassessment of Australia's agricultural research and its funding structure that is now occurring provides the ideal opportunity to consider moves toward a more systems-oriented approach. Open-minded attention should be given to current efforts, and the onus is on these projects to demonstrate value for money.

In conclusion, I see two compelling reasons for widespread use of an appropriate version of FSR in Australia. The first is to improve the relevance and efficiency of research in response to new expectations that research tangibly benefits agricultural systems. The second is to better respond to the several alarming land degradation problems of existing agricultural production systems and the increased sensitivity of the public regarding land conservation. The most immediate effect would be the contribution of a framework along the lines of Figure 1 to aid identification of research priorities and assist disciplinary research to be more relevant. However, I believe to adequately serve Australian needs for more effective research on systems issues, FSR methodology must include use of both simulation modelling and economic modelling. Economic modelling provides the ultimate integration; simulation modelling provides the flexibility for efficiently dealing with (a) variation in weather, soils, crops, etc; (b) the complex interactions between plants, animals and the environment; and (c) a wide range of possible management interventions.

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