The development of strategies for improved agricultural systems and land-use management

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"The structure of a farm system at any time ...depends on all technical economic, social, cultural, and political influences that impinge on the farmer..."
Hans Ruthenberg

"The capacity for control made possible by the empirical sciences is not to be confused with the capacity for enlightened action..."
Jurgen Habermas

Key words: decision models, farming-systems research, Kenya, land use, land-use management, simulation models, systems research

Abstract
There is a pressing need for better management of agricultural lands in much of the developing world. Understanding what changes are needed and how they might be stimulated is the central task of agricultural systems research. But past experience in systems research in non-agricultural fields, where systems research methods developed, shows that a scientific approach to management has had limited effect on what managers actually do. In agriculture, farming-systems research methodology has demonstrated the importance of farmer involvement if research is to change the practice of agriculture. Yet, although participation appears necessary, it has proved to be insufficient in systems where there are strong resource constraints.

Where such constraints exist, e.g., in the semi-arid tropics, progress requires a capability to compare options that are not currently available or feasible for farmers. An approach which uses improved agricultural production simulation models and economic decision models makes this possible. This approach is demonstrated using experiences from work in semi-arid Kenya where investment in soil enrichment in fertility-depleted croplands is deterred by the unreliability of rainfall. Although few farmers currently purchase fertilizer for maize production, augmentation of manure with modest amounts of nitrogen fertilizer appeared (a) to be needed for sustainable cropping, (b) to be profitable in the long term, and (c) to have variation in returns consistent with local farmers' attitudes concerning risk. This approach also was used to compare the risks and returns of two policy strategies, i.e. migration of farmers to drier areas vs. investment in increasing the soil fertility of existing croplands.

The paper concludes that the best prospects for developing better policy and management strategies lie with skilful use of "hard" systems tools within a "soft" systems philosophical framework.

Introduction

The above quotation from Ruthenberg (1980) reminds us that a way of farming is a complex adaptation, often displaying ingenuity deserving of high admiration. Yet today, there is widespread concern about the prevalence of apparently ill-adapted

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practices of many farmers around the world, as agricultural lands come under increased pressure. In industrialized societies, economic pressure often results in management strategies that are ecologically damaging. In many less-developed countries, population pressure is causing reductions in farm size, production and returns, and forcing damaging over-exploitation of land resources. In both situations, conflicts arise when adaptations that serve farmer objectives adversely affect the interests of the farmers of the future and/or of the wider community now. Adaptations expected of farmers are increasingly complex, costly and/or risky. Increasingly, it is recognized that better government policies and research and development (R&D) planning are necessary to create environments that result in different strategy choices by farmers, and ones that can be seen as adaptive in the broader context.

This paper is about agricultural systems research methodology that facilitates the exploration of alternative production strategies and their economic and ecological consequences. We begin with a glance at the history of systems research, and it becomes clear that any new venture must be aware of perils as well as prospects. Research methods using models to optimize strategic management in complex non-agricultural production systems have been in place for over half a century. In developing-country agriculture, farming-systems research (FSR) methodology has an experience spanning nearly two decades. Both of these disparate activities have resulted in considerable disappointment and disillusionment. However, what emerges from their combined experience provides the basis for what may be a more effective systems research approach for the development of improved farming strategies. We outline such an approach and describe applications for the development of improved farming and policy strategies in Africa.

The systems movement and its "crisis"

There is a new prominence in developed-country agricultural R&D of computer-based activities, such as simulation modelling, decision-support systems, and management information systems. The establishment of International Consortium for Application of System Approaches to Agriculture (ICASA) and the holding of this workshop is indicative of the high expectations for such technologies for benefiting developing-country agricultural R&D. Although seldom acknowledged, all these information technologies have been borrowed from a mainstream "systems movement" in non-agricultural fields, which began during World War II and later differentiated into the fields of systems engineering, operational (operations) research, RAND systems analysis, and management science. These all share a rational approach to solving complex problems that features an iterative process of problem definition, identification of alternatives, and evaluation of alternatives—the latter almost always using a model (Robertshaw et al. 1978). (In this paper we will mainly use the term "operational research" to refer to the use of models to develop management strategies.)

Some of the possibilities for agriculture were recognized a generation ago by perceptive agricultural scientists and economists, e.g., Van Bavel (1953), De Wit

(1965), Morley and Spedding (1968), and Dent and Anderson (1971). But to the disappointment of many, significant use of models for such research has had to wait nearly two decades, while models capable of adequately simulating the natural processes that are central to agricultural production systems were developed. To a considerable extent, the original concept of using models in this way has had to be rediscovered. During this period of discovery of ways to successfully model agricultural systems, an enormous experience in using models in non-agricultural production and distribution systems has accrued. What can we in agriculture learn from this experience, as we now enter a phase of model use?

The overwhelming single lesson is that information systems and technology developed by professionals to aid decision makers almost never "fits" the needs of decision makers as human actors in social systems (Ackoff 1967; Churchman 1974). Failure to recognize this has resulted in a crisis in systems research due to a general failure to influence what practitioners do (Checkland 1983). In agriculture, our experience of this failure has not been sustained for a period long enough to firmly reach this conclusion, but evidence is accruing (e.g., Cox 1993). Further impediments to making generally useful contributions are due to variations in the preferences, beliefs, and abilities of individual farmers, and conflict between the objectives of the farmer and the objectives of other stakeholders in the performance of agricultural production systems. The failure of traditional agricultural science to address this human factor, together with the influence of the new systems thinking stemming from mainstream systems research experience, have resulted in the emergence of different concepts and methodologies for dealing with the "softer", people-related, agricultural system issues. One of the perversities of contemporary agricultural systems research is that after 20 years developing biophysical models, just when they are ready for credible research on management, champions of a new, rapidly-growing, "soft" systems movement are sharply critical of this approach (e.g. Wilson and Morren 1990; Bawden and Packham 1992). The effect of this tends to reinforce the influence that FSR has had on agricultural R&D.

Clients, strategies, and FSR

FSR has long since demonstrated the inadequacy of new technology development alone as a basis for improvement of farming systems in developing countries. Although under intense scrutiny as the natural resource aspects of farming increase in priority, FSR has had a major role in changing the performance of R&D in appreciating farm problems and research needs and in including the farmer-client in the research process. As the focus shifts from strategies for improved production efficiencies to include strategies for the better care of natural resources, R&D planners and government policymakers are viewed increasingly as primary clients for research on such strategies. But ultimately, the key actors are farmers: new management strategies will be their new strategies. How then do researchers contribute to improved strategies?

While many would readily sympathize with the flippant answer, "not easily", FSR methodology provides a basic framework for a meaningful answer. Professionals work with farmers in gaining knowledge of the farm system and in identifying problems and opportunities (figure 1, upper left). Testing of potential innovations is done on farms with and by farmers (figure 1, upper right). As shown in figure 1, in concept, FSR provides the linkages between farmers and professionals that are needed. Yet, the achievements of this research approach have fallen far short of expectations, and, with clear hindsight, good reasons are not hard to find.

Norman and Collinson (1985) pointed out two strategies for dealing with a constraint in the farming system: relieve it, or avoid it by exploiting flexibility in the system. They observed that it is the presence of under-utilized resources that enables

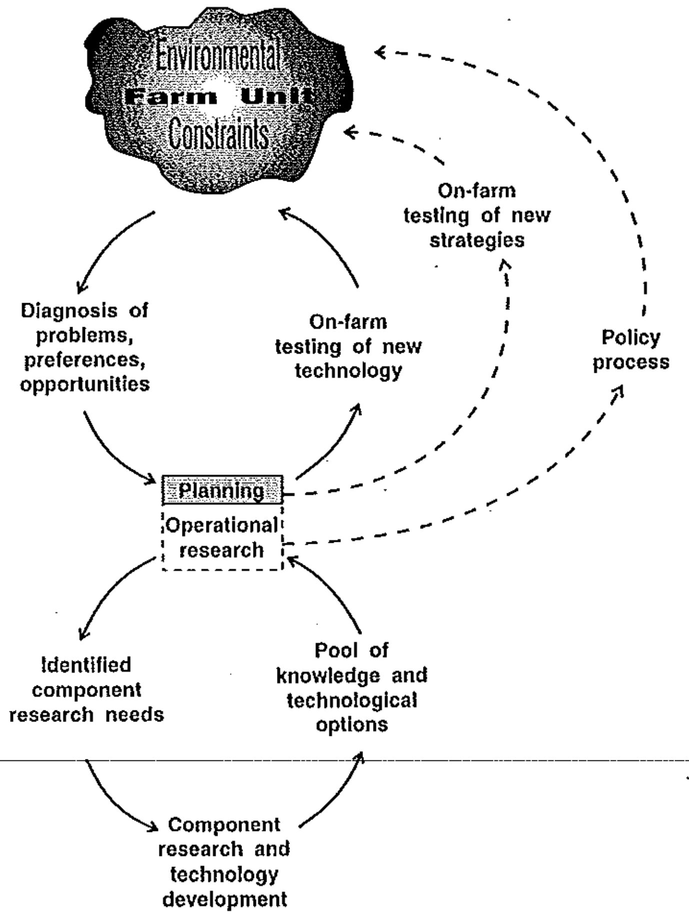

Figure 1. A schematic representation of farming systems research (adapted from Dillon and Vermani 1985)

flexibility in management, and that the success of FSR can be attributed to exploitation of such flexibility, rather than relieving constraints. They recognized that major long-term increases in productivity have to come through relieving constraints and argued that increase in productivity can provide the means to relieve a constraint. Seven years later, Waddington (1992) reported examples of successful on-farm experimentation by FSR teams. He observed that most examples could be regarded as "fine tuning" of existing technology in environments with some slack in resources. Where technologies did not already exist, and in regions with great pressure on resources, little success was experienced.

FSR workers progressively realized the probable need for government policy intervention if many farmers were to be able to adopt technology and strategies for sustainable farming (Norman and Collinson 1985; Biggs and Farrington 1992). FSR offered no methodical way to contribute to the policy process comparable to that for farm-level intervention, as indicated in figure 1 (Fox et al. 1990).

In the FSR procedure of figure 1, the key step for innovative change is that of planning (center). The potential for creative contribution by professionals is in response to questions such as the following: "Given this situation, what might be possible/feasible among the available options?"; "What new technology development initiatives are warranted?"; "What is the least unattractive option for relieving a soil-nitrogen constraint?"; "How much would the price of fertilizer need to fall before greater use could be expected?"; or "How should nitrogen fertilizer be marketed?" Traditionally, the most important ingredient for success in the planning step has been good judgement by an experienced and clever professional. While it is difficult to conceive that this ingredient will become less valuable in the future, it will increasingly need to be supported by quantitative analyses. The challenge is to introduce into this activity a methodology that enables quantitative comparison of possible management strategies in terms of their economic and ecological consequences. Not the least important contribution to be made here is demonstration of the poor chance of success of certain proffered options so that they can be dismissed, rather than forming the basis of expensive research programs.

A more analytical planning stage is not a new idea, but it is an idea whose time has come because of a new urgency and new capabilities that increase the chances of success. Dillon and Virmani (1985), in modifying the original FSR schema of Collinson (1982) substituted the term operational research (OR) for planning (see figure 1, center). While a term rarely used in agriculture, except by economists, this embodies the traditional "hard" systems approach to identifying optimal management strategies for large and complex systems, aided by models of the system or subsystems. Other FSR economists, while appreciating the value of the thinking process of OR, had previously judged that the benefits of "high-powered" economic modelling did not sufficiently outweigh the high costs of model development, testing, and application (Anderson et al. 1985). But by the late 1980s, simulation models had developed sufficiently so that marriage of this type of model (in conjunction with economic analyses) with FSR appeared to offer a new, more flexible and powerful systems approach (Thornton and McGregor 1988; McCown 1991; Thornton 1991).

FSR had a very beneficial effect in re-orienting researchers from disciplinary goals to serving clients, and the approach has been successful in identifying ways to more efficiently exploit slack in farm production resources. But in very resource-poor, climatically-variable situations, comparison of farmer options is problematic. Not only are options often apparently not economically feasible, but superiority of options will vary so much between years that comparisons in a short-term experiment cannot give a clear outcome. The quantitative methods in what is developing as an agricultural operational research approach provides a means of reducing this limitation. Simulated yields for a long period of years may indicate that an input such as fertilizer, while not profitable every season, is a good financial investment. There is also the possibility that the results could demonstrate a policy action that may make an ecologically sound farming strategy that is the "least unattractive" to the farm firm sufficiently attractive to result in its adoption as the best way to meet the farm's objectives.

Developments in using simulation modelling in an FSR perspective

The Agricultural Production Systems Research Unit (APSRU) was established in 1991 by the Queensland Department of Primary Industries and the Division of Tropical Pastures of CSIRO, Australia. Its aim is to provide benefits to a range of clients through agricultural systems research, leading to improvements in production efficiency, risk management, and sustainability.

The decision to establish a systems group of over 20 people in a period of shrinking research resources was taken on the strength of the achievements and the promise of simulation modelling as a tool in research for improved management. In spite of the harsh critique of the poor use or misuse of such "hard" approaches in other fields, they have been, and continue to be, unsurpassed in dealing with many well-structured problems (Checkland 1981; Jackson and Keys 1984). We are using our new hard systems tools in the applications that they clearly suit, and are trying to be good students, both of their limits and of complementary methodologies. In doing this, we are beginning to design a new, more effective systems research methodology. The shape this is taking, in the context of strategy development, is depicted in figure 3 and clearly has its origins in figure 2.

We view farmers as our primary clients, but we are also concerned with the decision problems faced by a range of other decision makers (figure 2, top) who have a stake in the performance of agricultural production systems and whose decisions influence, and are influenced by, farmers. Objectives vary among classes of clients, and it is to be expected that priorities for farm or farming-system performance will vary. On the other hand, some of these clients experience many of the same uncertainties as farmers, especially those concerning rainfall and prices.

Our aim is to contribute to better management and planning decisions (figure 2, right). To avoid the trap experienced in management research, which we described earlier, we invest in learning from and with clients the context and structure of decisions (figure 2, left). With farmer clients, we need to know their "rules" for

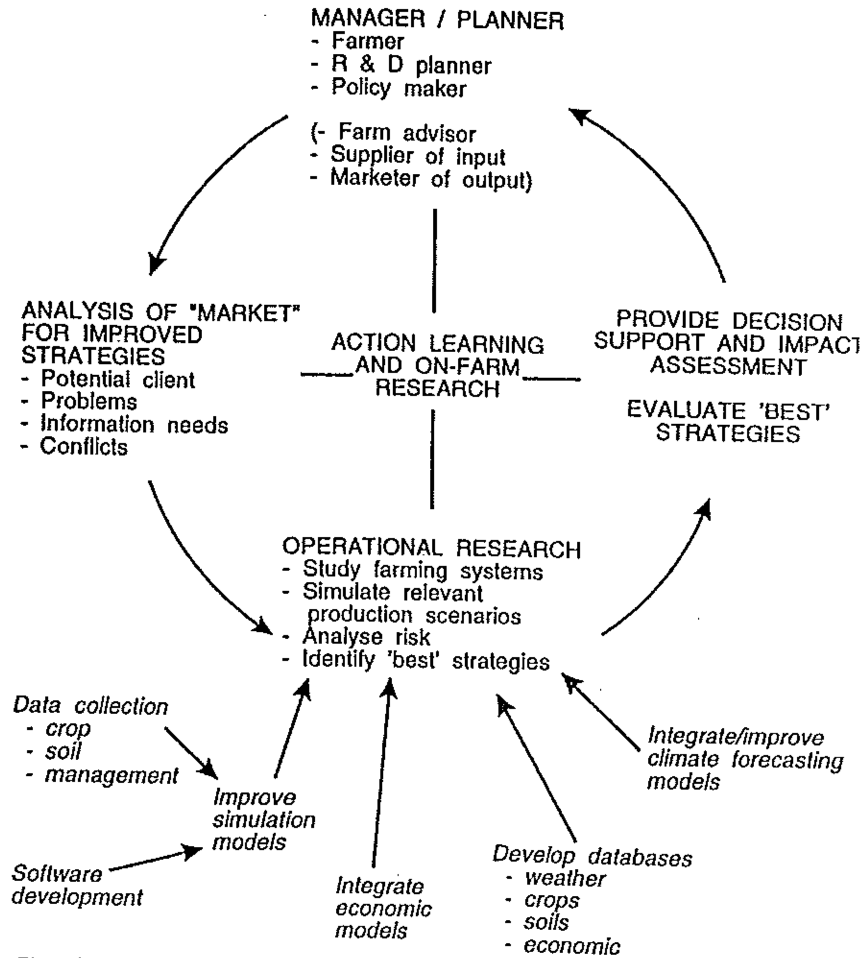

Figure 2. A systems research framework that is evolving in Australia

decisions. In many cases, farmers' rules are likely to be effective because they reflect the interdependence between different components, and the open character of agricultural production systems (Cox 1993). Change may be needed, but professional initiatives for change need to be carefully considered and tailored in the light of such knowledge. Similarly, to contribute to policy we must be knowledgeable about the policy process, the specific issues, and the niches for professional contribution.

We draw heavily from operational research principles in our systems approach (figure 2, center), but not on the stereotypic methods and algorithms and the rigid mathematical precision that have come to characterize that field. Our approach involves study of the simulated performance of farming systems primarily in terms of production efficiencies, production and price risks, and the cumulative effects on the soil resource. In each, the emphasis is on the economic consequences of alternative actions over time. This is the starting point for addressing such questions as "why don't more farmers invest more in soil fertility".

We use models in projects with clients. With farmers, this entails simulating the outcomes of collaborative on-farm experiments and then extrapolating the experiments in time, using historical weather records. With R&D managers, it entails similarly weakening the time and place "trap" of experiments, in order to add value to expensive research and to assist in the planning of future research. Clients with an appreciation of how the models work and how well the model simulates their own experiments are keen participants in the next step, which is to use models to explore strategies that take them beyond their experience. Absence of such appreciation results in distrust of even the glossiest information technology.

The effectiveness of this approach depends heavily on an adequate modelling capability. We agree with Seligman (1990) and Loomis (1985) that the R&D effort most likely to provide efficient progress using this approach is by testing and improving the best of existing models. This needs major effort in the collection of good field data. We have judged that acceptable rates and costs of progress will also require software designed to reduce the overheads of simulation modelling in research and to facilitate efficient convergence of modelling effort both within and among teams. APSRU has produced, and continues to develop and enhance, a novel software system, APSIM (McCown et al. 1993), for developing, testing, and using simulation models of crop and grazing animal production systems.

An example of operational research in FSR to identify strategies for sustainable agriculture in Kenya

Fertilizer-augmented soil enrichment

In much of sub-Saharan Africa, agricultural resources are under serious threat. Cropland productivity is being rapidly consumed as a result of high rates of rural population growth, shortage of suitable land for further expansion of cropping, and poverty, which precludes replacement of soil nutrients at rates that will sustain productivity (Broekhuyse and Allen 1988; Lynam 1978). Grazing lands are suffering similarly. The process, which impoverishes both land and people, is depicted in figure 3.

We encountered the "poverty trap" (figure 3) in a project in Ukambani in the Machakos-Kitui Districts of Eastern Kenya. Even in good seasons crop yields were low (due most conspicuously to nitrogen deficiencies), incomes from farming were low, and purchased inputs to production were correspondingly low. It seemed clear that the key to breaking this cycle was soil enrichment. But this view was not shared by our research colleagues. In the wake of a major FSR project in the region, which had focused the attention of the research establishment on farmer problems, our

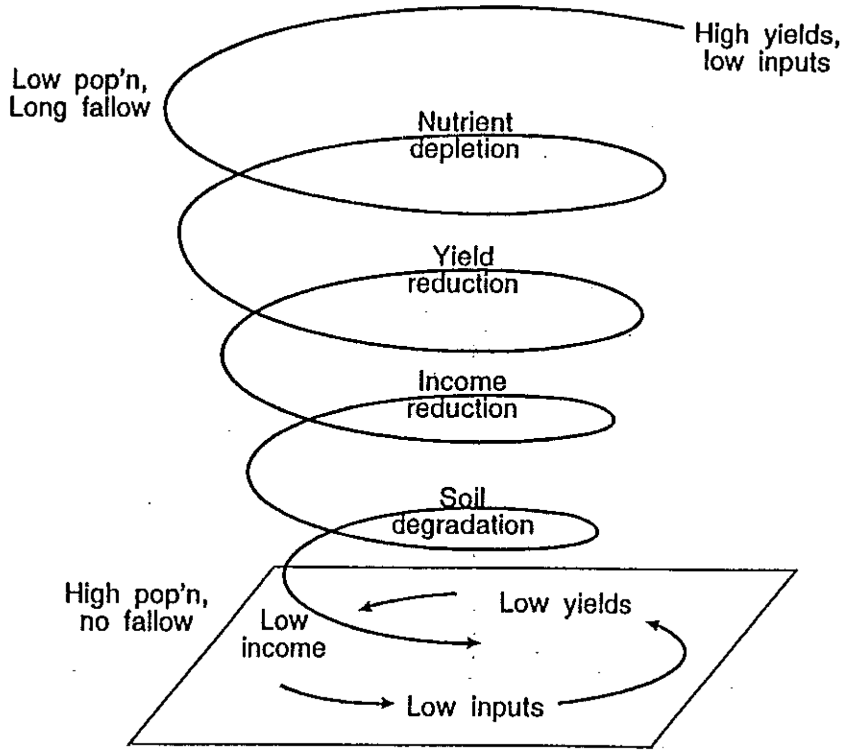

Figure 3. The poverty trap that results from human population pressure on land

proposed research focus was challenged because our proposal included investigation of the costs and benefits of commercial fertilizer (among other sources of nutrients). It was argued that this was not appropriate because "farmers here don't use fertilizer".

An important element of our research strategy was our study of a few farms where managers had come to recognize the value of fertilizer in augmenting manure applications, and were prospering from it. This sharpened the focus of the project on whether the many farmers who did not use fertilizer should be doing so in the farm's economic interests and at prices which are consistent with the manager's perception of risk. In order to quantify what the yield improvements might be in response to fertilizer inputs, we conducted a number of experiments on farmers' fields. But this could be in only a few places, and most importantly, in only a very few seasons. Since, in any given season, there is a high probability of water being more limiting than nitrogen, this would have been an inadequate approach were it not for the opportunity to use the model to "conduct" the experiment in many more years using historical daily rainfall records as inputs. The study and the outcome is reported by Keating et al. (1991). Gross margins from the application of nil and 40 kg fertilizer N for the long rainy season varied greatly from season to season. While fertilizer inputs incurred higher risk of losses, this was small compared to income foregone in good seasons without fertilizer input.

Our on-farm socioeconomic studies (Ockwell et al. 1991; Muhammad and Parton 1992) revealed that while farmers were acutely aware of, and profoundly influenced by, the uncertainty of rainfall, they were not more risk-averse than farmers reported from studies of smallholders in other parts of the world (McCown et al. 1991). This provided an opportunity to use an established technique for identifying the most risk-efficient fertilizer investments, i.e., the ones that farmers might be expected to choose. Figure 4 shows the average gross margin for each fertilizer rate (for standard initial soil N conditions) plotted against the standard deviation (s.d.) for each. The line connecting the points of highest average-lowest standard deviation forms a risk efficient frontier, upon which lies the optimal action. Based on findings that the attitudes to risk of many of these farmers were of the same magnitude of those reported by Ryan (1984), the 2:1 indifference line is drawn in figure 4. Ryan reported that subsistence farmers in a number of regions seemed to be willing to accept an added risk accompanying increased returns, as long as the increase in s.d. was no more than double the increase in the mean. Using this, the optimal fertilizer input is indicated where the 2:1 line is tangential to the risk efficient frontier (about 30 kg N per ha at medium plant density). The strategy of the typical farmer in the district in question is the Nil fertilizer point (lower left). McCown et al. (1991) discuss reasons for prevalent farmer practice being so far below the apparent optimum, and the implications for research, extension, and policy.

Our objective, to identify an improved soil management strategy for Ukambani, has been only partially achieved. The simulation study, as part of the operational research approach (figures 1, 2, center), is largely completed and indicates that a fertilizer-augmented soil enrichment (FASE) strategy has promise. But there are some ecological and economic complications (Probert et al. 1992; McCown et al. 1992). For the next steps, two activities are needed: testing of strategy with farmers, and exploring the regional fertilizer policy issue with the appropriate government bodies.

Resettlement of farmers to margins of crop production regions

Kenya's cropping regions are, and will continue to be, some of the most heavily populated rural lands in Africa (Binswanger and Pingali 1988). There is a continual out-migration of farmers from over-populated areas of higher production potential to less-populated, lower-potential areas. There is in-migration to the Midlands of Ukambani from the Highlands, and out-migration from the Midlands to Lowland pastoral areas. While this is in line with Kenyan government policy, the net consequences of this movement may be more negative than is presently appreciated.

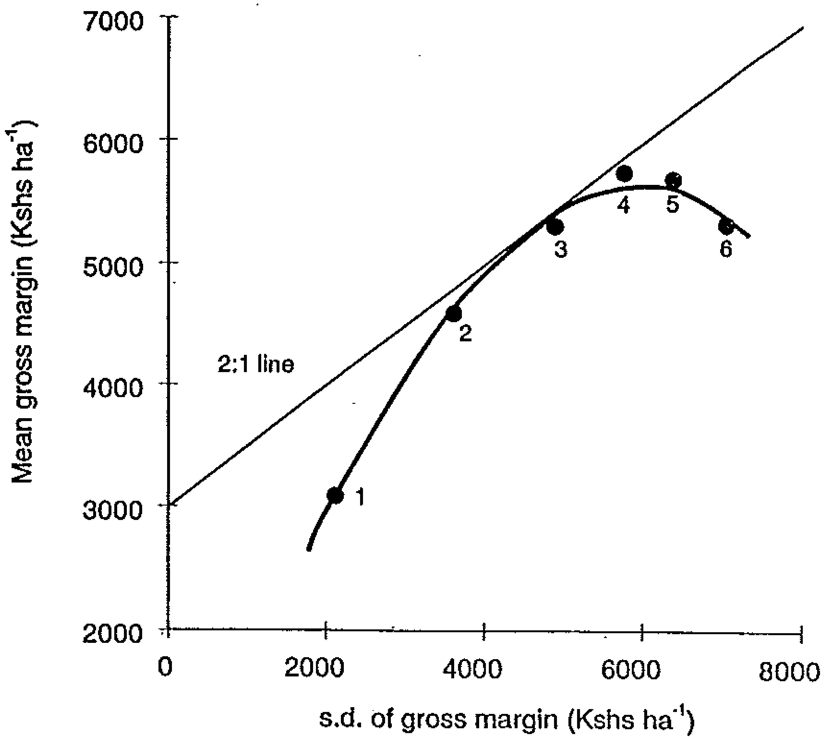

Figure 4. The values of various maize production strategies depicted in mean-standard deviation space. Strategies combined population density (plants/ha) and fertilizer nitrogen (kg/ha). Points 1-6 represent 22K, 0 kg; 27K, 15 kg; 33K, 30 kg; 38K, 45 kg; 44K, 60 kg; 55K, 80 kg.

Operational research using crop models and historical rainfall records from these regions provides a means of exploring some important questions about the implications of changing population pressure for the management of productive resources:

- The risks of crop failure, and hence the frequency of need for food relief from outside the region, is sufficiently great in the present croplands for its reduction to be the major objective of local agricultural research. How much worse will this problem be in the lands now being settled? It is possible to make a comparison using the maize model CMKEN. Figure 5 shows, first, the decline in expected yields in the old cropping areas, represented by Katumani, as soil fertility was mined. Migration from a depleted shamba at Katumani to the drier Makindu district, where newly-cultivated land has high fertility, results in large increases in yield in the best 30 percent of years with little difference in yield distribution in the other 70 percent of years, apart from a modest increase in the frequency of near-zero yields. Expected yields at Makindu after the soil fertility is depleted by prolonged cropping are considerably less than at Katumani; near zero yields can be expected for four in 10 years rather than two in 10 at Katumani. Economic disincentives for investment in soil enrichment now existing at Katumani will be considerably greater at Makindu.

- How long until the original high soil fertility is exhausted, and the same (but more serious) problems of investment in soil enrichment are faced? This would, of course, depend very much on levels of manure application, but it would be instructive to explore various scenarios. This has not been done in the project in Kenya, but models exist for achieving certain aspects of this. Keating (unpublished) has investigated the long-term effects of continuous cropping on a vertisol of initially high fertility at Roma, Queensland, Australia. This region is on the dry margin of the northern wheat belt. Simulations show that soil management would not be expected to affect gross margins for the first 20 years to 40 years (figure 6). Although the cumulative returns from the use of 40 kg N can be seen to be progressively less than from the hypothetical "forever-fertile" situation after 20 years, the difference between this substantial input and no input was not evident until after 40 years. Impressive differences between these feasible options occurred only after 60 years. Not only are the effects of nutrient mining so slow in appearing on this very fertile clay soil that noticeable effects span generations of farmers, but, even on old croplands, differences are masked by the high variability in rainfall. Differences between the most extreme scenarios are large only in the best seasons. This analysis could now be conducted for Makindu. The same tools also provide a means of exploring strategies for reversing the degradation processes in figure 3.

The future of systems research for strategy development in agriculture

We can expect that the technologies that enable the capture, derivation, handling and integration of information will continue to improve. Improved models should contribute to improved insights into agricultural system function and new bases for enlightened management and policies. Contributing to improved simulation will be:

1. improved representation of certain aspects of cropping systems, enabling important phenomena to be better simulated, e.g., the long-term effects of crop sequences on soil N, and the competition between intercrops;
2. development of models of additional crops;
3. greater flexibility in re-combining good routines in different models to provide a superior configuration for a given task; and
4. improved software design and quality that facilitate the efficient evolution of models in response to testing and adaptation (McCown et al. 1993).

There is no doubt that pressures in both developing and developed countries will result in greater intervention by governments in the way that land is used. As the pressure on land grows, so do political pressures and conflict. Almost all agricultural professionals concerned with land resources were trained in agricultural science. They are familiar with soil processes, the effects of mismanagement on the soil, and

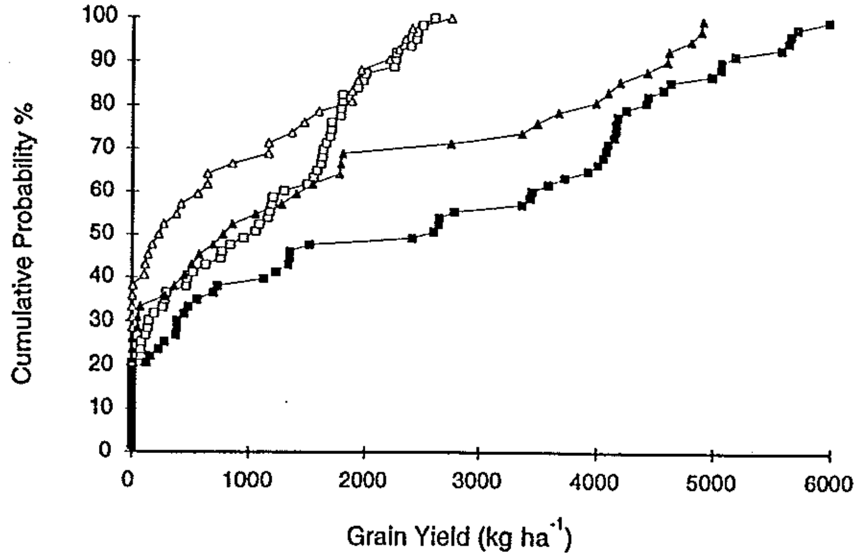

Figure 5. Cumulative probability distributions of maize production for pristine and seriously depleted nitrogen fertility states at a climatically Medium Potential site (Katumani) and a Low Potential site (Makindu). Pristine (medium) fertility represented by bold line; low fertility by light line.

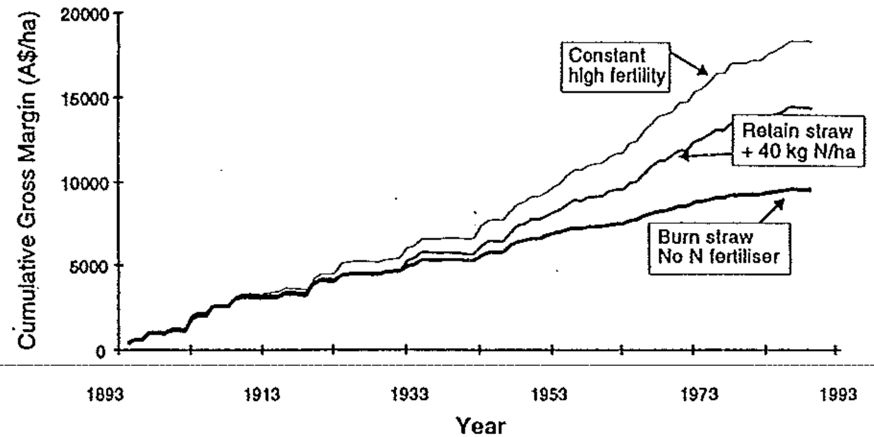

Figure 6. Cumulative gross margins of simulated wheat production at Roma, Australia for three scenarios. (The "Constant high fertility" is hypothetical.)

indicators of degradation. This natural science knowledge is the basis of sound "theoretical (scientific) reasoning", and is generally accepted by policymakers and public administrators as a basis for policy, all other things being equal. But in the real world of the politics of land use, the "practical reasoning" of land holders, which conflicts with the scientific, has a legitimate place, and this is institutionalized in democratic systems. The failure of hard systems thinking and practice to recognize this legitimacy has given rise to other systems philosophies that embrace these aspects of systems function (Ulrich 1983; Flood and Jackson 1991).

While it is unlikely that direct involvement in these aspects of agricultural systems should be a high priority for many agricultural R&D professionals, improved awareness of modern systems thinking is important in the shaping of perceptions of the limits of their hard systems activities, and, in turn, the expectations they raise with others about the ramifications of their work. We need to discover not only how we can be "involved" in the policy process (Maxwell and Randall 1989), but also how we can learn from, and influence, the views of those who are the "affected" in the policy process (Oliga 1988). Thus, implementation of the process of figures 1 and 2 is the key to an alliance between science and policy which results in enlightened action rather than merely control (opening quote from Habermas) and which, on the other hand, is important in preventing the socially important contributions of science being overridden by narrow sectoral interests. Development of better strategies for agricultural production and land use will depend on such an eclectic systems approach.

Acronyms

APSRU	agricultural production systems research unit
FSR	farming-systems research
ICASA	International Consortium for Application of System Approaches to Agriculture
OR	operational research
R&D	research and development

References

Ackoff R L (1967) Management misinformation systems. Management Science 14:147-156.

Anderson J R, Dillon J L, Hardaker J B (1985) Socioeconomic modeling of farming systems. Pages 77-88 in Remini J V (ed.) Agricultural systems research for developing countries: proceedings of an international workshop held at Hawkesbury Agricultural College, Richmond, N.S.W., Australia, 12-15 May 1985. ACIAR Proceedings No.11.

Van Bavel C H M (1953) A drought criterion and its application in evaluating drought incidence and hazard. Agronomy J. 45:167-172.

Bawden R J, Packham R G (1991) Improving agriculture through systemic action research. Pages 261-270 in Squires V and Tow P (eds.) Dryland farming—a systems approach. Sydney University Press, Sydney, Australia.

Biggs S D, Farrington J (1992) Farming systems research and the rural poor: A political economy approach. J. for Farming Systems Research and Extension 3:59-82.

Binswanger H, Pingali P (1988) Technological priorities for farming in sub-Saharan Africa. World Bank Research Observer 3(1):81-98.

Broekhuyse J Th, Allen A M (1988) Farming systems research on the northern Mossi Plateau. Human Organization 47 (4):330-342.

Checkland P B (1981) Rethinking a systems approach. J. of Applied Systems Analysis 8:3-14.

Checkland P B (1983) O.R. and the systems movement: Mappings and conflicts. J. Operational Research Society 34:661-675.

Churchman C W (1975) Towards a theory of application in systems science. Proc. IEEE 63:351-354.

Collinson M P (1982) Farming systems research in Eastern Africa: The experience of CIMMYT and some national agricultural research services, 1976-81. MSU International Development Paper No. 3.

Cox P G (1993) Uses and abuses of complexity in an uncertain world: Indicators for design of decision support. Pages 233-237 in Proceedings Australia Pacific Extension Conference, Gold Coast.

Dent J B, Anderson J R (1971) Systems analysis in agricultural management. John Wiley, Sydney, Australia. 394 p.

Dillon J L, Virmani S M (1985) The farming systems approach. In Muchow R C (ed.) Agro-research for the Semi-arid Tropics: North-west Australia. Univ. Queensland Press, Brisbane, Australia.

Flood R L, Jackson M C (eds.) (1991) Critical systems thinking: Directed readings. John Wiley & Sons, New York, USA.

Fox R, Finan T, Pearson S, Monke E (1990) Expanding the policy dimension of farming systems research. Agric. Systems 33:271-287.

Habermas J (1971) Toward a rational society; Student protest, science, and politics. Beacon Press, Boston, Mass, USA.

Jackson M C, Keys P (1984) Towards a system of systems methodologies. Pages 139-158 in Flood R L, Jackson M C (eds.) Critical systems thinking: Directed readings. John Wiley & Sons, New York.

Keating B A, Wafula B M, Watiki J M (1992) Development of a modeling capability for maize in semi-arid eastern Kenya. Nairobi Workshop.

Keating B A, Godwin D C, Watiki J M (1991) Optimising nitrogen inputs in response to climatic risk. Pages 329-358 in Muchow R C, Bellamy J A (eds.) Climatic risk in crop production: Models and management for the semi-arid tropics and subtropics. Ch.16. CAB International, Wallingford, UK.

Loomis R S (1985) Systems approaches for crop and pasture research. Pages 1-8 in Proceedings of the 3rd Australian Society of Agronomy Conference, 1985, Hobart, Tasmania, Australia.

Lynam J K (1978) An analysis of population growth, technical change, and risk in peasant, semi-arid farming systems: A case study of Machakos District, Kenya. PhD Thesis. Stanford University, California, USA.

Maxwell J A, Randall A R (1989) Ecological economic modeling in a pluralistic, participatory society. Ecological Economics 1:23-249.

McCown R L (1991) In Research in a farming systems framework. Pages 241-249 in Squires V, Tow P (eds.) Dryland farming—a systems approach. Sydney University Press, Sydney, Australia.

McCown R L, Hammer G L, Hargreaves J N G, Holzworth D, Huth N I (1993) APSIM: An agricultural production system simulation model for operational research. Proceedings of the International Congress on Modeling and Simulation, Modeling Change in Environmental and Socioeconomic Systems, 6-10 December 1993, Univ. Western Australia, Perth, Australia.

McCown R L, Keating B A, Probert M E, Jones R K (1992) Strategies for sustainable crop production in semi-arid Africa. Outlook on Agriculture 21:21-31.

Morley R H W, Spedding C R W (1968) Agricultural systems and grazing experiments. Herbage Abstracts 38:279-287.

Muhammad L W, Parton K A (1992) Smallholder farming in semi-arid eastern Kenya—basic issues relating to the modeling of adoption. Pages 119-123 in Probert M E (ed.) A search for strategies for sustainable dryland cropping in semi-arid Eastern Kenya. Proceedings of a symposium held in Nairobi, Kenya, 10-11 December 1990. ACIAR Proceedings No.41.

Norman D, Collinson M (1985) Farming systems research in theory and practice. Pages 16-30 in Remini J V (ed.) Agricultural systems research for developing countries. Proceedings of an international workshop held at Hawkesbury Agricultural College, Richmond, NSW, Australia, 12-15 May 1985. ACIAR Proceedings No.11.

Ockwell A P, Muhammad L, Nguluu S, Parton K A, Jones R K, McCown R L (1991) Characteristics of improved technologies that affect their adoption in the semi-arid tropics of Eastern Kenya. J. of Farming Systems Research-Extension 2:133-147.

Oliga J C (1988) Methodological foundations of systems methodologies. Pages 159-184 in Flood R L, Jackson M C (eds.) Critical systems thinking: Directed readings. John Wiley & Sons, New York, USA.

Probert M E, Okalebo J R, Simpson J R, Jones R K (1992) The role of boma manure for improving soil fertility. In Probert M E (ed.) A search for strategies for sustainable dryland cropping in semi-arid Eastern Kenya. Proceedings of a symposium held in Nairobi, Kenya, 10-11 December 1990. ACIAR Proceedings No.41, 63-70.

Robertshaw J E, Mecca S J, Rerick M N (1978) Problem solving: A systems approach. Petrocelli Books Inc., New York, USA. 272 p.

Ruthenberg H (1980) Farming systems in the tropics. 3rd edition. Clarendon Press, Oxford, UK.

Ryan J G (1984) Efficiency and equity considerations in the design of agricultural technology in developing countries. Australian J. of Agric. Econ. 28:109-35.

Seligman N G (1990) The crop model record: Promise or poor show? Pages 249-258 in Rabbinge R, Goudriaan J, Van Keulen H, Penning de Vries F W T, Van Laar H H (eds.) Ch.14, Theoretical production ecology: Reflections and prospects. PUDOC, Wageningen, The Netherlands.

Thornton P (1991) Application of crop simulation models in agricultural research and development in the tropics and subtropics. International Fertilizer Development Center, Paper 15. 23p.

Thornton P K, McGregor M J (1988) The identification of optimum management regimes for agricultural crop enterprises. Outlook on Agric. 17:158-162.

Ulrich W (1983) Critical heuristics of social planning. Paul Haupt, Berne, Switzerland.

Waddington S R (1992) The future for on-farm crop experimentation in southern Africa. Paper presented at the CIMMYT FSR Networkshop on Impacts of On-farm Research, 23-26 June 1992, Harare, Zimbabwe.

Wilson K, Morren G E B Jr (1990) Systems approaches for improvement in agriculture and resource management. Collier Macmillan, London, UK.

De Wit C T (1969) Dynamic concepts in biology. Paper presented to the IBP/PP Technical Meeting, Productivity of Photosynthetic Systems Models and Methods. Trebon, Czechoslovakia.

Discussion on Section B: The role of systems approaches as an aid to policy decisions and as practical tools for resource management

The use of systems approaches in agroecological research

The additional complexity of the issues to be addressed when NRM is integrated into the agricultural research agenda (multiple objectives, increased information needs, more complex decision procedures, and the interdisciplinary nature of NRM research) makes the use of systems approaches essential. In addition, as noted in the discussion on Section A, the methods used help in defining levels and scales at which NRM objectives can be met, and they focus attention on the relationships between production and the environment, including the social, cultural, and economic components of the environment.

For agroecological purposes it is not sufficient to describe the biological, physical, and economic characteristics of the environment. It is necessary also to be able to associate variations in these factors conceptually and quantitatively, with the variations in productivity of resources, and in the way they are used. These relationships are represented by models which, as understanding improves, progress from statistical relationships to increasingly complete descriptions of the processes involved.

Over the past 30 years or more, systems simulation techniques have been developed for use in research and decision making at different levels in the hierarchy of agricultural systems; at the level of a crop, a farm unit, a farming system, and at a national and regional level, for land-use planning. Some of the earliest work was on the use of heuristic simulation models in crop science, as research tools and integrators of new and existing knowledge on the physiological processes of plant growth. Used in this manner, the models served to focus attention on areas where knowledge was lacking and where further research was required. Currently, simulation methods are used widely for the study of a great variety of issues in NRM.

The papers in this Section have provided examples of the application of systems approaches to different kinds of resource management problems. The applications include: a combination of an economic and an ecological analysis to determine research priorities (Wood and Pardey); use of a crop growth model to compare crop and fertilizer management strategies in a dryland environment (McCown et al); and examples of the application of systems approaches as aids to different levels of decision making that concern the use of natural resources (Rabbinge et al).

How compatible are economic and ecological approaches?

There are more examples of an economic analysis having provided the basis for the determination of national policy on NRM issues than there are examples of biophysical models having influenced decision making at this level. One of the few examples where biophysical models have had an influence is the application of Multiple Goal Linear Programming (MGLP) that WARDA has used in West Africa (see Dingkuhn, section F). The shared interests between economists and policy makers (many of whom are economists) may account in part for the wider affinity for economic-based approaches.

At present, economists and natural scientists differ in their perceptions of NRM issues. This is partly because their vocabularies are different, and concepts rooted in one discipline may translate poorly into the other. Economic approaches take account of the possibility of a divergence between private and social values. For instance, farmers may not adopt a resource-conserving practice because of short-term "costs". If society places a value on externalities such as impacts on future productivity, public health, conservation, or other social uses of natural resources, then a shift in the policy environment may be needed to achieve socially more favorable behavior. While an economics approach takes account of these factors, the more deterministic, process-oriented approaches used by natural scientists generally do not.

On the other hand, one of the limitations of the economic-ecologic approach described by Wood and Pardey, in which an economic surplus analysis is used, is that, in its present stage of development, the analysis is applied to single commodities. A commodity approach is generally not a satisfactory way of addressing system-level sustainability issues. Although the estimated benefits can be integrated across a number of component commodities of a production system, this does not reflect the component interactions. The process models of production systems are better able to represent these interactions, but as yet only imperfectly. Economists would therefore argue that at present the models are of only limited value for their purposes.

In spite of these incompatibilities, there was a consensus among the workshop participants that economic and ecological approaches are complementary and that both are needed. The workshop noted that there are very few examples of an effective combination of economic and ecological modelling approaches in which the issues have subsequently been pursued to the point where some change in system performance has been achieved. This self-criticism by a mixed disciplinary group was seen as both a prompt for more vigorous efforts to integrate biophysical and economic modelling with a focus on some outcome to clients, and as a cautionary note against talking-up expectations too much. A much stronger link between the two approaches needs to be sought, and more interdisciplinary dialogue is needed. The focus of the discussion was on how this can be achieved so that the strengths of one overcome the limitations of the other.

Limitations of models

The impact of changes in the pattern of resource use on the natural resource base may be evident only over long time periods, and the time frame for technology development is therefore generally also long. This makes it difficult to evaluate research priorities. For current research to be relevant it must address constraints that will affect the pattern of resource use well into the future. One of the limitations of currently available models and systems approaches is their inability to deal adequately with these long-term trends; a shortcoming which is in part a reflection of the focus on crop models in the past.

There are four elements that limit the level of confidence that can be attributed to the output from systems models that refer to distant objectives: the limited availability and quality of data; the limits of our understanding of the physical, biological, and socioeconomic processes involved, especially the stochastic elements in them; the unpredictability of human behavior (even at lower, disaggregated levels); and the evolution of the context in which problems are seen, with the passing of time (e.g., changes in prices or in the availability of capital, which greatly affect the options and objectives). This last point reflects that the world outside the boundary of the system is not static. These limitations apply particularly to applications of biophysical models to high levels of system aggregation (e.g., at an ecoregional level), and at lower levels to the predictions from behavioral models (e.g., decision trees to reflect farm management responses).

Although current models sometimes fall short of what is required to predict long-term trends, there has been significant progress in recent years in modelling production systems, and also in modelling soil processes as indicators of long-term effects on productivity. Economists perceived the ability to model trends as one of the main strengths of biophysical models. A question that remains, though, is how the validity of long-run models will be tested (e.g., for predictions of sustainability).

There is an important group of models that are intended to evaluate policy options for land-use and resource management. These options may be exclusive, in which case the outcomes from the model help structure and inform the political debate that accompanies such decisions. However, the models provide very little understanding of how the actual goals indicated by the preferred option (such as pesticide reduction or erosion control) can be achieved. In other words, they do not evaluate the relevance of policy instruments. In effect, they leave the decisions on this sort of question to the intuition of the reigning policy makers. Models help define where we want to go, but often fail to help choose the vehicle or the road to get there.

Because of their limitations, the principal use of agricultural systems models is to explore what the probable outcome of different policies or planning strategies is likely to be. Though they are imperfect, they can help identify key land-use technologies and, by improving estimates of the probable physical benefits from research, they can provide decision makers (farmers, scientists, or policy makers) with a better understanding of what is at stake and how their actions influence their expected future position.

Additional comments on the limitations of models, coming from the NARS as users, are found in the discussion following the papers in Section D.

System level

In the discussion on Section A, the need to define the level and scale of the system under study was noted as one reason why systems approaches are particularly valuable when addressing environmental concerns in agriculture. Failure to define clearly the boundaries of the system causes confusion that hinders the exchange of ideas on systems issues.

In a research program where agricultural and NRM objectives are integrated, the systems levels of interest may extend from single crops to whole land-use systems or even ecological regions. Within this range there is a continuum of intermediate levels in which the nature of the problems and the solutions changes. An optimum solution at one level is not necessarily optimum at another (as the study of fertilizer use on maize in Kenya illustrates, see McCown, p. 89).

While it is important to define clearly the level and the boundaries of the system under study, economists and biologists point out the difficulties of deciding on the appropriate place to draw the boundaries; changes at one level may well move the analysis up to another, higher level (see also Lynam, Section A, p. 10). In addition, modellers have found it difficult to establish the hierarchical linkages between systems levels that would permit easy movement from one level of analysis to another. For example, when attempting to integrate information from household surveys and anthropological studies to greater spatial scales. The workshop heard that the problem arose in the global project on "Alternatives to Slash-and-Burn Agriculture", coordinated by ICRAF and involving CIAT, IFPRI, IITA, IRRI, and CIFOR (Hoekstra, Section F, p. 305).

One of the challenges of hierarchical integration is to link the different decision-making levels for purposes of planning, e.g., at strategic and tactical levels. The IARCs have found a systems approach more useful at some levels than others. It has been more useful for strategic planning (as in CIAT's major use of its land-use databases) and at the project level, than at intermediate levels (e.g., for determining priorities between the center's research programs, see Torres and Gallopin, Section F).

Determination of priorities

A key question for NARS will be how to balance short-term production objectives with the long-term objectives of NRM research. The second of the three tasks that need to be undertaken to determine what the balance should be (namely, estimating the costs and benefits of different resource-use strategies; see discussion on Section A, p. 41-42) poses many methodological problems of measurement and evaluation. Also, the intergenerational nature of NRM objectives gives rise to questions of equity and discount rates concerning how the use of resources for current production affects the future use of those same resources. Consideration will have to be given to how these environmental considerations are to be taken into account in setting agricultural research priorities. This is another area in which systems approaches are required and where systems modelling can be used to develop measures of costs and benefits, based on estimates of changes in the physical status of both natural and man-made capital used in production, and on estimates of the change in potential productivity over time.

Recommendations

Integration of economic and ecological approaches

Economic and ecological approaches are complementary in systems research. Both are needed, and a much stronger link between the two approaches needs to be sought so that the strengths of one overcome the limitations of the other. The workshop recommends more vigorous efforts on the part of the national and international organizations to promote an interdisciplinary dialogue on ways to integrate biophysical and economic modelling with particular attention to the needs of NARS for research and development planning.

System level

By specifying their needs, model users in national and international organizations should encourage modellers to devote special attention to the hierarchical linkages between systems levels that would permit easier movement from one level of analysis to another. There is a particular need for better hierarchical integration to link the different decision-making levels for purposes of agricultural research planning (e.g., at strategic and tactical levels).

Improved methods for determining priorities

The workshop recognized that because of the additional complexity of the issues to be addressed when production-oriented objectives and research to improve the efficiency and ensure the sustainability of resource use in agricultural production are combined, IARCs and the NARS urgently need improved procedures for determining priorities and making decisions about the allocation of research resources. Procedures are needed that include appropriate measures of the costs and benefits of the environmental and natural resource consequences of different resource-use options.

The workshop recommends that the development of such procedures should be one of the main objectives of the integration of economic and ecological approaches recommended above.