AGROECOSYSTEM ANALYSIS

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C O N T E N T S

In recent years there has been a growing demand for a more multidisciplinary and holistic content to agricultural research and development and for the formulation of methods by which this can be acheived. Farming systems research and integrated rural development are two responses to this demand but, in common with other multidisciplinary approaches, they face the problem of trying to encompass a breadth of expertise while at the same time generating a common agreement on worthwhile practical action. Resort to bureaucratic methods or to formal systems analysis is unsatisfactory for a variety of reasons. The procedure of agro-ecosystem analysis which is described and illustrated here steers a middle course, combining a rigorous framework with sufficient flexibility to encourage genuine interdisciplinary interaction. This procedure has been designed and tested in several workshops held in Thailand over the past five years.

At the heart of the procedure are the concepts of the system, system hierarchies, system properties and the agro-ecosystem. The participants begin by defining the objectives of the analysis and the relevant systems, their boundaries and hierarchic arrangement. This is followed by pattern analysis, the systems being analysed by all the participating disciplines in terms of space, time, flows and decisions. These patterns are important in determining the important system properties of agro-ecosystems, namely productivity, stability, sustainability and equitability. The outcome of the analyses are a set of agreed key questions for future research or alternatively a set of tentative guidelines for development.

Experience suggests that the procedure can be applied at any

time in a project's life, but is particularly useful at the beginning when data are scarce. Ideally it should be repeated and updated at regular intervals.

INTRODUCTION

Farmers, of necessity, adopt a multidisciplinary, holistic approach to their work and it would seem logical that this should also apply to the design and implementation of agricultural development programmes in the less developed countries (LDC's). Indeed many programmes have approached their goals in this way, but for the most part they have tended to focus on a limited number of factors - high yielding varieties of key food grains, irrigation water, fertilisers, pesticides, the provision of credit - which promise a quick and high return. It is only in the last decade that there has been a significant demand for a more multidisciplinary and holistic content to agricultural research and development and for the formulation of methods and procedures by which this can be achieved. In this paper I report one such procedure which has been developed and practised in Thailand over the past five years.

THE CASE FOR A HOLISTIC APPROACH

Part of the justification for a more holistic approach to agricultural development lies in the recent performance of the agricultural revolution that has been taking place in the LDC's since World War II. While real and gratifying increases in per

capita food production have been achieved (up by about 8% since the early 1960's for the LDC's as a whole, FAO, 1977), the incremental returns to the varieties and inputs on which the revolution depends have begun to diminish. There are several reasons for this. Since the beginning the adoption of the new technologies has been highly uneven; the technologies were primarily designed for the better favoured classes of farmer and for the best endowed agroclimatic regions; they have been slow to spread to the poorer farmers and the more marginal areas (IRRI, 1976). Even when conditions are considered favourable, the gap between performance on the agricultural research station and in the farmer's field has proved highly persistent (IRRI,1978,1979a). The new technologies have also been accompanied by a number of serious short and medium term problems. These include increasing incidence of pest, disease and weed problems (Nickel,1973; IRRI,1979b), sometimes aggravated by pesticide use (IRRI,1980, 1981), deterioration in soil structure and fertility (Hauri,1974; McNeil,1972), increased indebtedness and inequity (Collier,1977; Collier et al.,1974; Murdoch,1980; Palmer,1976; Pearse,1980). Finally the oil crisis of the mid 1970's generated soaring costs of precisely those inputs on which increased agricultural production was becoming dependent. The potential returns relative to the costs of inputs have become less dramatic and in many cases inputs, even if still profitable, are no longer affordable by farmers with poor access to credit.

One answer has been to tackle these various issues and problems individually as they arise. However there has been a

growing realisation that many, if not all, of the problems are essentially systemic in nature; they are linked to each other and to the performance of the system as a whole. Moreover they arise as a consequence of fundamental incompatabilities between the existing agricultural systems and the newly introduced technological elements. It is, of course, almost axiomatic that revolutions, agricultural or otherwise, involve such incompatabilities. The size and magnitude of change is of the essence of success and undue preoccupation with problems and side-effects may impede the realisation of the main objectives. Nevertheless, recent experience suggests that the problems are often so great that they directly threaten the main objectives themselves (Conway and McCauley,1983). Even where there is some success in attaining increased yields, the success may be short lived if attention is not quickly diverted to side effects which threaten other equally important development goals.

The last decade has also been characterised by the return of large numbers of LDC agricultural scientists from postgraduate studies in the industrialised countries with, far too often, a training which reflects the increasing degree of specialisation that characterises much of modern agricultural education. As a consequence they are often overwhelmed by the complexity of agricultural development issues and find it easier to treat problems in purely disciplinary terms. In practice there is often little or no interaction between the agricultural disciplines, notwithstanding physical proximity within a university faculty or agricultural research station. It is true that many recent technological advances have been made by multidisciplinary

teams, but for the most part these were small teams, with narrow goals and composed of a limited range of traditional agricultural disciplines. Contemporary problems require teams which have a broader perspective and draw on a wider range of disciplines, in particular spanning the natural and social sciences.

The argument, it should be stressed, is not that we should dispense with or by-pass specialisation. Given the complexity of agricultural systems, anything more than a superficial understanding requires the insights of highly trained specialists of all kinds. Compared to the farmer the agricultural specialist has a narrower range of knowledge, which is deeper and, within its range, more complete. There is much that the specialist knows that the farmer is ignorant of and could use. But where the farmer tends to be superior, not least at the practical level, is in those areas of knowledge where the specialist disciplines overlap (Figure 1) and it is precisely in such areas that the current problems of agricultural development lie.

One response has been the development of farming systems research (FSR) (Gilbert et al.,1980; Harwood,1979; Norman,1980; Shaner et al.,1981). This focusses on the farm as the basic system for research and development and seeks, through the sequential stages of analysis, design, testing and evaluation, to discover and implement technological improvements that are appropriate to the farm's capacities and capable of overcoming its constraints. This approach arose primarily as a specific response to the problems of small farms in the LDC's and is also characterised by a strong involvement of the farmers themselves

at all stages in the process, capitalising on their knowledge of problems and goals and their capacities as experimenters and innovators.

A second approach has been that of integrated rural development (IRD) (Conde et al.,1979; FAO,1975; Gomez and Juliano,1978). This is even more holistic in scope but directed primarily toward the development end of the research and development spectrum. Its focus is the organisation of development projects which deliberately go beyond a consideration of the needs of improved agricultural production to encompass such aspects as increased fish, forest and handcraft production, more opportunities for off-farm employment, and better provision of health, education and other communal services. In practice IRD projects are commonly seen as a means of improving coordination and better working relations between different government agencies.

Both these approaches have proved of practical value, although they are not without their critics. The major problem they face, which is common to all holistic research and development enterprises, is that of trying to encompass a breadth of view and range of disciplines and talents while at the same time generating a common agreement on worthwhile practical acion for research and development. One solution has been to rely on bureaucratic procedures and a hierarchic leadership of the research or development team. This may be efficient but it is likely to become rigid and non-innovative with time, losing the valuable insights and cross-fertilisation of ideas that is possible with a multidisciplinary group. An alternative is to rely on formal techniques of systems analysis, using mathematical

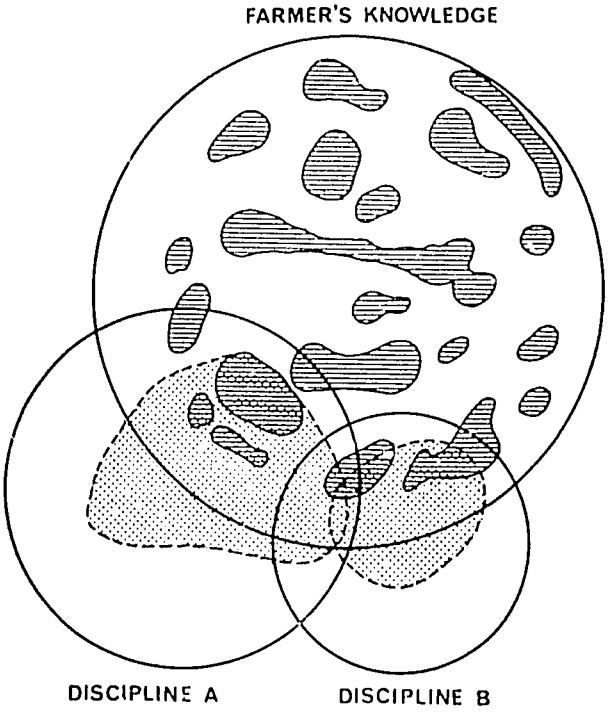


FIGURE 1 Overlapping knowledge between farmers and research specialists (eg soil scientists and agricultural economists). Hatched and striped areas indicate extent of knowledge

or computer models. But this has the drawback of requiring relatively specialised skills, so excluding the breadth of experience of the research and development workers whom the approach is meant to involve and help.

The procedure I report here is intended to steer a middle course. It is developed from the basic concepts of systems analysis and is thus rigorous and well focussed. Yet it is also flexible in design and encourages wide and easy participation and the flow of new ideas and insights. The procedure is not intended an an alternative to FSR or IRD but is offered as a technique that can be used within the framework of these approaches and, indeed, in any multidisciplinary research and development programme whether the focus be the crop, field plot, farm, village, watershed, or region.

In this paper I describe the underlying philosophy of the approach and the details of the procedure and then give some examples of its application, drawn from several workshops held recently in Thailand. Detailed reports on those workshops are published in Gypmantasiri et al. (1980) and KKU-Ford Cropping Systems Project (1982a, 1982b). Summaries and a discussion of the findings will be presented in two further papers in this series.

THE CONCEPTUAL BASIS

The goal of multidisciplinary analysis is to achieve an interaction between the disciplines that produces insights which significantly transcend those of the individual disciplines.

Arranging the physical or social environment so as to promote ease of communication among the disciplines is an essential prerequisite, but the process of interaction may remain casual, too often producing results that are superficial and mundane. Experience suggests that the generation of good interdisciplinary insights also requires organising concepts and frameworks and a relatively formal working procedure which encourages and engineers cross-disciplinary exchange.

The concepts have to be simple and basic and involve a minimal set of assumptions that are acceptable to all the disciplines participating in the exercise. At the core of the procedure reported here is the concept of the system and the related concepts of system hierarchy, system properties and the agro-ecosystem.

A system is here defined as an assemblage of elements contained within a boundary such that the elements within the boundary have strong functional relationships with each other, but limited, weak or non-existent relationships with elements in other assemblages; the combined outcome of the strong functional relationships within the boundary is to produce a distinctive behaviour of the assemblage such that it responds to many stimuli as a whole, even if the stimulus is only applied to one part.

We can conceive of the natural living world as a nested hierarchy of such systems (gene-cell-tissue-organ-organism-population-community-ecosystem-biome-biosphere) each with a more or less well defined boundary and a distinctive system behaviour. It is assumed that systems higher in the hierarchy tend to control those beneath them and, most important for the task of

analysis, that the behaviour of higher systems is not readily discerned simply from a study of the behaviour of lower systems (Checkland,1981; Milsum,1972; Simon,1972; Whyte et al.,1969). For the three ecological systems (populations, communities and ecosystems) the system behaviour can be disassembled into three system properties: productivity, stability and sustainability. These properties are relatively easy to define, although not equally easy to measure. Productivity is the net increment in numbers or biomass per unit of time. Stability is the degree to which productivity is free from variability caused by small disturbances inherent in the normal fluctuations of climate and other environmental variables; it is most conveniently measured by the reciprocal of the coefficient of variation in numbers or biomass. Sustainability can be defined as the ability of a system to maintain productivity in spite of a major disturbance such as is caused by intensive stress or a large perturbation. A stress is here defined as a regular, sometimes continuous, relatively small and predictable disturbance, for example the effect of soil salinity. A perturbation is an irregular, infrequent, relatively large and unpredictable disturbance, such as is caused by a rare drought or flood. Satisfactory methods of measuring sustainability have still to be found, however. Lack of sustainability may be indicated by declining productivity but, equally, collapse may come suddenly and without warning.

In agricultural development, ecosystems are transformed into hybrid agroecosystems for the purpose of food or fibre production. These too can be arranged in a hierarchic scheme (e.g.

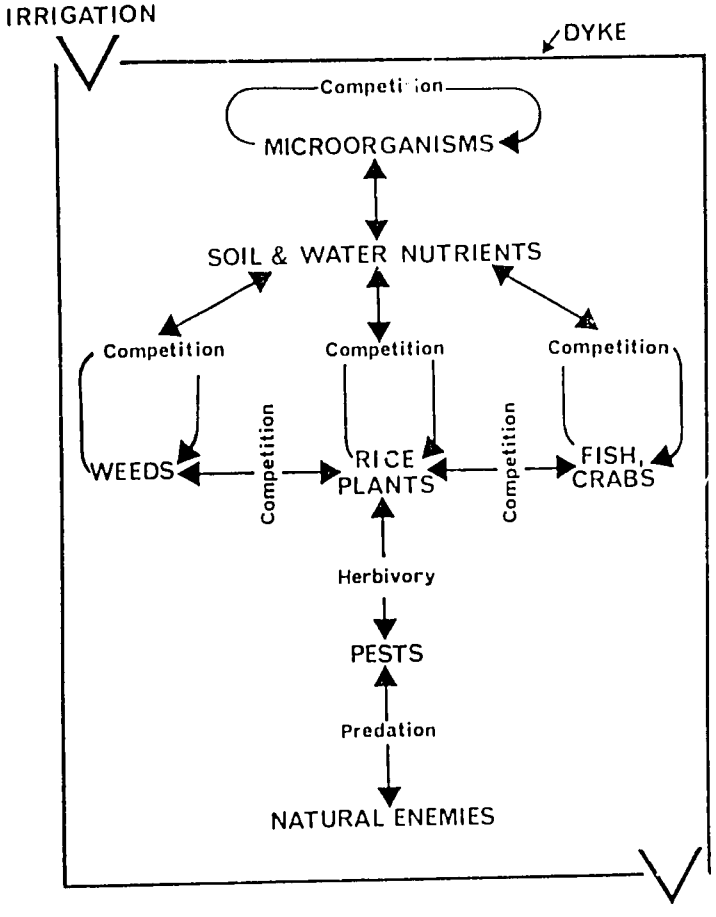


FIGURE 2 Representation of a ricefield as a system showing key elements and functional relationships

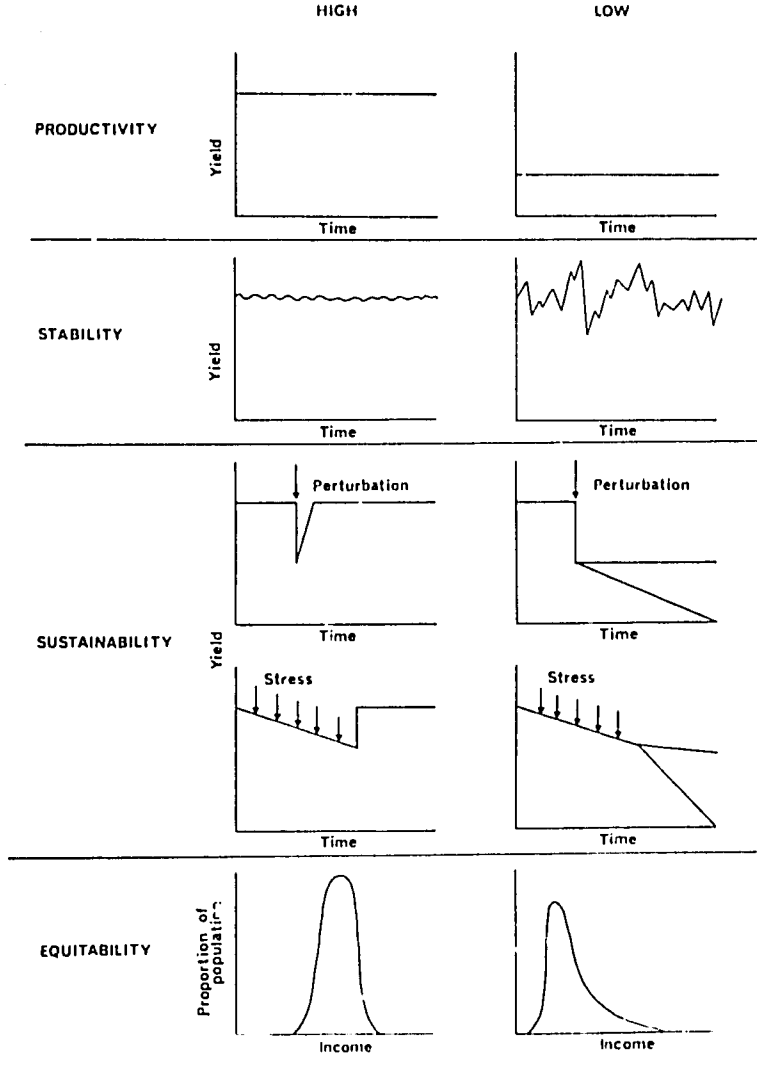


FIGURE 3 The system properties of agroecosystems

field-farm-village-watershed-region). The transformation involves several significant changes. The systems become more clearly defined, at least in terms of their biological and physico-chemical boundaries. These become sharper and less permeable; the linkages with other systems are limited and channelled. The systems are also simplified by the elimination of many species and various physico-chemical elements. A good example is the ricefield (Figure 2): the water-retaining dyke or bund forms a strong, easily recognisable boundary, while the irrigation inlets and outlets represent some of the limited outside linkages.

The important system properties remain essentially the same, except that productivity is now measured in terms of yield or net income (Figure 3). In the ricefield productivity is in terms of rice, fish and crabs, but the important functional relationships which determine this property remain essentially ecological in character, involving competition, herbivory and predation.

However, at the higher levels of the agroecosystem hierarchy the inclusion of human beings, their social, cultural and economic activities, reintroduces considerable complexity, but of a different nature. Figure 4 orders the components of a typical LDC farm. Some of the important functional relationships remain ecological or, at least in dynamic terms, are analogous to ecological processes. For example, forms of competition, mutualism and predation can be discerned not only in the natural interactions but also in the socio-cultural and economic interactions. An important new system property consequent on the inclusion of human beings is equitability. This expresses how evenly the

products of an agroecosystem are distributed among its human beneficiaries; the more equitable the system the more evenly are the agricultural products shared among the members of, say, a farm household or a village. Equitability can be readily described using statistical distribution parameters (Figure 3).

In natural ecological systems the operation of natural selection on the reproductive success of individual organisms favours numbers, and hence the productivity of ecological systems, and survival, and hence sustainability. It may or may not select for stability, as here defined. In agroecosystems human manipulation, operating on both individuals and whole systems, partly replaces natural selection. Different system properties are favoured according to predominant human goals and values. It is thus possible to view agricultural development as a progression of changes in the relative values of the important system properties.

In general, traditional agricultural systems such as swidden cultivation (shifting cultiviaiton) have low productivity and stability, but high equitability and sustainability (pattern A in Table I). Traditional sedentary cropping systems tend to be more productive and stable, yet retain a high degree of sustainability and some of the equitability (B). However the introdution of new technology, while greatly increasing the productivity, is likely to also lead to lower values of the other properties (C). This was particularly true, for example, of the introdution of the new high yielding rice varieties, such as IR8 and its relatives, in the 1960's; yields fluctuated widely, but have tended to decline,

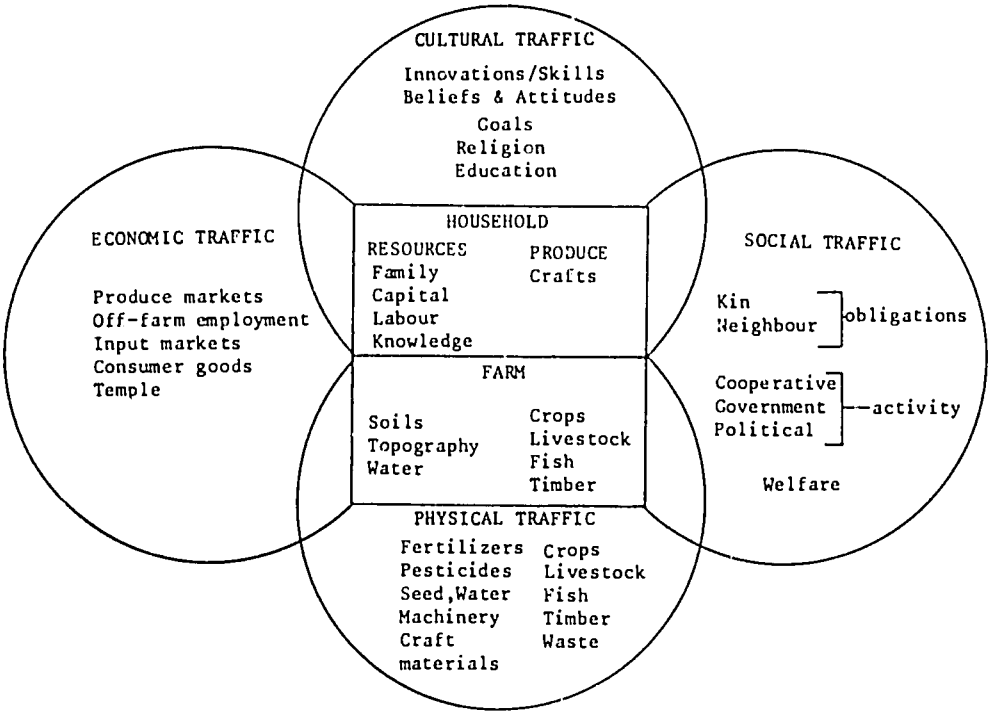


FIGURE 4 Components of a typical less developed country farm indicating linkages with other systems

in part due to growing pest and disease attack. More recent varieties combine high productivity with high stability, but still have poor sustainability (D). The ideal goal is probably pattern E or on marginal lands, where there is a conflict between productivity and sustainability, pattern F may be more appropriate.

THE PROCEDURE OF ANALYSIS

The procedure has evolved over the past five years from one originally designed for ecosystem analysis (Walker et al. 1978). It rests on the concepts described above and on five further assumptions:

1. It is not necessary to know everything about an agro-ecosystem in order to produce a realistic and useful analysis.
2. Understanding the behaviour and important properties of an agroecosystem requires knowledge of only a few key functional relationships.
3. Producing significant improvements in the performance of an agroecosystem requires changes in only a few key management decisions.
4. Identification and understanding of these key relationships and decisions requires that a limited number of appropriate key questions are defined and answered.
5. Since there is, as yet, no easy guide to defining key questions or identifying key relationships and decisions, the most productive approach is for a multidisciplinary team to

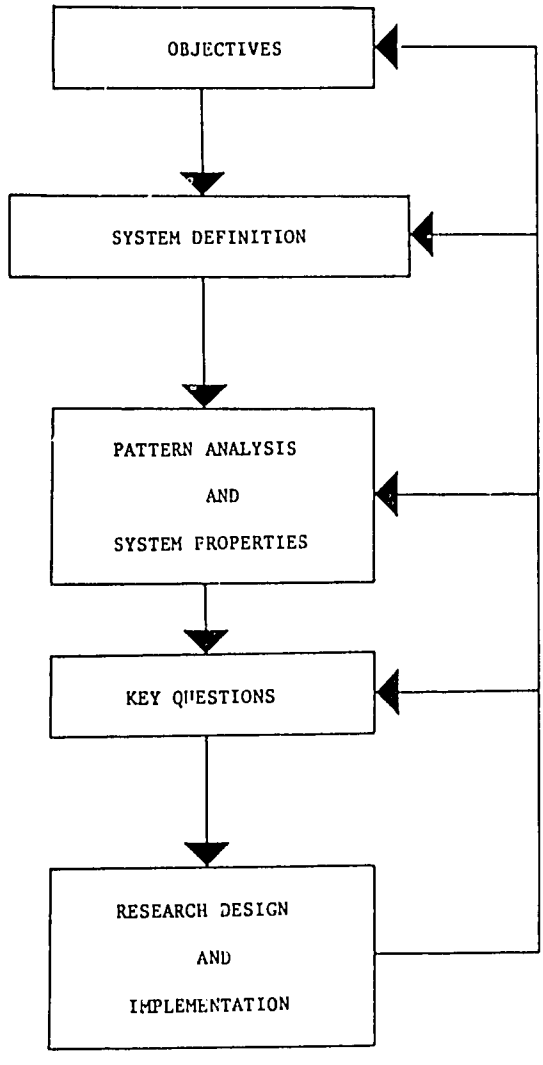


FIGURE 5 Basic steps of the procedure for agroecosystem analysis

Table I

Agricultural development as a function of agroecosystem properties

	Productivity	Stability	Sustainability	Equitability
A Swidden cultivation	LOW	LOW	HIGH	HIGH
B Traditional cropping system	MEDIUM	MEDIUM	HIGH	MEDIUM
C Improved	HIGH	LOW	LOW	LOW
D Improved	HIGH	HIGH	LOW	MEDIUM
E ?Ideal (best land)	HIGH	MEDIUM	HIGH	HIGH
F ?Ideal (marginal land)	MEDIUM	HIGH	HIGH	HIGH

attempt to collectively define questions through a process of system definition, analysis of system patterns and the investigation of system properties.

The basic steps of the procedure are described in Figure 5. Experience has shown that the procedure is best followed in a seminar or workshop environment, in which meetings of the whole team are interspersed with intensive work sessions involving small groups of individuals. Although the first workshop in Thailand (Gypmantasiri et al., 1980) ran intermittently for a period of a year, more recently they have been confined to one week, but with a month-long preparatory period for data acquisition. Table II describes an appropriate timetable.

The key to success lies in clear communication between the different disciplines present. In the Pattern Analysis phase, in particular, it is important for the participants to strive to present their disciplinary and specialist knowledge in such a fashion that all other members of the workshop can easily grasp its significance. This process is greatly helped by the use of diagrams and in the workshops extensive use has been made of maps, transects, graphs, histograms, flow diagrams, decision trees, venn diagrams and any other pictorial device that appears to aid communication. One practical, but essential, requirement is for the workshop room to be well equipped with overhead projectors, transparencies, pin boards, graph paper etc.

Table II

Timetable for a week-long workshop of agroecosystem analysis

Day 1	Participant introductions. Conceptual basis and details of procedure. Examples from previous workshop results.
Day 2	System Definition by whole workshop team. Break into sub-groups, each assigned a level in the system hierarchy (e.g. field plot-farm-village -region) or one of a series of agroecosystems (e.g. different farms or villages). Each group carries out Pattern Analysis and Key Question Identification.
Day 3	Continuation of Day 2. (Brief whole team meetings if necessary).
Day 4	Field visits to agroecosystems.
Day 5	Presentation by subgroups of findings. Whole team discussion of Key Questions and Research Design and Implementation.
Day 6	Continuation of Day 5 as necessary. Writing of draft report by editorial team.
Day 7	Completion of draft report.

OBJECTIVES AND DEFINITIONS

Objectives

As in all exercises in systems analysis the quality of the final resutls depends crucially on a having a definition of objectives at the outset which is couched in simple, precise and unambiguous language and is acceptable to all members of the team. Recent workshops have had objectives of the form:

1. To identify research priorities that will lead to improvements in the level and stability of net income of farm households in the x region.
2. To identify tentative guidelines for improving agricultural productivity of the poor farmers in y village.

Precise definition of targets is crucial. For example, is the objective to improve mean agricultural productivity of an area, or the productivity of the poor farmers in the area (the former may not imply the latter)? Also is the aim to increase productivity only, or is improved stability, sustainability or equitability to be explicitly included?

System Definition

This phase involves identification of systems, system boundaries and system hierarchies.

At the outset the identification of systems and their boundaries is subjective and tentative. The biological and chemico-physical boundaries are often fairly clear: the ricefield is

bounded by a dyke; the valley by the extent of the watershed. But the cultural and socio-economic boundaries are more elusive. For example, defining a farm household solely in terms of the farm itself - the land that is cultivated or otherwise exploited - is frequently inadequate. A member of the farm household may be deriving income from far away; the sale of produce may depend on distant markets and the farmer's goals and values may be influenced by political or religious movements of a complex origin. In Northeast Thailand members of the family may be working temporarily in Saudi Arabia; the price of a major crop, cassava, is influenced by quotas established by the European Economic Community and the values of Buddhist farmers may be influenced by religious developments in Sri Lanka. The answer is to translate these, as far as possible, into physical or geographic terms and to elaborate system hierarchies that link or combine systems whose boundaries are defined in different terms (Figure 5).

The systems and boundaries can be revised as the workshop proceeds, particularly in the light of a growing understanding of the system properties since the extent and quantification of the important functional relationships contributing to these properties will provide more objective criteria upon which to draw the boundaries. The procedure of analysis will also indicate which systems are strong in terms of their relevance to the objectives of the workshop and increasingly only these will be analysed in any detail.

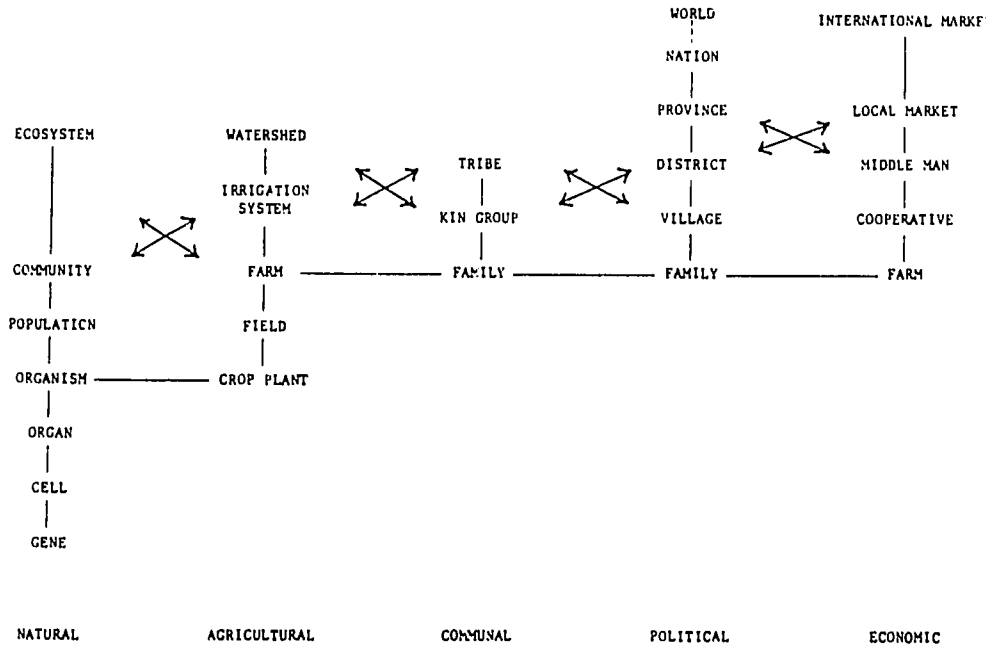


FIGURE 6 System hierarchies in a less developed country (Conway 1983)

PATTERN ANALYSIS

Four patterns are chosen as likely to reveal the key functional relationships that determine system properties. Three of these - space, time and flow - are known to be important in determining the properties of ecological systems (May,1981). All three are significant factors in productivity. Variability or heterogeneity in space is also an important promoter of stability and sustainability (e.g. predator-prey systems, Hassell,1978). Variability in time, however, can be destabilising; systems with long time lags are often very unstable (May,1975). Flows are either stabilising or destabilising depending on whether the feedback loops are negative or positive (Levins,1974).

All three patterns also have the virtue of being neutral with respect to scientific disciplines. Space, time and flow are equally important patterns for both natural and social science analysis and hence provide a basis for the generation of cross-disciplinary insights. The fourth pattern - decisions - arises directly from the need to understand the consequences of human manipulation and to identify those decisions which bear most significantly on agroecosystem sustainability and equitability. Although this pattern is primarily the object of socioeconomic analysis, experience shows that it generates lively discussion among both social and natural scientists.

Space

Spatial patterns are most readily revealed by simple maps and transects. Overlay maps are useful in uncovering potentially important functional relationships. Thus in the Chiang Mai

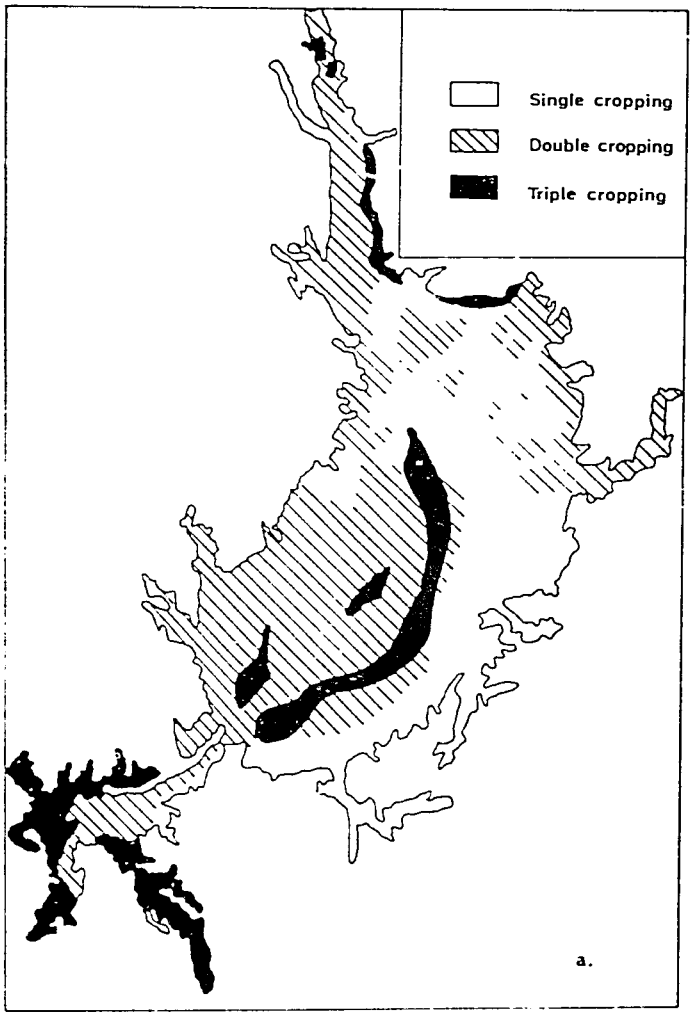
Valley of Northern Thailand they indicated that cropping intensity was more a function of the farm irrigation system rather than soil type (Figure 7). Subsequent analysis of the pattern of decision making in irrigation in the Valley suggested that triple cropping is likely to be more reliable in traditional and tube or shallow dug well systems because farmers exercise greater control and hence the water supply is more reliable.

Transects are particularly useful in identifying problem areas and the important spatial relationships both between and within farms. In the analysis of Northeast Thailand agroecosystems the recognition of the mini-watershed agroecosystem and its subdivisions pin-pointed the role of the upper paddy fields as the generator of instability in rice production (Figure 8).

Time

Patterns in time are best expressed by simple graphs. Three patterns appear to be important for agroecosystems. The first is that of seasonal change and can be analysed by the superimposition or simultaneous graphing of cropping sequences, labour, credit peaks, prices etc. on various agrometeorological parameters. This helps, in particular, to idenfity those periods in the year where the timing of operations and the availability of resources is critical for productivity and stability (Figure 9).

Longer term changes, in prices, production, climate, demographic parameters etc., can be graphed in a conventional manner (10 years of data is minimum requirement). These reveal trends in productivity and a measure of stability (Figure 10), possible



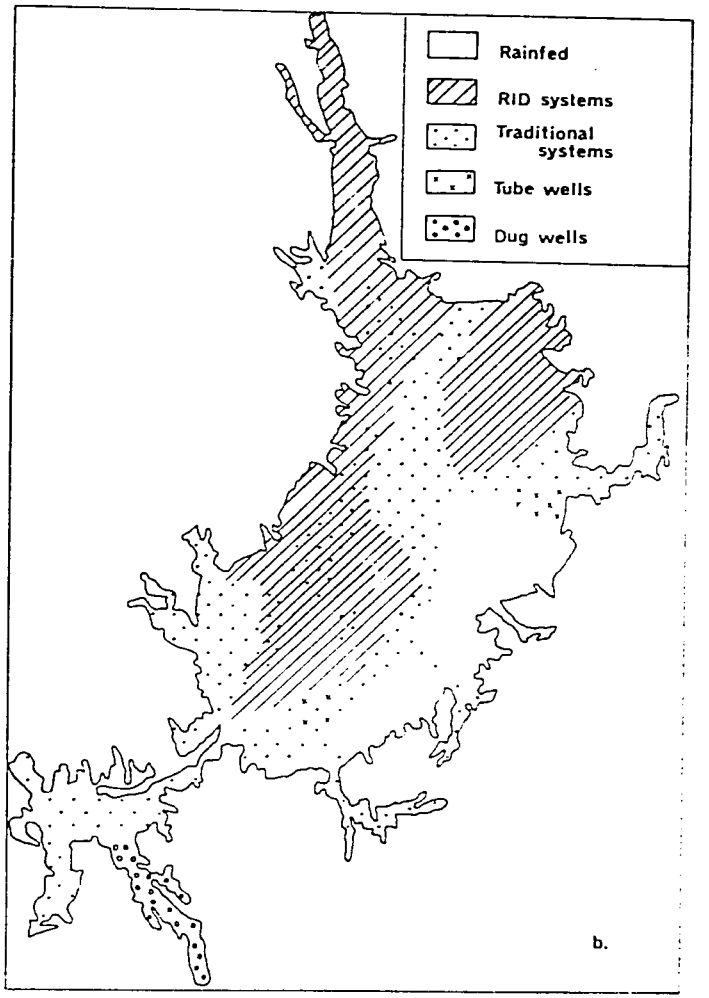
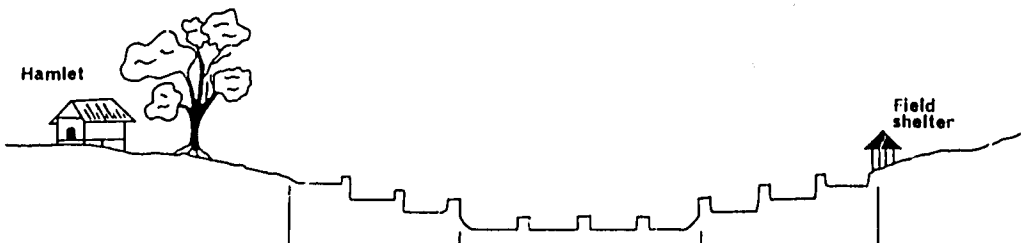


FIGURE 7 Spatial patterns in the Chiang Mai Valley, Thailand: (a) cropping intensity, (b) government (RID) and non-government irrigation systems (Gypmantasiri et al. 1980)



	Upland	Upper Paddy	Lower Paddy	Upper Paddy	Upland
Soils	Paleustult	Paleaquult/ Paleustult	Paleaquult		
Crops	Cassava Kenaf Sugarcane Water melon	Cassava Rice	Rice followed by vegetables		
Problems	Drought Erosion	Insufficient water	Occasional flooding		

FIGURE 8 Transect of a miniwatershed in Northeast Thailand (KKU-Ford Cropping Systems Project 1983a)

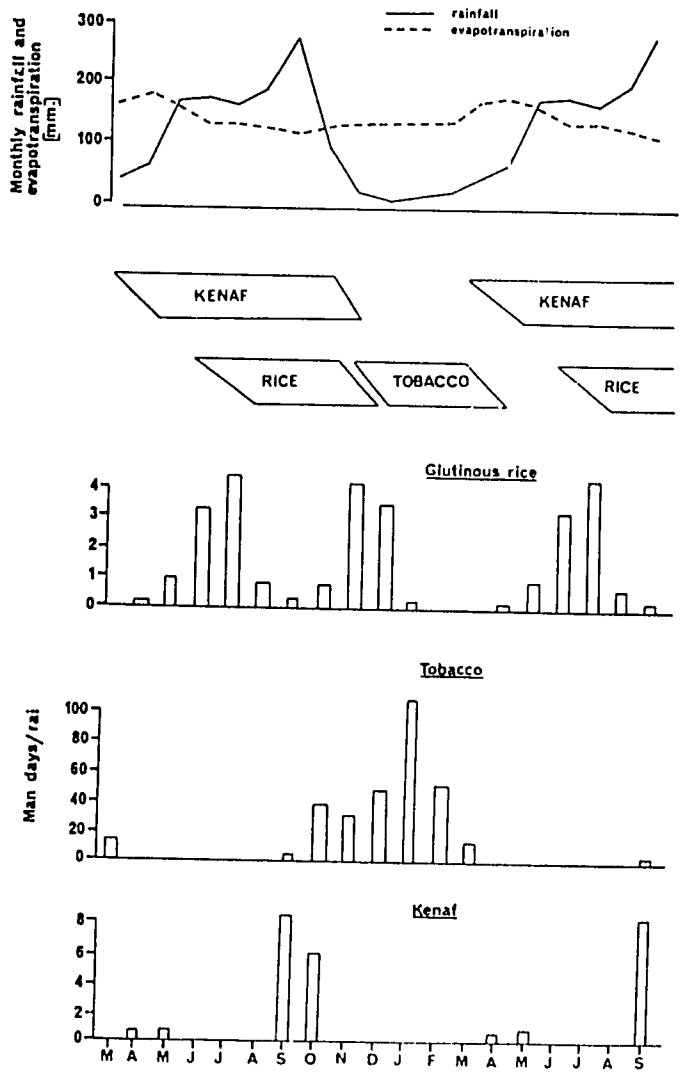


FIGURE 9 Seasonal patterns of rainfall, cropping and labour demand for an area of Northeast Thailand (KKU-Ford Cropping Systems Project 1982a)

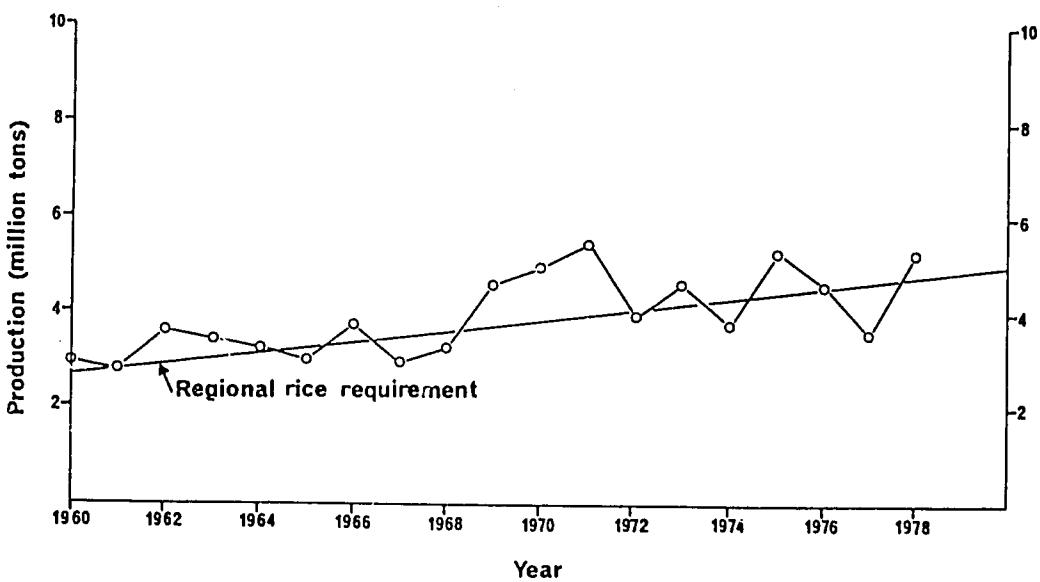


FIGURE 10 Rice production in Northeast Thailand (KKU-Ford Foundation Cropping Systems Project 1982a)

time lags in the system and other causes of instability (Figure 11) and any signs of lack of sustainability (Figure 12).

The final pattern in time is of the response of important variables to stress and perturbation. Stresses, as defined earlier, include soil deficiencies and toxicities, pests, diseases and weeds etc. Perturbations include major floods or droughts or a sudden outbreak of a pest or disease. The distinction between the two forms of disturbance rests on the degree of predictability. In some regions of the world, for example in Northeast Thailand, floods and droughts are so common as to constitute stresses; in Northern Thailand where wet season rice pests are relatively unimportant an outbreak of a new pest, such as the brown planthopper (Nilaparvata lugens) would constitute a perturbation. In the analysis actual and possible stresses and perturbations need to be identified and the known or likely responses of the variables graphed (Figure 13).

Flow

Included under this heading are the patterns of flows and transformations of energy, materials, money, information etc. in the agroecosystems. While these may be described by conventional flow diagrams the aim should not be to trace out all the detailed relationships. Flows should be principally analysed for the major causes and effects and for the presence of stabilising or destabilising feedback loops. The flow diagrams should thus be kept as simple as possible (Figure 14). Tables, matrices, bar histograms (Figure 15) and regression graphs may also be useful in indicating important relationships.

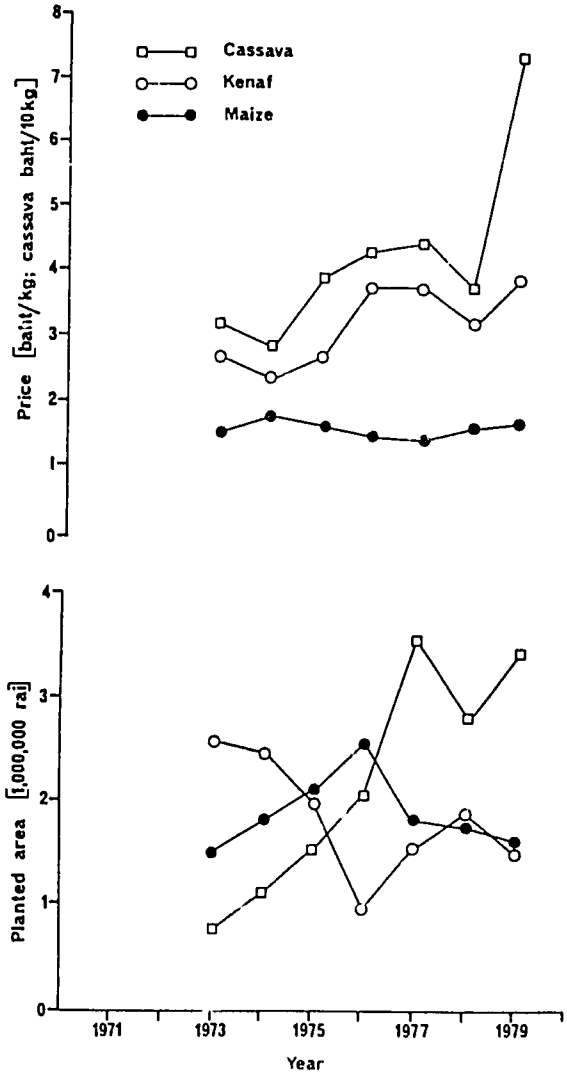


FIGURE 11 Annual fluctuations in price and planted area for major crops in Northeast Thailand (22 baht = US$1 approx; 1 rai = .16 ha) (KKU-Ford Cropping Systems Project 1982a)

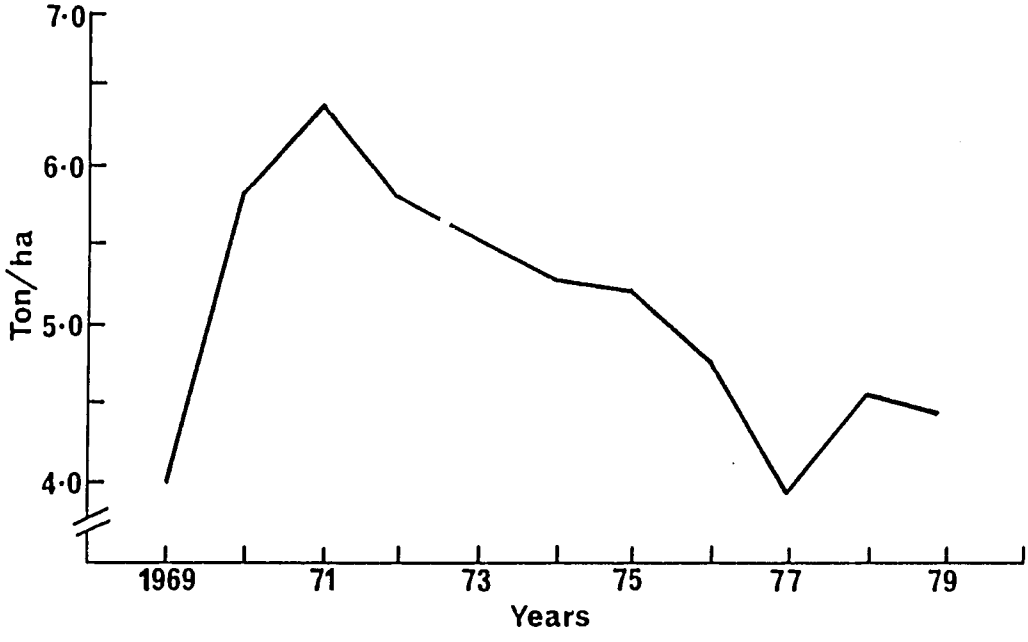


FIGURE 12 Declining rice yields under intensive cropping on a research station in Northern Thailand (Gypmantasiri el al. 1980

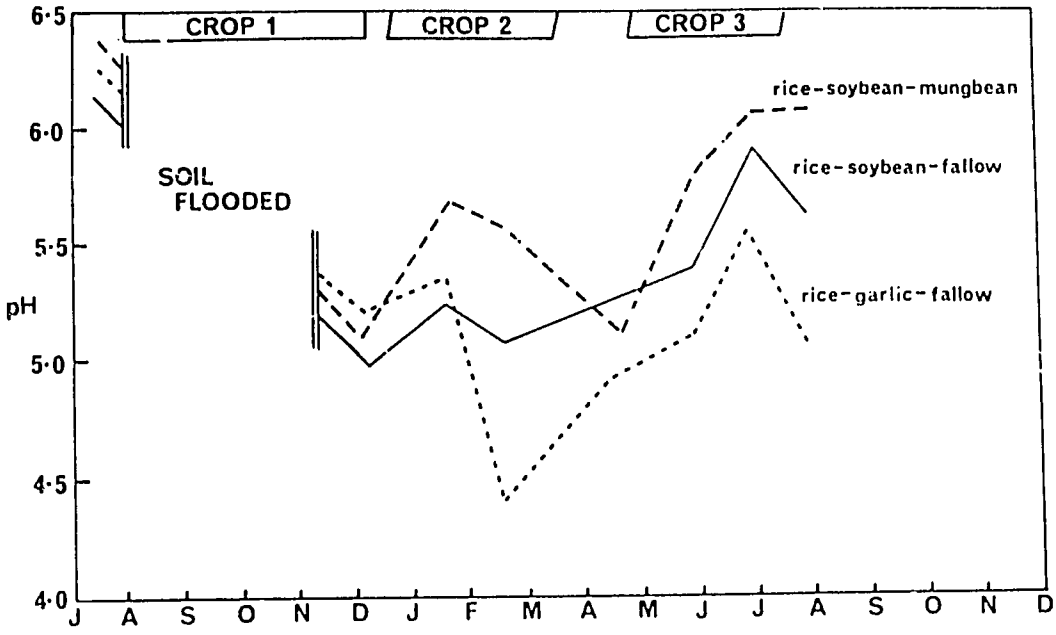


FIGURE 13 Fluctuations in soil acidity under three cropping systems in Northern Thailand (pH measured in 0.01M $CaCl_2$) (Gypmantasiri et al. 1980)

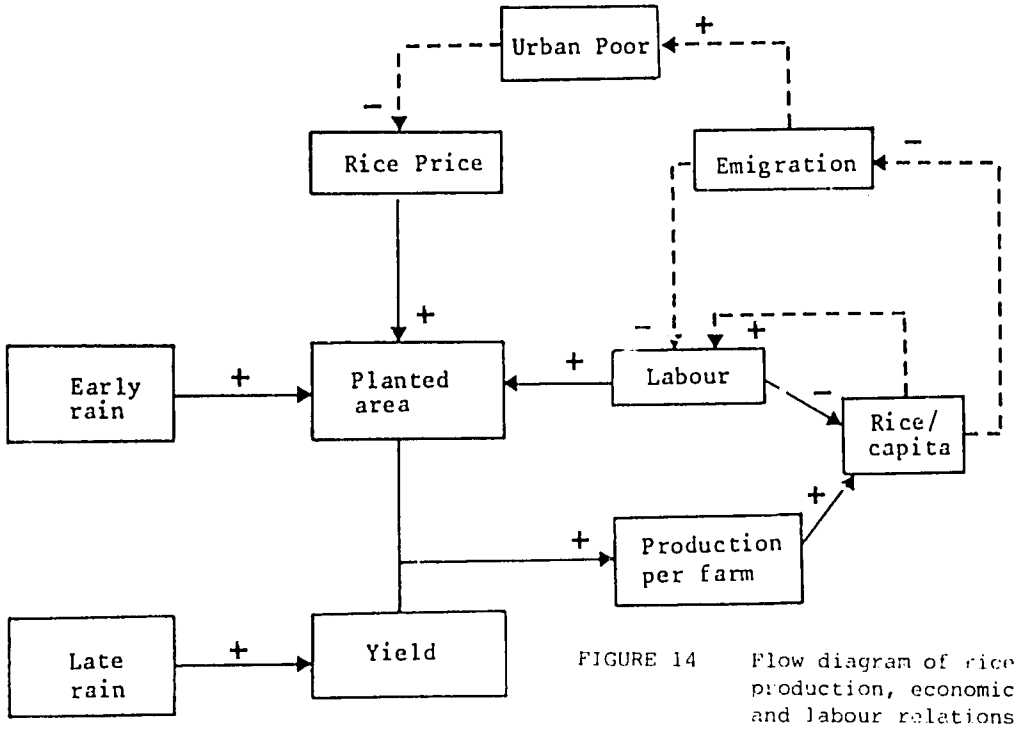


FIGURE 14 Flow diagram of rice production, economics and labour relations for Northeast Thailand

Decisions

Decisions, ranging from those of national agricultural policy to the individual farmer's day-to-day choices, occur at all levels in the hierarchy of agroecosystems. Two patterns are important. The first is of the choices made in a given agroecosystem under differing conditions and is best described by means of a decision tree. Construction of the tree helps to reveal both the goals of the decision maker and the constraints on choice that are present in the agroecosystem. Decision trees produced for Northeast Thailand agroecosystems suggested the importance of labour and land type constraints on farm and village production (Figure 16).

The second pattern is of the spheres of influence of decision makers. Here analysis is primarily required in order to identify the critical decision makers in the system hierarchy and simple diagrams are useful in distinguishing the points of contact and overlap in decision making. Analysis of irrigation water control in the Chiang Mai Valley, for example, reveals the extent of farmer participation in decision making under different systems (Figure 17).

SYSTEM PROPERTIES

Discussion of system properties should guide the form of pattern analysis, helping to indicate the likely key relationships and decisions. However at the end of the pattern analysis phase it may be useful to summarise what has been learnt of system properties and to tabulate the most important contributing

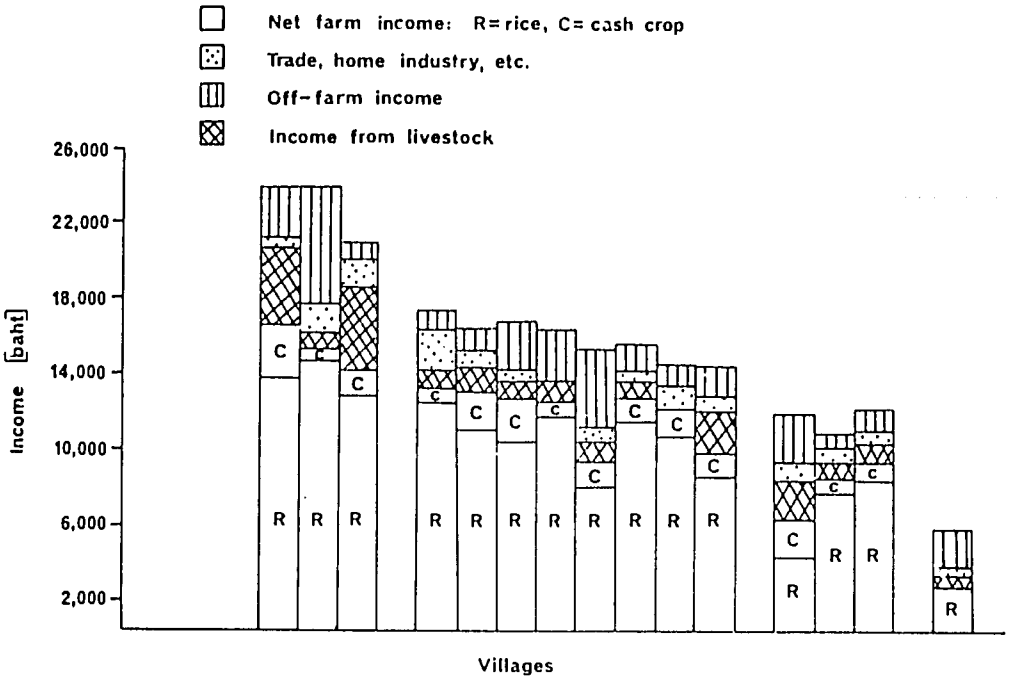


FIGURE 15 Components of farm income for 16 adjoining villages in Northeast Thailand (22 baht = US$1 approx.) (KKU Ford Cropping Systems Project 1982b)

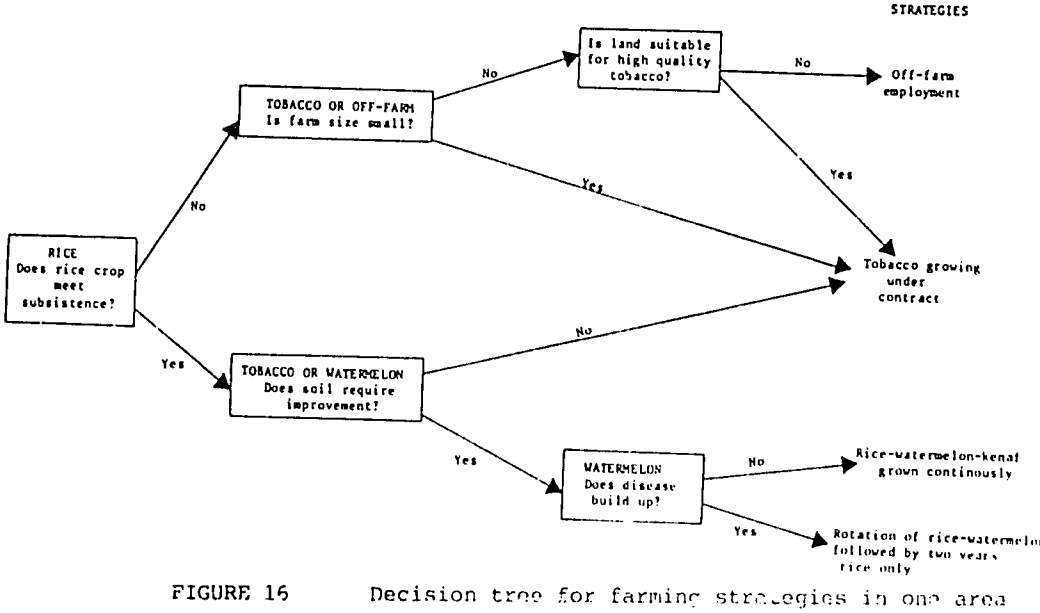


FIGURE 16 Decision tree for farming strategies in one area of Northeast Thailand

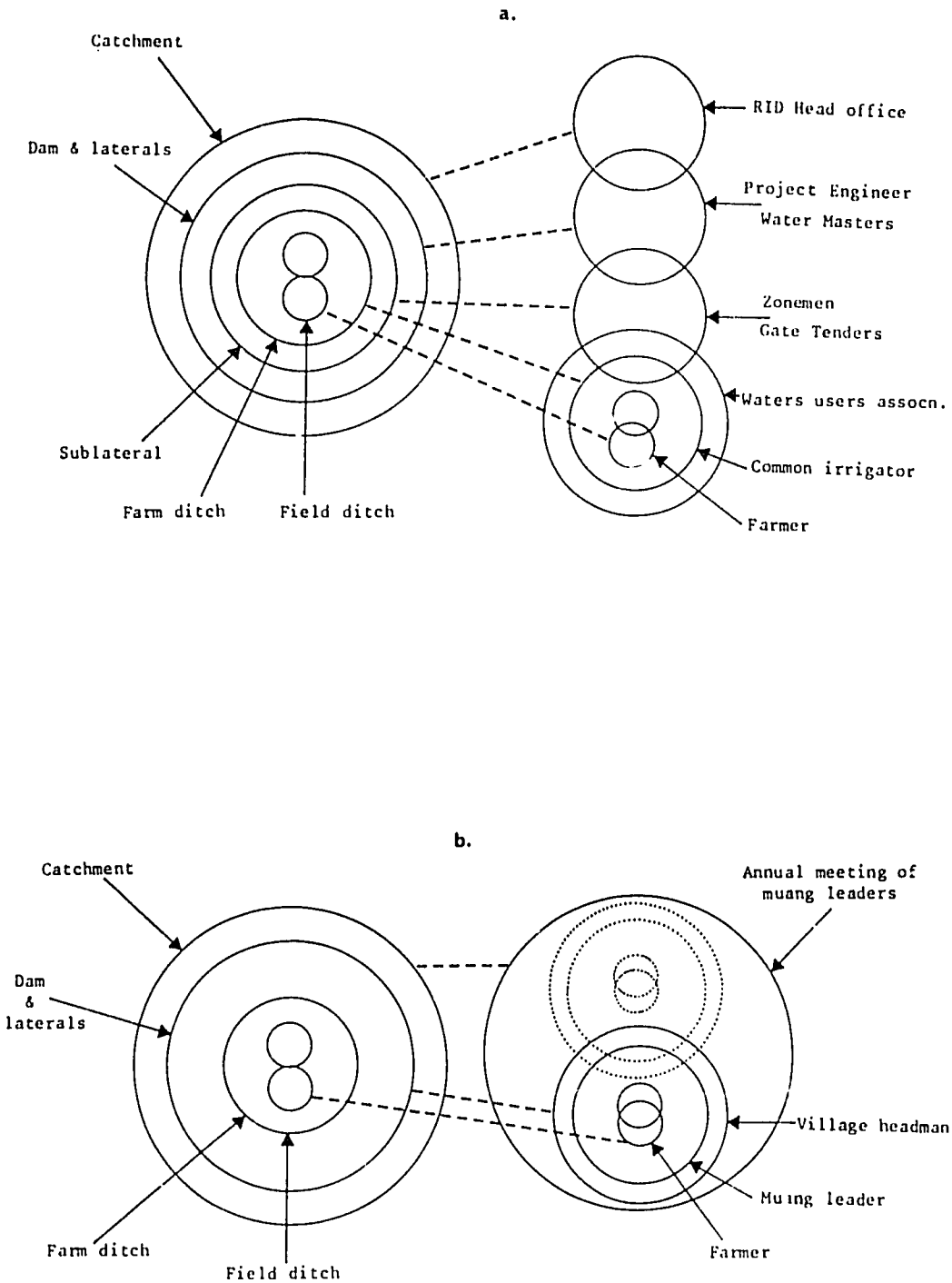


FIGURE 17 Diagram showing points of contact and overlap in irrigation decision making in Northern Thailand: (a) government (RID) systems; (b) traditional systems (in each diagram the physical systems are on the left and the decision making systems on the right).

relationships and variables (Table III).

KEY QUESTIONS

Key questions arise throughout the procedure, during system definition, pattern analysis and the discussion of system properties. They should be noted down as they emerge and then collectively revised by the members of the subgroup in the light of all the information available. Experience suggests that a field trip to the agroecosystem sites is useful at this stage: some questions may be quickly answered; others may be revealed as poorly based or inappropriate. The full list of key questions should then be extensively discussed by the workshop team as a whole.

Experience shows that the questions take a variety of forms. In many, if not most, situations the analysis is likely to reveal broad gaps in knowledge which require further investigation to uncover suspected key functional relationships. A typical gap question is:

"What are the most appropriate meteorological parameters for characterising the agricultural seasons in the Valley?"

(In the Chiang Mai Valley farmers appear to recognise at least four distinct cropping seasons but their meteorological definition is not clear.)

However most questions will be more narrowly defined, focussing on suspected key processes or decisions. For example:

"Can new rice varieties be bred to produce more stable yields on the upper poorly watered paddy fields?"

Table III

Examples of key relationships and variables determining the system properties of agroecosystems of Northeast Thailand.

PRODUCTIVITY

- Demand by world markets (especially EEC)
- Government rice and fertilizer policies
- Water resource development

STABILITY

- Rainfall, especially floods and droughts
- Rice production in upper paddy fields
- Human migration
- Diversification of production

SUSTAINABILITY

- Increasing salinity
- Increasing indebtedness
- Deterioration of communal mutual help arrangements

EQUITABILITY

- Subsistence rice crop
- Diversification of production
- Government rural works programme
- Availability of credit

(The high instability of rice yields in Northeast Thailand is largely a function of poor performance in the upper elevation fields and of the mini watersheds.); or

"What is the optimal application of fertilizers to traditional rice varieties under highly variable rain-fed conditions?"

(In Northeast Thailand rainfall is highly variable and it is not clear that encouragement of higher fertilizer use would produce a reasonable return to the farmer or to the region.)

Many important questions span different levels in the system hierarchy. For example:

"How is the form and productivity of cropping systems in the Chiang Mai Valley affected by government policy on the price of rice?"

(Various government price policies essentially mean that farmers get a relatively poor return for rice, the basic crop of most existing cropping systems.)

However in our experience the most powerful questions are those that directly address system properties and in particular the actual or potential trade-offs between them:

"To what extent are the gains in productivity and stability from land consolidation in the Chiang Mai Valley likely to be offset by a decline in sustainability and equitability?"

(Land fragmentation in the Valley, although promoting inefficiency, seems also to encourage crop diversity and hence sustainability. It is also probably more equitable.) Questions of this kind also often implicitly raise doubts about the conventional wisdom.

Where the object of analysis is to identify possible ways of developing an agroecosystem the key questions may be framed in the form of tentative guidelines:

"It is likely that crop production in village x will be significantly improved by the provision of better quality second crop seed."

(Under intensive rotational cropping good establishment of the second crop following rice is critical to success.) Although written in this form, the implicit question and hypothesis are apparent. If better quality seed is provided it should be seen strictly as an experiment and the results used to modify the overall analysis.

As far as possible the key questions should be turned into carefully phrased, test hypotheses so that by the end of the workshop there is a list of questions each accompanied by a hypothesis, a discussion of the issues involved and some indication of the investigations now required.

RESEARCH DESIGN AND IMPLEMENTATION

The remaining phase of the procedure is one of conventional research. The hypotheses are tested as appropriate: by laboratory or field experiments, field surveys or extension trials, or by development trials in which guidelines are enacted and assessed. The multidisciplinary activity of the workshop may or may not extend into the research phase; many of the key questions will be phrased in terms of single disciplines and are best answered by the appropriate specialists. To this extent the outcome of the workshop may appear superficially similar to research programmes

arising from a collection of individual initiatives, but will crucially differ in that the individual research projects are the direct consequence of a multidisciplinary systems analysis and the results feed back to and modify that analysis. The research has thus a better contextual basis and is likely to be more appropriate and relevant, while the results have a greater chance of being acted upon.

It is, of course, not necessary that all the key questions be tackled by the workshop team. Some of the questions may raise issues or require methods of approach that lie outside the competence of the group But if the questions are well phrased and their importance clearly justified they should interest and excite other research workers to find answers.

DISCUSSION

Figure 18 shows the final detailed form of the procedure. The arrowed lines connecting the various stages indicate that the procedure is intended to be iterative. New knowledge and perspectives at each stage are likely to require revision of earlier stages; in particular answers to the key questions when they are found will modify earlier assumptions, updated at regular intervals. Experience suggests that the procedure can be applied at any time in a project's life but it is particularly useful at the beginning of a project when data are scarce. Ideally it should be repeated and updated at regular intervals. The first run-through of the procedure is likely to produce more "gap" than

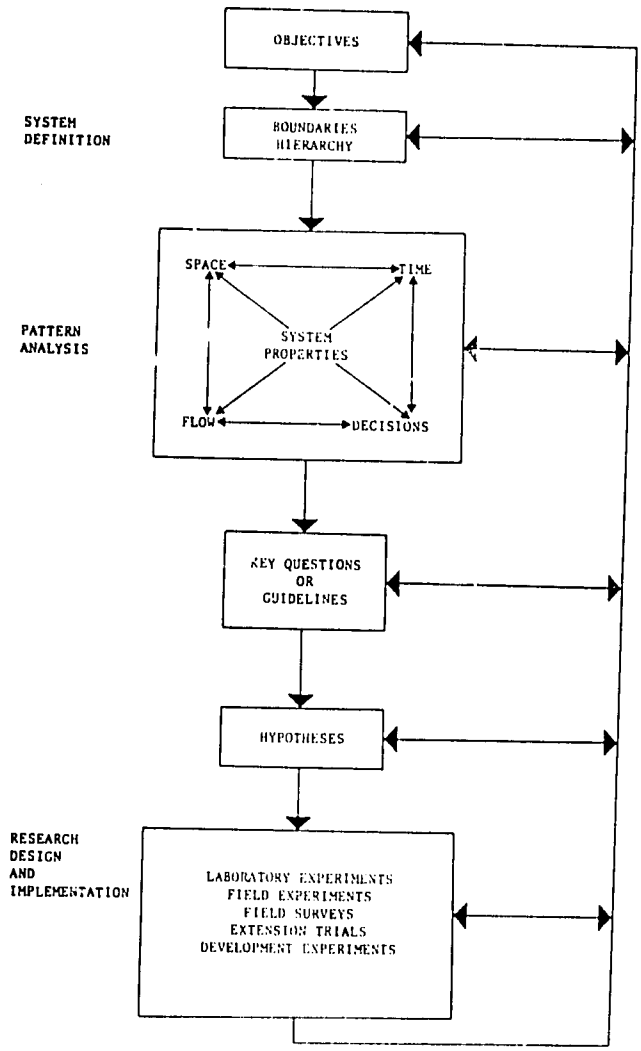


FIGURE 18 The full procedure of agroecosystem analysis

true key questions; but with time and answers the original questions will be replaced by better, more precisely focussed questions.

It should be stressed that the procedure is intended to be flexible. Our experience is that it changes in quite important respects from workshop to workshop, depending on the objectives of the workshop and the background, experience and interest of the participants. New ways of presenting, analysing and interpreting information should be actively encouraged.

Despite its foundation on the concepts of systems analysis the procedure makes no explicit mention of the role of mathematical models. We have deliberately avoided the conventional approach of using a large scale simulation model as the focus of analysis. This is partly because many individuals may be excluded from the analysis through a lack of skill or inclination to interact with the model, and partly because in such large scale modelling exercises the key issues and questions tend to be obscured by a preoccupation with the details of construction. Nevertheless it is clear that the potential for use of a wide variety of models (matrix models, regression, linear programming models, simulation models etc.) exists throughout the procedure, for example in the analysis of the patterns of time, space, flow and decisions and of the dynamics of system properties, in formulating key questions and hypotheses and, indeed, in some cases in answering these questions. The extent to which models will be used in practice depends on the interests and skills of the workshop participants.

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