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3 Rice Ecosystems Analysis for Research Prioritization

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I. Introduction

The prioritization of rice research among environments relies on reasonably useful and accurate information on what those environments are, how much rice area there is and how production is distributed among them. To date the rice resource allocation debate has been limited to relatively broad ecosystem distinctions, i.e. irrigated, rainfed lowland, upland and deepwater (Barker and Herdt, 1982; Herdt *et al.*, 1987). Consequently, data pertinent only to fairly general classes has been used. Detailed rice environmental datasets, with their inevitably more complex nature, have not been much employed.

There has been progress during the past decade in developing agroecological classifications at continental and national scales (Higgins *et al.*, 1987). In the rice world, a broadly applicable international ecosystems classification was derived (IRRI, 1984). Geographic databases and maps have been developed that are more or less consistent with these classes (e.g. Huke, 1982; Garrity *et al.* 1986; Jones and Garrity, 1986). Likewise, at the national level, massive agroecological classification efforts have been completed in several Asian countries, as in Bangladesh (FAO, 1988) and India. But the deployment of these classifications, and their rich datasets, in research prioritization analysis has been very limited.

Analyses at broad levels will continue to be needed, since major issues in research allocation are unresolved even at these levels. But as the formal tools of research prioritization are trained upon the rice sub-ecosystems, and the geographic scales of analysis are refined for national, regional and local levels, the need for the products of detailed ecosystems analysis is becoming more apparent.

This chapter reviews some of the databases that have been assembled through rice ecosystems analysis and their applicability to rice research prioritization. Section II explains the methodologies used in agroecological and ecosystem classification. Section III presents a review of existing databases and an examination of the issues of ecosystems data application at four scales: mega, macro, meso and micro. Section IV presents two applications of the ecosystem analysis, one for characterization of the agroecological zones in Asia and the other characterization of ecosystems at different scales in eastern India. The final section makes some concluding remarks regarding research priority setting in an agroecological framework *vis-à-vis* the conventional commodity-based approach. It examines the externalities imposed by a crop-production activity in one ecosystem on others.

II. Methodologies for Ecosystem Classification

A. *Agroecological classification*

To what extent can rice research prioritization rely upon the several important efforts at broad agroecological classification at the global level, specifically the classic work in climatic classification systems and the FAO agroecological zones (AEZ) studies? There are natural advantages in doing so, if this is feasible, since these efforts are generalized (with relatively fewer classes) and they are widely known.

Among the global climatic classifications, those of Koppen (1936), Thornthwaite (1948), Holdridge *et al.* (1971) and Papadakis (1975) have had wide currency. The Koppen system recognizes 13 tropical and subtropical climatic zones; the Thornthwaite system identifies 21. These relate locations to general climates, but are undeniably broad. Papadakis' work led to a much more complex classification system (with over 500 classes). It was a move in the direction of comprehensiveness but this sacrificed simplicity.

The FAO AEZ system (Kassam *et al.*, 1982) includes a broadly defined climate component based on temperature and length of the growing period, determined by the seasonal distribution of rainfall and evapotranspiration. The major climates can be used independently, or combined with growing period zones. This system of seven basic agroecological units (see below) was adopted for an analysis (TAC, 1990) of research priorities across commodities, and allocation of resources among the International Agricultural Research Centers (IARC). The major objective of the FAO system was to assess the suitability of land for different crops (Higgins *et al.*, 1987). When the climatic classification is combined with soils data, it yields a more comprehensive and complex global agroecological zones system. In addition to global and continental level studies, AEZ studies have been conducted in a number of countries, for example Bangladesh (FAO, 1988). A world databank on the AEZ system is maintained at the FAO headquarters in Rome.

The above review covers only some of the most well-known efforts. Young (1987) has reviewed a number of other systems and has discussed their relative utility for varied user purposes.

B. Rice ecosystems classification

Although the methods just discussed provide quite a range of flexibility in aggregation and data requirements, they have not been widely applied in characterizing and classifying rice environments. The main reason has been the uniqueness of rice's environmental situation compared to all other major crops: rice environments are dominated by surface flooding patterns. Therefore virtually all the rice classification systems (and there are at least 38) developed at national and international levels consider surface hydrology to be the dominant delineating variable (Garrity, 1984; Bowles and Garrity, 1988). Therefore, a meaningful classification of rice environments must proceed independently of the commonly known global systems.

The agroclimatic classification for rice and rice-based cropping systems that has been widely adopted (Oldeman, 1980; Oldeman and Frere, 1982) is based on the length of the rice-growing season. This is specified as the months in which surface flooding can be maintained (assumed to be the period with monthly rainfall exceeding 200 mm month^{-1}). National agroclimatic maps based on this system were derived for a number of countries, for example the Philippines, Bangladesh and Indonesia (Oldeman, 1980). Maps that uniformly classified all the countries of South and Southeast Asia in this system were compiled by Huke (1982).

The international *Terminology of Rice Growing Environments* (IRRI, 1984) established a standardized scheme of rice ecosystems. Its two-tiered structure subdivided the commonly accepted rice environments (i.e. irrigated, rainfed lowland, upland, deepwater and tidal wetlands) into varying numbers of sub-ecosystems, based on hydrological and (in some cases) soil factors (Table 3.1). The dominant emphasis in this definition was toward broad agronomic constraints, particularly those related to genetic improvement of the rice crop. The environmental characterization of the sub-ecosystems, and the rice area covered by each sub-ecosystem, remained uncertain. Subsequent efforts have attempted to sharpen the classes and provide better estimates of their overall extent.

III. Agroecosystem Databases: a Review

A. Mega-level analysis

When the IRRI restructured its research programs to explicitly address the rice ecosystems (IRRI, 1989b), decision criteria upon which to allocate funds on an ecosystem basis became more explicit. The rice area and production in each ecosystem were fundamental information in applying a resource-allocation

Table 3.1. Terminology for rice-growing environments.

Environment	Sub-ecosystem
Irrigated	Irrigated, with favourable temperature
	Irrigated, low temperature, tropical zone
	Irrigated, low temperature, temperate zone
Rainfed lowland	Rainfed shallow, favourable
	Rainfed shallow, drought-prone
	Rainfed shallow, drought- and submergence-prone
	Rainfed shallow, submergence-prone
	Rainfed medium deep, waterlogged
Deepwater	Deepwater
	Very deepwater
Upland	Favourable upland with long growing season (LF)
	Favourable upland with short growing season (SF)
	Unfavourable upland with long growing season (LU)
	Unfavourable upland with short growing season (SU)
Tidal wetlands	Tidal wetlands with perennially fresh water
	Tidal wetlands with seasonally or perennially saline water
	Tidal wetlands with acid sulphate soils
	Tidal wetlands with peat soils

Source: IRRI, 1984

model. In congruence prioritization models, for example, in which the rice produced in each ecosystem is considered as a distinct commodity, the allocation of resources would be in direct proportion to the relative production of the ecosystem (Ruttan, 1982; Salmon, 1983).

Aggregate data and maps of the area of rice by cultural type have been standardized for more than a decade (Huke, 1982) on the basis of judicious estimates. The accuracy of the mega-level data on the amount of riceland in the five major ecosystems is still uncertain, however, because national-level statistics that distinguish the various types of non-irrigated riceland are generally unavailable. The IRRI *Rice Almanac* (IRRI, 1993), based on Hukes' work, contains a breakdown of estimated rice areas by cultural type in each country.

The work of Huke (1982) yielded standard maps of the regional allocation of rice land by ecosystem. The maps provided the basis for more comprehensive mega-level geographic databases to characterize the micro-regions and classify sub-ecosystems, particularly for the rainfed ecosystems.

The IRRI developed several mega-level geographic databases; the upland rice ecosystem geographic database was the initial product (Garrity, 1984; Garrity and Agustin, 1984; Jones and Garrity, 1986). It contains data for several agroclimatic and soil parameters for each of the approximately 4000 upland rice-growing locations designated on the Huke maps for South and Southeast Asia. The sites are uniformly classified according to a two-factor upland rice environmental classification based on the length of growing season and inherent soil fertility constraints, and also on a three-factor system which includes an estimate of seasonal moisture sufficiency (Garrity and Agustin, 1984). The two-factor classification conforms with the four broad upland sub-ecosystems specified in the international terminology of rice environments (IRRI, 1984). The three-factor classification recognizes 12 major classes and, at a more detailed level, 72 classes.

The rainfed lowland rice ecosystem database (Garrity *et al.*, 1986) was compiled using a similar methodology. Approximately 6300 rainfed sites were classified according to a number of agroclimatic and soil parameters. All of the rainfed lowland ricelands were then classified in a three-factor environmental classification that included the length of growing season, water balance and soil constraints as delimiters. The distribution of shallow rainfed environments for the region is shown in Fig. 3.1.

The Asian riceland soil constraints database covers all riceland in South and Southeast Asia, including irrigated and deepwater areas (IRRI, 1987). This database includes data from the FAO soils maps of the world (FAO, 1977, 1979), with soil constraints interpreted according to the fertility capability classification (Buol and Cuoto, 1981). It has enabled a breakdown of the rice area in each ecosystem by major soil constraints (Fig. 3.2).

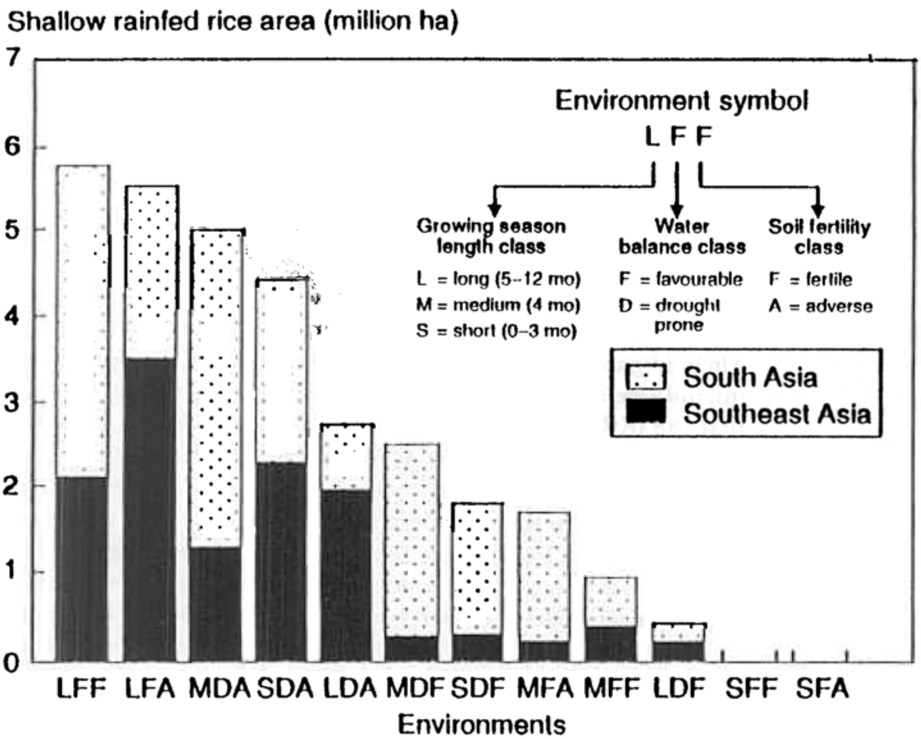


Fig. 3.1. Distribution of major shallow rainfed rice environments in South and Southeast Asia. Favourable water balance includes intermediate balances; drought-prone includes highly drought-prone.

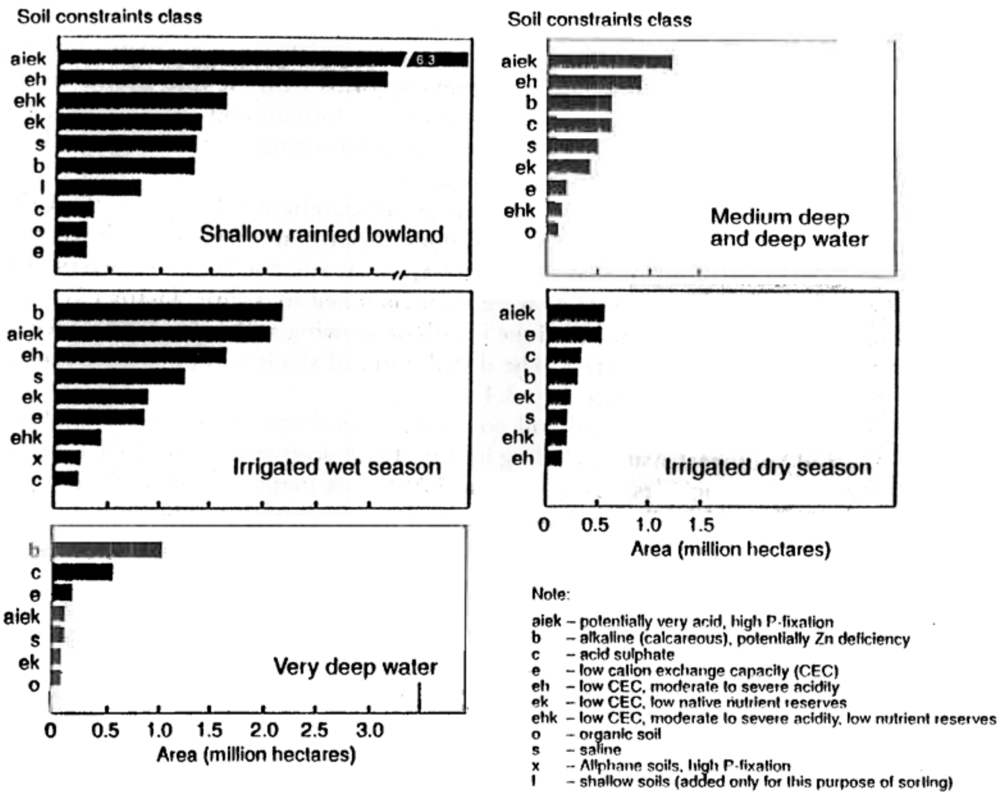


Fig. 3.2. Relative distribution of rice-cropped areas under various types of soil fertility constraints in the five lowland rice culture types for South and Southeast Asia.

These databases are useful in addressing general questions about the rice environments, particularly research priorities based on the congruence method. Their impact has been significant. Quantification of the dominant extent of upland rice area in the less favoured sub-ecosystems gave conclusive evidence that the IRRI's upland research was overly targeted to inherently fertile soils. The data helped initiate a major shift in upland breeding and agronomic research in the early 1980s, from young volcanic soils to acid upland soils, and from flat land to sloping lands.

The rainfed lowland database has had a lesser impact. This is most likely due to the limitation that it does not include data on the surface-water depth regime, particularly the frequency and duration of crop submergence and droughts. Although the database includes the length of growing season and a crude water-balance classification, data does not exist to classify the surface-water accumulation dynamics at the micro-region level. In its absence there is as yet no means to definitively classify and map the rainfed lowlands into the five sub-ecosystems. Confusion lingers as to the aggregate area and localities of 'favourable rainfed' and the four categories of 'unfavourable rainfed'. In lieu of a more precise delineation, it is often assumed that favourable rainfed corresponds to the area where semidwarf modern cultivars have been adopted.

The rice ecosystems geographic databases were originally developed as computerized databases linked to hand-drawn maps. The maps are now digitized and the entire database is being integrated into the Rice Ecosystem Geographic Information System (REGIS). The convenience and analytical power introduced by this transformation enhances the utility of the information. Recently, for example, the rice geographic databases and maps have seen application in an unanticipated research sphere: estimation of the impact of global climate change on rice production in Asia (Bachelet *et al.*, 1992). The project is modelling productivity changes on a spatial basis using the databases' climatic and soil information.

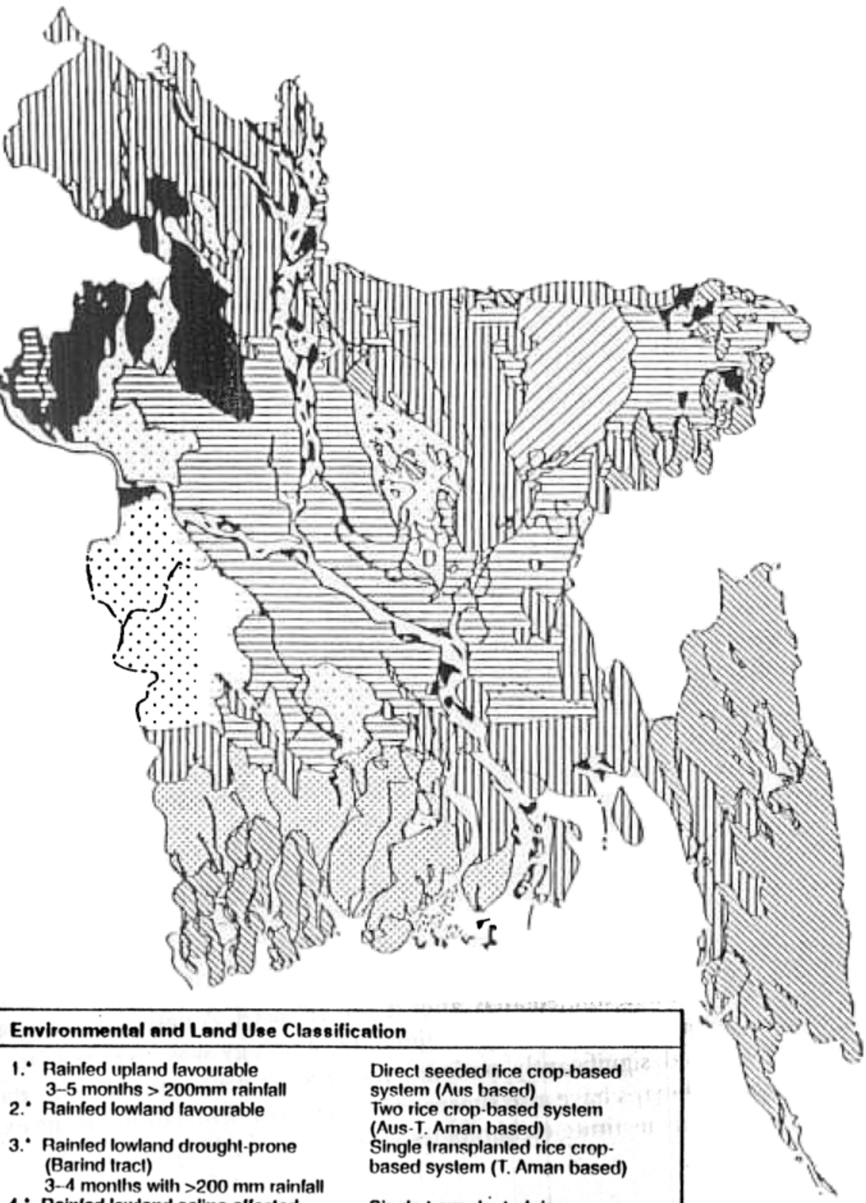
B. Macro-level analysis

The generalized nature and small scale of mega-level databases strongly limit their application beyond international issues. The nations are interested in research prioritization and extrapolation that typically require much more detailed information – at least at the macro (i.e. national) level. In a growing number of countries, some remarkably comprehensive and useful datasets have been developed; the challenge is to make better use of this data. An excellent example is the case of Bangladesh (Ahmed *et al.*, 1992). Extensive soil and land-use datasets and maps were developed over two decades by the Soils Resources and Development Institute in collaboration with the FAO (FAO, 1988). This included standard countrywide data on the surface flooding regime, a rare form of data in most countries. But in Bangladesh it was recognized early on to be critical to ecosystems analysis in this flood-prone country.

The Bangladesh Rice Research Institute perceived the value of this vast information pool, and began employing the data in research planning and extrapolation immediately after it was released. A national rice ecosystem map that conformed to the international terminology was prepared (see Fig. 3.3). It has aided significantly national research priority setting. The database and national maps have also sharpened target area delineation for the extrapolation of various institute technologies (Ahmed *et al.*, 1992).

C. Meso-level analysis

A major positive trend in many countries in recent years is the setting up of regional research stations for addressing local problems. The strengthening of regional universities and governmental research centres is enabling the development of institutions that strongly identify with the unique problems and research priorities of the specific areas where they are located. These institutions seek methods to establish priorities that are suited to these smaller



LEGEND

Environmental and Land Use Classification	
1.* Rainfed upland favourable 3–5 months > 200mm rainfall	Direct seeded rice crop-based system (Aus based)
2.* Rainfed lowland favourable	Two rice crop-based system (Aus-T. Aman based)
3.* Rainfed lowland drought-prone (Barind tract) 3–4 months with >200 mm rainfall	Single transplanted rice crop-based system (T. Aman based)
4.* Rainfed lowland saline affected	Single transplanted rice crop-based system (T. Aman based)
5.* Deep water	Deep water rice crop-based system
6. Bottom land deeply flooded	Winter rice crop only
7. Reserve forest and hill areas	Forest, gardens, orchard or shifting hill cultivation
8. New land (river and ocean) and seasonally flooded grasslands	Grassland

*Irrigated systems dispersed throughout these environments and cover 20–25%.

Fig. 3.3. Environments and land-use associations in Bangladesh for rainfed systems.

geographic areas and larger mapping scales. The process is suited to more direct feedback from extension personnel and farm-level adaptive research.

Meso-level analysis is typically associated with a cultivated area in the range of about 100,000 ha or so, using a mapping scale of 1 : 25,000 to 1 : 100,000. Analysis at this scale can efficiently identify and delineate the rice ecosystems and sub-ecosystems in terms of surface hydrology, landform and soil classes. Associated with each rice ecosystem are the flood and drought frequencies and duration, prevalent cropping patterns and crop management practices.

An example of a useful meso level analysis was that conducted for Bahraich district, Uttar Pradesh, India, to identify the problems causing low rice yields and to prepare the priority research agenda at a district level in eastern India (Singh and Pathak, 1990). The analysis determined the ecological variability in the district in terms of hydrology (rainfall pattern, water table depth, irrigation sources and drainage), landform and slope, length of growing season, frequencies and duration of floods and drought, and major insect, disease and weed pressures.

After characterization, the factors were combined to identify and delineate the area into homologous zones. They were manually mapped at a scale of 1 : 50,000 and classified under major rice cultural types (ecosystems). Combining the hydrological and topographic maps indicated that 70% of the rice area in this district was shallow rainfed (0–30 cm depth), 10% in medium-deep lowland (30–50 cm depth) and 15% in deepwater and very deepwater categories (50 to > 100 cm). Cropping pattern, variety use, crop management practices and input use and socioeconomic conditions were separately superimposed on each of the rice ecosystem maps. The rice ecosystems were then prioritized for research on the basis of the physical extent of area, number of affected households and potential possibilities of research success.

The IRRI and the Department of Agriculture Regional Office for the Cagayan Valley, Philippines (Region II) developed a meso-level classification of the valley's complex mosaic of rainfed ricelands (Garrity *et al.*, 1992). The exercise explored the utility of a computerized geographic database correlated with village-level maps of rainfed rice land types. The information was packaged as a field manual for extension personnel. Six rainfed rice sub-ecosystems were recognized on a hydrological basis. They were explicitly correlated with a range of associated information to specify their identification and the technology associated with them. The data on rice area, and the yield constraints associated with each rainfed riceland type, has facilitated rice research efforts, particularly the relative emphasis given to applied and adaptive research among land types.

D. *Micro-level analysis*

Agroecosystems analysis has become a very popular set of tools in micro-level prioritization (Conway, 1986; KEPAS, 1985). Fujisaka (1991) reviewed the use of micro-level diagnostic methods in greater detail. Micro-level analysis has been used extensively in the rainfed regions of eastern India, covering the states of Uttar Pradesh, Madhya Pradesh, Bihar, Assam, West Bengal and Orissa, to set research priorities within and among dominant rice-farming systems. Agroecosystems analysis techniques and rapid rural appraisal methodology were extensively employed. The methodology involved a two-tier training program for researchers on the methodology for setting research priorities by agroecosystems analysis with farmer participation. The analysis was carried out by 15 research centres in the region covering upland, rainfed lowland and deepwater rice ecosystems. The research diagnosis and prioritization at this level were conducted by multidisciplinary teams in the respective centres, with continuous involvement and interaction from groups of farmers.

The micro-level agroecosystem analyses (100 locations in eastern India) included detailed characterization and classification of the static and dynamic factors which differentiate agroecosystems in soils, hydrology, farming system practices and socioeconomic conditions (IRRI, 1989a). The sites were mapped on the scale of 1:2000 to 1:5000. At all sites the static factors studied were land types, land use, source of water supply and soil properties. The dynamic factors were field-water depth, rainfall land cropping patterns, crop yields, varieties and management practices, insects, diseases and weeds; landholding size, production costs and returns; labour supply pattern prices, assets and income distribution; and demography by social class.

The geographic area was zoned into agroecosystems and the problems and opportunities elucidated in each major agroecosystem. Among the different agroecosystems, highest priority was given to that with the largest extent. The research problems were then prioritized on the basis of the physical extent (coverage), number of affected households, complexity of the problem, severity of the problem (crop-loss estimates), frequency of problem occurrence and the importance of the affected enterprise in the farming system.

IV. Application of Ecosystem Analysis: Two Examples

A. Socioeconomic characterization by agroecological zones

AEZs are geographic mapping units developed by the FAO. They are based on climatic conditions and landforms that determine relatively homogeneous crop-growing environments. Characterization of AEZs permits a quantitative assessment of biophysical and socioeconomic constraints that agricultural research should address to improve the well-being of the people while preserving the resource base.

The Technical Advisory Committee (TAC) of the Consultative Group of International Agricultural Research (CGIAR) delineates the AEZs by applying simple crop-growth criteria on the FAOs agroecological database. These criteria are: (i) the moisture regime based on the length of growing period (LGP) under rainfed conditions, which uses data on the seasonal distribution of rainfall and evapotranspiration at different times of the year; and (ii) the thermal regime based on mean monthly temperature (MMT).